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The Nuclear Programs of Russia, China, North Korea, and Iran

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Abstract

The Deputy Assistant Secretary of Defense for Nuclear and Countering Weapons of Mass Destruction Policy asked CNA to provide an unclassified report on the nuclear programs of four countries: Russia, China, North Korea, and Iran. In accordance with section 1634 of the FY 2021 National Defense Authorization Act, CNA's report details the factors that influence each country's nuclear program; the country's nuclear command, control, and communications (NC3); nuclear program funding and budgeting; the nuclear weapons related activities of each country, including fissile material production, weapons and delivery system testing and exercises; nuclear weapons related research and development (R&D); nuclear weapons R&D sites and facilities; the human capital of the scientific and technical workforce involved in nuclear programs; and the country's nuclear weapons inventory, capabilities, and deployment locations. CNA conducted its research using original language sources (Russian, Mandarin Chinese, Korean, and Persian-Farsi) as well as unclassified English-language resources to provide the best available insights. The paper also uses callout boxes, tables, and figures to provide additional background information and context as appropriate.

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Introduction

In accordance with section 1634 of the fiscal year 2021 National Defense Authorization Act (NDAA), the Deputy Assistant Secretary of Defense for Nuclear and Countering Weapons of Mass Destruction Policy asked CNA to provide an unclassified report on the nuclear programs of four countries: Russia, China, North Korea, and Iran.

In accordance with NDAA requirements, this report covers the following topics as they pertain to each country's nuclear program:[1] the factors that drive the country's nuclear program, including its policies, interests, and threat perceptions; the country's nuclear command, control, and communications; nuclear program funding and budgeting; the nuclear weapons–related activities of each country, including fissile material production and weapons and delivery system testing and exercises; nuclear weapons–related research and development (R&D); nuclear weapons R&D sites and facilities; the human capital of the scientific and technical workforce involved in nuclear programs, including matters relating to the education, knowledge, and technical capabilities of that workforce; and the country's nuclear weapons inventory, capabilities, and deployment locations.

We have attempted to address these questions as uniformly as possible across all four countries. However, the enormous differences among them necessitated flexibility in terms of what information we presented and how we presented it. For example, Russia has a large and diverse nuclear arsenal that has been roughly on par with that of the United States for decades. In contrast, Iran does not have an active nuclear weapons program. In all cases, we have strived to ensure the following:

- The information we provide is drawn from the best, most accurate unclassified open-source research material available.

[1] The NDAA language requires the final report to cover 10 topics for each country: (1) the activities, budgets, and policy documents regarding the nuclear weapons program; (2) the known research and development activities with respect to nuclear weapons; (3) the inventories of nuclear weapons and delivery vehicles with respect to both deployed and nondeployed weapons; (4) the capabilities of such nuclear weapons and delivery vehicles; (5) the physical sites used for nuclear processing, testing, and weapons integration; (6) the human capital of the scientific and technical workforce involved in nuclear programs, including matters relating to the education, knowledge, and technical capabilities of that workforce; (7) the known deployment areas for nuclear weapons; (8) information on the nuclear command and control system; (9) the factors and motivations driving the nuclear weapons program and the nuclear command and control system; and (10) any other information that the federally funded research and development center determines appropriate. The topics addressed in this working paper collectively address all 10 of the NDAA-mandated topics.

- We address each question with respect to each country as thoroughly as possible—while acknowledging that in many cases providing definitive answers may be impossible.
- We note areas of uncertainty or scholarly debate.

Some of these topics, such as arsenal sizes and weapons capabilities, are well documented in existing English-language open-source literature. Other topics, such as education and training of nuclear programs' scientific personnel, have not been extensively researched—likely because they are inherently difficult to study. In these areas, CNA has carried out focused research using original language sources (Russian, Mandarin Chinese, Korean, and Persian-Farsi) as well as unclassified English-language resources to provide the best available insights. The paper also uses callout boxes, tables, and figures to provide additional background information and context as appropriate.

The following subsections summarize of our key findings for each country.

Russia: key findings

Because of its large arsenal of nuclear weapons, Russia poses an existential threat to the United States. Until recently, the two countries were in a relationship of mutual deterrence and numerical parity buttressed by arms control limits and intrusive monitoring and verification measures on their strategic nuclear forces that began during the Cold War. In addition to a sizeable and modernizing strategic nuclear force, Russia has a nonstrategic nuclear weapons (NSNW) arsenal that is not limited by arms control and has the capability to threaten US allies in Europe. A chief reason that Russia maintains this arsenal is to offset its perceived conventional military inferiority against the United States and NATO in the European theater.[2]

In the ongoing Russia-Ukraine war, Russian leadership has used nuclear rhetoric to signal the possibility of nuclear escalation and to deter the United States and North Atlantic Treaty Organization (NATO) allies from direct military intervention. Russia's strategic nuclear triad, NSNWs, and supporting nuclear complex and defense industrial base are undergoing modernization to ensure that Russia's nuclear capabilities remain a symbol of Russia's great power status as well as a formidable deterrent to a perceived threat of US and NATO aggression.

[2] Kristin Ven Bruusgaard, "Russian Nuclear Strategy and Conventional Inferiority," *Journal of Strategic Studies* (2020), https://www.tandfonline.com/doi/full/10.1080/01402390.2020.1818070.

Nuclear weapons as ultimate guarantor of sovereignty and security

The Soviet Union officially acquired nuclear weapons in 1949 and gradually developed a triad of strategic nuclear forces consisting of strategic bombers, intercontinental ballistic missiles (ICBMs), and nuclear-powered ballistic missile submarines. Russia's strategic nuclear forces have been steadily modernizing for more than two decades. These efforts have extended to all three legs of the Russian nuclear triad, command and control, and early warning infrastructure. Modernization has focused on preservation of a retaliatory capability and development of asymmetric capabilities that could hedge against a US breakthrough in missile defense technologies.

According to Western estimates, Russia devotes about 13.5 to 16 percent of its defense spending to its nuclear weapons program.[3] Reports have indicated a recent increase in nuclear spending to develop new warheads and continue the procurement of relevant systems.[4]

Moscow views nuclear weapons as the ultimate guarantor of its security and an insurance policy to protect against nuclear and large-scale conventional attacks.[5] In Russia's "strategic deterrence" framework, nuclear weapons also play a role in deterring global and regional threats.[6]

Russian nuclear weapons no longer limited by arms control

Until Russia announced its suspension of the New START Treaty in February 2023, legally binding US-Russian arms control had kept Russian strategic nuclear forces around the treaty's ceiling of 1,550 deployed strategic nuclear warheads.[7] Open-source estimates suggest that Russia's overall stockpile consists of 4,489 deployed and nondeployed nuclear warheads

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[3] Julian Cooper, "Russia's Spending on Nuclear Weapons in a Comparative Perspective," Changing Character of War Centre, Oct. 2018, https://www.ccw.ox.ac.uk/blog/2018/10/19/russian-military-expenditure-by-julian-cooper.

[4] "Russian Nuclear Weapons Stand Out in Defense Budget Request," *Defense News*, Nov. 1, 2021, https://www.defensenews.com/global/europe/2021/11/01/russian-nuclear-weapons-stand-out-in-defense-budget-request/.

[5] Anya Loukianova Fink and Olga Oliker, "Russia's Nuclear Weapons in a Multipolar World," *Daedalus* 149, no. 2 (Spring 2020), https://www.jstor.org/stable/pdf/48591311.pdf; Nikolai N. Sokov, *The Evolving Role of Nuclear Weapons in Russia's Security Policy*, James Martin Center for Nonproliferation Studies, 2009, https://www.jstor.org/stable/pdf/resrep09891.8.pdf.

[6] Michael Kofman, Anya Fink, and Jeffrey Edmonds, *Russian Strategy for Escalation Management: Evolution of Key Concepts*, CNA, Apr. 2020, https://www.cna.org/archive/CNA_Files/pdf/drm-2019-u-022455-1rev.pdf.

[7] See US Department of State, "New START Treaty," June 1, 2023, https://www.state.gov/new-start/.

assigned to strategic and nonstrategic delivery vehicles.[8] Of these, about 2,000 warheads are intended for NSNW, and this stockpile may expand in the future.[9]

According to the US intelligence community, because of the damage to Russia's ground forces and Russia's extensive expenditure of precision-guided munitions during the Russia-Ukraine war, Russia will likely become even more reliant on nuclear weapons in the future.[10]

Nuclear use in response to nuclear or conventional aggression

Russian nuclear declaratory policy focuses on the role Russia assigns to nuclear weapons and outlines conditions in which the Russian military could recommend, and the Russian political leadership could consider, employing nuclear weapons. It states:

> The Russian Federation reserves the right to use nuclear weapons in response to the use of nuclear and other types of weapons of mass destruction against it and/or its allies, as well as in the event of aggression against the Russian Federation with the use of conventional weapons when the very existence of the state is in jeopardy.[11]

But in practice, as nuclear threats by the Russian leadership in the current Russia-Ukraine war suggest, Russia's true nuclear threshold is open to interpretation.

An extensive nuclear and missile production complex

Russia's nuclear forces are supported by a sizable nuclear complex managed by Rosatom state-owned nuclear corporation that has been modernized and optimized since the collapse of the Soviet Union. Russia also has a vast network of defense institutes and enterprises that support the government's procurement and employment planning of missiles and nuclear weapons–relevant systems and platforms.

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[8] Hans M. Kristensen, Matt Korda, and Eliana Reynolds, "Russian Nuclear Weapons, 2023," *Bulletin of the Atomic Scientists* 97, no. 3 (2023), https://fas.org/wp-content/uploads/2023/05/Russian-nuclear-weapons-2023.pdf.

[9] Robert P. Ashley Jr., "Russian and Chinese Nuclear Modernization Trends," (Remarks at the Hudson Institute, May 29, 2019), https://www.dia.mil/Articles/Speeches-and-Testimonies/Article/1859890/russian-and-chinese-nuclear-modernization-trends/.

[10] ODNI, "Annual Threat Assessment of the US Intelligence Community," Feb. 6, 2023, https://www.dni.gov/files/ODNI/documents/assessments/ATA-2023-Unclassified-Report.pdf.

[11] Ministry of Foreign Affairs of the Russian Federation, *Basic Principles of State Policy of the Russian Federation on Nuclear Deterrence*, June 2, 2020, https://archive.mid.ru/en/web/guest/foreign_policy/international_safety/disarmament/-/asset_publisher/rp0fiUBmANaH/content/id/4152094; also see CNA unofficial translation of the document at https://www.cna.org/reports/2020/06/state-policy-of-russia-toward-nuclear-deterrence.

Russia has extensive stocks of highly enriched uranium (HEU) and separated plutonium and is standing up additional tritium production. Today, because of its large stocks of fissile materials, Russia does not produce plutonium and may enrich only small amounts of HEU for niche uses and export to foreign clients. Recent reports suggest that Russia may be supplying HEU to China.[12] Russia has a commercial enrichment program that supplies fuel for light water reactors for Russia's domestic market and clients abroad as well as spent fuel reprocessing capabilities. Fissile material production enterprises include four gas centrifuge uranium enrichment facilities, one active reprocessing facility, and a new reprocessing center currently under development.

The Russian nuclear complex engages in activities to ensure that the Russian stockpile is reliable and safe. Warheads are designed, assembled, evaluated, refurbished, life extended, dismantled, and remanufactured. This work is carried out in a handful of design, production, and testing facilities.

As a successor to the Union of Soviet Socialist Republics, Russia is a signatory to numerous Cold War treaties that ban nuclear testing and is a party to the Comprehensive Nuclear-Test-Ban Treaty (CTBT). However, Russia may be engaged in activities that the US intelligence community assesses to be in contravention of its CTBT obligation of generating "zero yield" during nuclear tests. US officials allege that Russia may be conducting tests that create low nuclear yields.

Human capital is a challenge, but investment is extensive

Russia has heavily invested in the improvement of the state of its science and technology ecosystem. However, it continues to lag behind the US, China, and a handful of states in Europe and Asia with respect to R&D spending, patents, scientific publications, and university rankings.[13] Sanctions and other restrictions on Russia after the beginning of the war in Ukraine have also affected international collaborations for Russian science, and concerns about being mobilized by the Russian armed forces have exacerbated the brain drain—the mass departure of well-educated Russians to other countries. Rosatom has taken a very active role in the development of human capital and infrastructure in nuclear-related disciplines and specialties. The state-owned corporation, which currently employs 330,000 people, estimates that it will need to hire up to 100,000 new professionals in physics, chemistry, math, information

[12] US Department of Defense, "Russia Reportedly Supplying Enriched Uranium to China," Mar. 8, 2023, https://www.defense.gov/News/News-Stories/Article/Article/3323381/russia-reportedly-supplying-enriched-uranium-to-china/.

[13] A. N. Klepach, L. B. Vodovatov, and E. A. Dmitrieva, "Russian Science and Technology: Rise or Progressive Lag (Part I)," *Studies on Russian Economic Development* 33, no. 6 (2022): 631–644, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9707188/.

technology, and other areas by 2030 and has spearheaded numerous initiatives.[14] Despite the challenges in Russia's science and technology ecosystem and human capital, these issues alone are unlikely to preclude Russia from maintaining nuclear parity with the United States or holding a commanding position on the global nuclear reactor market.

China: key findings

China is a rapidly maturing nuclear weapons state with a declared no-first-use employment policy. Historically, China maintained a relatively low number of nuclear weapons compared to the United States and Russia. People's Republic of China (PRC) leaders viewed this "lean and effective" arsenal as a part of the PRC's asymmetric strategic posture—maintaining low but sufficient numbers to ensure mutual vulnerability and to provide for a retaliatory strike if attacked with nuclear weapons. China's current perceptions of an evolving global strategic landscape appear to be encouraging the modernization and expansion of its nuclear arsenal as well as extending its suite of strategic options. China is now developing a resilient nuclear triad of sea-, air-, and ground-based delivery systems (as well as testing space-based delivery systems) and may be considering changing its nuclear posture to a launch-on-warning alert level, more in alignment with the US and Russian postures.

Although China declares that it stopped producing fissile material in the 1980s, it still maintains a stockpile adequate to double its arsenal and could turn to its civilian reactors to increase its fissile stockpile. In addition, China's research facilities; human talent in science, technology, engineering, and mathematics (STEM) fields; and state-sanctioned scientific recruitment policies and investments in STEM education likely give it the capabilities necessary to modernize and advance its nuclear arsenal in accordance with strategic demands.

China's concept of an effective nuclear deterrent may be changing

PRC officials see advancements in technology and ballistic missile defense changing the global strategic landscape in fundamental ways that make China's long-standing asymmetric strategic posture more vulnerable to nuclear threats and China less confident in its ability to ensure a second strike. China therefore is expanding its definition of strategic deterrence to include a larger nuclear arsenal as well as developing a range of conventional weapons, such as

[14] "Rosatom Is Planning to Attract 100,000 New Specialists by 2030" (Росатом до 2030 года планирует привлечь еще 100 тысяч новых специалистов), Atomnaya Energiya, Jan. 19, 2023, https://www.atomic-energy.ru/news/2023/01/19/132102.

hypersonics and missile defense, and cyber and space capabilities that could have strategic effects.

Increasing the alert level of some of its nuclear force

PRC leaders state that China remains committed to a no-first-use policy. However, military strategists within China appear to be debating over increasing the alert level of some of China's strategic weapons, particularly its new silo-based ICBM units. This change from historically storing nuclear warheads separate from their delivery systems to maintaining warheads mated to missiles would bring Chinese forces into closer alignment with the higher alert and readiness levels of US and Russian forces and give PRC leaders to ability to launch nuclear weapons on the warning of an incoming strike.

An expanding and diversifying nuclear arsenal to increase survivability

China has been upgrading, diversifying, and increasing its ground-based strategic ICBM arsenal and is developing new stealth air platforms and submarine-launched delivery systems to form a nascent nuclear triad. This diversification includes not only upgrades to current missile designs but also new types of ICBMs with multiple independently targetable reentry vehicle capabilities, intermediate-range ballistic missiles (IRBMs), ground-based cruise missiles, and hypersonic glide vehicles capable of carrying an ICBM into space for a fractional orbital launch. US government estimates show that China has upward of 400 operational warheads in its stockpile, and if it continues its nuclear modernization and expansion at the current pace, it will have at least 1,500 deliverable warheads by 2035.[15] In addition, China has been constructing up to 300 ICBM silos in sites in the western and central-northern part of the country, significantly improving the People's Liberation Army Rocket Force's nuclear-capable missile force.

Fissile stockpile sufficient to double nuclear arsenal

Any increase in a nuclear weapons stockpile requires fissile material. China's current stockpile of plutonium, HEU, and tritium can easily support a doubling of the stockpile, but to triple or quadruple the numbers of nuclear weapons in its arsenal would likely require production of additional material. Given that China likely ended its military production of plutonium in the 1980s, nuclear experts assess that it could theoretically turn to its civil reactors for additional plutonium. This additional production could occur under the PRC's "military-civil fusion" plan,

[15] Office of the Secretary of Defense, US Department of Defense, *Military and Security Developments Involving the People's Republic of China,* Annual Report to Congress, 2022.

a national strategy aimed at eliminating barriers between China's civilian research and commercial sectors and its military and defense industrial sectors.[16]

Scientific personnel likely adequate to meet its strategic development goals

China is investing heavily in its STEM education system, has a national mandate to become self-reliant in its technology sector, and has more than 200 state-sanctioned talent recruitment programs incentivizing high-level PRC-born scientists to return to China.[17] In addition, China has a high concentration of universities offering degree programs directly linked to the nuclear technology field; 72 universities in China run programs on nuclear engineering, 47 of which have separate schools on nuclear science, compared with 34 institutions in the United States that offer nuclear engineering programs.[18] Although China's top STEM universities are not the most elite ranked schools globally, they still are rated in the top 10 percent on average for global school rankings.[19] These factors indicate that the PRC likely has a relatively large, high-quality scientific talent pool that is capable of modernizing and advancing the PRC's nuclear weapons program to meet its strategic objectives.

North Korea: key findings

North Korea is committed to becoming a regional nuclear power with the ability to strategically deter the United States. Pyongyang's desire for a nuclear weapons program dates to the earliest years of the state and is intrinsically linked to ensuring the security of the Kim family regime.

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[16] US Department of State, "Military-Civil Fusion and the People's Republic of China," accessed June 28, 2023, https://www.state.gov/wp-content/uploads/2020/05/What-is-MCF-One-Pager.pdf; "State Council's Notice on the Release of the 13th Five Year National Science and Technology Innovation Plan (国务院关于印发"十三五"国家科技创新规划的通知), July 28, 2016, http://www.gov.cn/zhengce/content/2016-08/08/content_5098072.htm.

[17] See, for example, "Questions and Answers from the Organization Department of the Central Committee on the 'Thousand Talents Program' for the Introduction of Overseas High-level Talents (中央组织部就引进海外高层次人才"千人计划"问答)," Central Government of the People's Republic of China (中华人民共和国中央人民政府), Mar. 20, 2009, accessed Mar. 29, 2023, http://www.gov.cn/govweb/jrzg/2009-03/20/content_1264192.htm; Shi Dongbo, Liu Weichen, and Wang Yanbo, "Has China's Young Thousand Talents Program Been Successful in Recruiting and Nurturing Top-Caliber Scientists?" *Science* 379 (2023): 62–65.

[18] "Full Text: Nuclear Safety in China," State Council Information Office of the People's Republic of China, Sept. 2019, http://english.scio.gov.cn/2019-09/03/content_75166934.htm; "Nuclear Engineering," DATA USA, accessed Mar. 28, 2023, https://datausa.io/profile/cip/nuclear-engineering.

[19] "QS World University Rankings by Subject 2022: Engineering & Technology: China," QS World University Rankings, accessed Mar. 31, 2023, https://www.topuniversities.com/university-rankings/university-subject-rankings/2022/engineering-technology?&countries=cn.

Under Kim Jong Un, North Korea has consistently and steadily made progress toward this goal despite unprecedented international efforts to dissuade the regime in the form of diplomatic pressure and international sanctions. As of 2023, North Korea has conducted six nuclear tests and hundreds of tests of short-, medium-, and long-range missile systems. Although questions remain about the status of North Korea's ICBM capability, Pyongyang has demonstrated many capabilities that can be used to target vital US interests in Northeast Asia and the Pacific and has signaled that the development of its nuclear deterrent will be an enduring priority for the regime. North Korea's continued development of an ICBM could position Pyongyang to directly threaten the United States homeland as part of a strategy to deter outside aggression against the regime.

Guarantor of regime survival

The drivers of North Korea's nuclear program include both historical and ideological factors. Strategic decision-making by North Korea's rulers has primarily been driven by two key objectives: regime survival and perpetuation of the Kim family's rule. North Korea, as an economically and diplomatically isolated state, views nuclear weapons as the ultimate guarantor of its security and a deterrent to any attempt at regime change. This perception hardened amid North Korea's growing military and economic weakness vis-à-vis US-allied South Korea. In the post–Cold War time frame, North Korea's interpretation of the international security environment contributed to the calculus that without nuclear weapons it would be vulnerable to potential US-led efforts to overthrow the Kim regime.

The ideological foundation of the North Korean regime rests on the philosophy of *Juche*, which means "agency" but is often translated as "self-reliance." The nuclear program and national ideology are inextricably linked in that they feed off each other with respect to how the regime portrays itself to the people and how the people view the legitimacy of the regime. Possibly more important to the Supreme Leader and the wider leadership, the nuclear program undergirds the ideology by providing the means by which *Juche* can be executed. By providing the "treasured sword" to protect the North Korean people, the nuclear program conveys legitimacy on the regime as the provider of that sword as well as on the Supreme Leader.

Toward a strategic capability

As a nascent nuclear state, North Korea's nuclear activities are focused on R&D in pursuit of a nuclear weapons capability that can credibly threaten the United States and its allies. These activities include the full range of steps that a state must take to advance its military nuclear program, including fissile material production and warhead and missile testing. North Korea has built out its national infrastructure and organizational structure to support the activities of its nuclear and ballistic missile enterprises, including the development of a robust domestic science and technology capability that allows the regime to rely on indigenous personnel and expertise as it advances its program. North Korea is developing a diverse inventory of strategic and tactical ballistic missiles and multiple delivery systems. These include ICBMs as well as IRBMs, medium-range ballistic missiles, short-range ballistic missiles, and sea-launched ballistic missiles. North Korea has pursued both ground- and sea-launched missile systems and prioritized mobile-based systems in what appears to be an attempt to make its launch systems more survivable. It is unclear how many missiles North Korea has in its arsenal; however, in his public statements, Kim Jong Un has emphasized the need to mass produce the elements of North Korea's strategic arsenal, including warheads and ballistic missiles. During the Kim Jong Un period, North Korea has expanded the number of testing sites for its missile program across the country, indicating a potential desire to be able to disperse and launch its ballistic missiles from more locations.

Based on North Korea's estimated ability to produce fissile material, outside analysts have posited that North Korea may have between 40 and 60 nuclear weapons, but some analysts have estimated that North Korea could have as many as 100 warheads in its current inventory. There is speculation regarding the characteristics of North Korea's nuclear weapons, but experts have generally concluded that North Korea likely has implosion devices and possibly a thermonuclear device. North Korea's six nuclear tests (2006, 2009, 2013, 2016 (2), 2017) have demonstrated increasingly higher detonation yields. North Korea has claimed progress toward miniaturizing warheads to fit on its missiles. However, several questions remain regarding North Korea's ability to operationalize its nuclear warhead inventory. North Korea has yet to demonstrate or prove that it can successfully mate a warhead with a ballistic missile, although some experts posit that North Korea likely has a capability to put a warhead on its short- and medium-range missiles.

Emerging nuclear doctrine

As North Korea's nuclear program has developed, Pyongyang has incrementally clarified its emergent nuclear policy through public statements, legislative activities, and political rhetoric. During the Kim Jong Un era, North Korea has consistently emphasized the defensive nature of its nuclear weapons program while simultaneously alluding to its potential for preemptive and offensive employment if it were to be threatened or attacked. In recent years, a shift in North Korea's rhetoric has more explicitly emphasized the possible preemptive use of nuclear weapons and potential employment of tactical nuclear weapons and provided more insight on conditions that would affect North Korean nuclear decision-making.

In 2022, North Korea's Supreme People's Assembly passed DPRK's Law on Policy of Nuclear Forces, which provides the most clarity on North Korea's nuclear employment policy and nuclear command and control. The law states that the primary missions of the country's nuclear forces are to deter attack and counter or repel an attack should deterrence fail. The law also describes various conditions in which North Korea would employ nuclear weapons. The law reiterates North Korea's position that nuclear weapons would be used only in a scenario in which the regime was threatened.

Enduring priority for the Kim regime

North Korea has consistently emphasized the central role of the country's nuclear capability for its security. Kim Jong Un is frequently depicted attending events related to the country's nuclear and missile programs and has begun including his young daughter, signaling North Korea's enduring commitment to its nuclear deterrent and prioritization of national resources toward these programs. Sanctions and international pressure have curtailed North Korea's nuclear progress and access to foreign support and material, but North Korea has demonstrated that it can continue to fund these programs, develop new capabilities, and demonstrate technological progress despite these barriers. North Korea has proven adept at adapting to sanctions and using licit and illicit means to fund its nuclear and missile activities, which outside analysts estimate to cost between $500 million and $1 billion annually. North Korea's evolving nuclear doctrine of preemptive use to deter aggression based on its perception of imminent threat highlights North Korea's pursuit of an operationalized strategic and tactical nuclear capability.

Iran: key findings

Iran does not currently possess nuclear weapons nor does it appear to have an active nuclear weapons program. However, Iran has engaged in activities relevant to developing nuclear weapons should Iran's leadership decide to pursue such an initiative. These activities include producing HEU and conducting research and experiments with warhead design, metallurgy, and mating warheads with missiles. Iran also has the largest ballistic missile inventory in the Middle East.[20] Although these systems are conventionally armed, they could potentially be adapted to deliver nuclear payloads. In addition, Iran has an active space launch vehicle program that could serve as the basis for ICBM development should Tehran desire to acquire such a system.[21]

[20] "Arms Control and Proliferation Profile: Iran," Arms Control Association, Mar. 2022, https://www.armscontrol.org/factsheets/iranprofile.

[21] "Iran Missile Overview," Nuclear Threat Initiative, July 12, 2017, https://www.nti.org/analysis/articles/iran-missile/.

In July 2015, negotiations between Iran and the P5+1[22] resulted in the Joint Comprehensive Plan of Action (JCPOA), a 25-year agreement limiting Iran's nuclear capacity and subjecting the country to stringent inspections in exchange for sanctions relief.[23] However, doubts about the Iranian government's transparency regarding its nuclear program lingered. In May 2018, the US unilaterally withdrew from the JCPOA, reimposing nuclear-related sanctions on Iran. In response, Iran resumed enriching uranium beyond JCPOA-mandated limits.[24]

Nuclear weapons program shelved in 2003

Iran's efforts to develop a nuclear explosive device began in the late 1980s under the auspices of the Iranian Ministry of Defense and Armed Forces Logistics. The military's efforts were later consolidated within the AMAD Project, which produced components and mock-up parts for engineering a reentry vehicle for a nuclear warhead, conducted engineering studies that examined how to integrate a new spherical payload into the existing payload chamber of a ballistic missile reentry vehicle, and conducted computer modeling studies to evaluate prototypes of missile reentry vehicles, including a prototype firing system for a missile payload that would allow the warhead to safely reenter the atmosphere and then explode above a target or upon impact.[25] According to the International Atomic Energy Agency (IAEA), which has conducted two investigations into Iran's past nuclear activities, a "range of activities relevant to the development of a nuclear explosive device were conducted in Iran prior to the end of

[22] The P5+1 includes the five permanent members of the United Nations (UN) Security Council (China, France, Russia, the United Kingdom, and the US) plus Germany.

[23] Under the terms of the deal, Iran agreed to limit the numbers and types of centrifuges it could operate, the level of its enrichment, and the size of its stockpile of enriched uranium to no more than 300 kilograms of up to 3.67 percent enriched uranium hexafluoride or its equivalent in other chemical forms until 2031. Iran also agreed to reduce its stockpile of low enriched uranium. UN Security Council Resolution (UNSCR) 2231, which endorses the JCPOA but is technically separate from the agreement, placed additional restrictions on Iran's ballistic missile program and its import and export of conventional arms. According to the US government, Iran has repeatedly violated the provisions of UNSCR 2231, most notably through its continued development of ballistic missiles that can serve as nuclear delivery systems and through the sale of conventional weapons to foreign countries such as Russia. See, for instance, Robert Wood, "Remarks at a UN Security Council Briefing on Requests for the UN Secretariat to Investigate Violations of UNSCR 2231," United States Mission to the United Nations, Oct. 26, 2022, https://usun.usmission.gov/remarks-at-a-un-security-council-briefing-on-requests-for-the-un-secretariat-to-investigate-violations-of-unscr-2231/. For an overview of the provisions of UNSCR 2231, see Kali Robinson, "What Is the Iran Nuclear Deal?" Council on Foreign Relations, updated July 20, 2022, https://www.cfr.org/backgrounder/what-iran-nuclear-deal.

[24] Wood, "Remarks at a UN Security Council Briefing"; Robinson, "What Is the Iran Nuclear Deal?"

[25] *Implementation of the NPT Safeguards Agreement and Relevant Provisions of Security Council Resolutions in the Islamic Republic of Iran*, IAEA Board of Governors, GOV/2011/65, Nov. 8, 2011, https://www.iaea.org/sites/default/files/gov2011-65.pdf. See also Kelsey Davenport, "IAEA Investigations of Iran's Nuclear Activities," Arms Control Association, Sept. 2022, https://www.armscontrol.org/factsheets/iaea-investigations-irans-nuclear-activities.

2003 as a coordinated effort, and some activities took place after 2003."[26] The IAEA's investigations into the military dimensions of Iran's nuclear program have found "no credible indications" of activities relevant to weaponization after 2009 or any diversion of nuclear materials for military purposes.[27]

Enrichment a source of concern

Current concerns about Iran's nuclear program are mostly focused on the country's enrichment activities, especially Iran's use of advanced gas centrifuges to generate HEU from hexafluoride (UF6) gas. HEU is one of the two types of fissile material (the other is plutonium) that can be used in nuclear weapons. According to the IAEA, the Atomic Energy Agency of Iran appears to have mastered all the stages of nuclear reactor fuel production.[28] Furthermore, Iran has developed the necessary infrastructure to support each phase of the enrichment process. Iran has three enrichment facilities: an aboveground Pilot Fuel Enrichment Plant at Natanz, an underground Fuel Enrichment Plant also at Natanz, and the deeply buried Fordow Fuel Enrichment Plant.[29] Iran also operates a yellowcake production plant at Ardakan, a UF6 conversion facility in Esfahan, a uranium mine at Gchine, and a uranium production plant for processing uranium ore near Bandar Abbas.

The JCPOA capped Iran's enrichment at 3.57 percent HEU, suitable for powering a civilian nuclear reactor but far short of the 90 percent required for a nuclear weapon. However, following the US withdrawal from the JCPOA, Iran began to install more advanced centrifuges at its enrichment facilities and to incrementally increase the levels at which it was enriching uranium. On February 28, 2023, the IAEA assessed that Iran had produced 87.5 kilograms (192.9 pounds) of uranium enriched to 60 percent using advanced IR-6 centrifuges.[30] Uranium

[26] *Final Assessment on Past and Present Outstanding Issues Regarding Iran's Nuclear Programme*, IAEA Board of Governors, GOV/2015/68, Dec. 2, 2015.

[27] *Verification and Monitoring in the Islamic Republic of Iran in Light of United Nations Security Council Resolution 2231 (2015)*, IAEA Board of Governors, GOV/2022/62, Nov. 10, 2022.

[28] *Verification and Monitoring in the Islamic Republic of Iran in Light of United Nations Security Council Resolution 2231 (2015)*.

[29] David Albright, Sarah Burkhard, and Spencer Faragasso, *A Comprehensive Survey of Iran's Advanced Centrifuges*, Institute for Science and International Security, Dec. 2, 2021, https://isis-online.org/isis-reports/detail/a-comprehensive-survey-of-irans-advanced-centrifuges/, p. 8.

[30] *Verification and Monitoring in the Islamic Republic of Iran in Light of United Nations Security Council Resolution 2231 (2015)*, IAEA Board of Governors, GOV/2023/8, Feb. 28, 2023. Agency inspectors also found traces of uranium enriched to 83.7 percent at the Fordow Fuel Enrichment Plant, very close to weapons-grade purity (90 percent). The IAEA concluded, however, that Iran had not accumulated uranium enriched to 83.7 percent. Laurence Norman, "U.N. Inspectors Detect Near-Weapons-Grade Enriched Uranium in Iran," *Wall Street Journal*, Feb. 19, 2023, https://www.wsj.com/articles/near-weapons-grade-enriched-uranium-detected-in-iran-64dfbdc9?mod=article_inline.

enriched to this level has no practical civilian purpose, but it could vastly reduce the time required for Iran to achieve a nuclear breakout capability. On March 29, 2023, General Mark Milley, the chairman of the US Joint Chiefs of Staff, warned that the time Iran needed to produce enough HEU at a suitable level for one bomb was down to 10 to 15 days.[31]

Large inventory of potential delivery systems

Iran has the largest ballistic missile inventory in the Middle East, including more than 1,000 close-, short-, medium-, and intermediate-range missiles and a smaller inventory of land-attack cruise missiles.[32] Before 2003, the Iranian military had conducted research on weapons design and mating nuclear warheads with ballistic missiles.[33] United Nations Security Council Resolution (UNSCR) 2231, which endorses the JCPOA, calls upon Iran not to undertake any activity related to ballistic missiles designed to be capable of delivering nuclear weapons, including launches using such ballistic missile technology.[34] The Iranian government has asserted that conventionally armed ballistic missiles are essential to the country's defense and are not designed for nuclear use and are thus outside the purview of UNSCR 2231 and its annexes.[35] Successive US administrations have considered Iran's development, acquisition, and use of ballistic missiles as "provocative and destabilizing" and "inconsistent with" UNSCR 2231 because of their inherent capability to carry a nuclear warhead.[36] Iran is not a signatory to international regimes to prevent missile proliferation, such as the Missile Technology Control Regime.

Brain drain limits nuclear talent

Iran's nuclear program has benefited from Iranian students returning from abroad with advanced degrees in STEM-related subjects, particularly physics and nuclear engineering. In 2020 to 2021, approximately 130,000 Iranian-born students were enrolled in foreign universities, including 9,614 in US universities, making Iran the 13th highest ranking country

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[31] Mark A. Milley, Statement Before Department of Defense Budget Hearing, House Armed Services Committee, Mar. 29, 2023.

[32] "Arms Control and Proliferation Profile: Iran."

[33] *Implementation of the NPT Safeguards Agreement and Relevant Provisions of Security Council Resolutions*.

[34] UNSCR 2231, 2015, (S/RES/2231 (2015), https://documents-dds-ny.un.org/doc/UNDOC/GEN/N15/225/27/PDF/N1522527.pdf?OpenElement.

[35] "Appendix E: Iran's Ballistic Missiles and the Nuclear Deal," Arms Control Association, https://www.armscontrol.org/2015-08/appendix-e-iran%E2%80%99s-ballistic-missiles-nuclear-deal.

[36] Kenneth Katzman, *Iran's Foreign and Defense Policies*, Congressional Research Service Report R44017, Jan. 30, 2020, p. 13.

as a source of foreign students studying in the US.[37] However, Iran is also experiencing a "brain drain," which has significantly reduced the pool of available academic talent in Iran. Enticed by the prospect of better, higher paying jobs and financial and political stability, many Iranian students traveling abroad for their education now tend to stay abroad after they earn their degrees. Unlike China, which has invested heavily in strategies to retain academic talent, Iran has tended to downplay or ignore the issue of academic flight, suggesting that the problem is likely to persist, especially if the country continues to experience high levels of unemployment and political unrest.

[37] Kourosh Ziabari, "Iran's Brain Drain Accelerates as Crackdown on Dissent Intensifies," Stimson, May 2, 2023, https://www.stimson.org/2023/irans-brain-drain-accelerates-as-crackdown-on-dissent-intensifies/.

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Contents

Russia's Nuclear Program

Because of its large arsenal of nuclear weapons, Russia presently poses an existential threat to the United States. The relationship of mutual deterrence and numerical parity between the two countries, which began during the Cold War, has until recently been buttressed by legally binding and verifiable arms control limits on their strategic nuclear forces. Russia's nonstrategic nuclear weapons (NSNWs), also not bound by arms control, have the capability to threaten US allies in Europe. In the ongoing Russia-Ukraine war, Russian leadership has used nuclear rhetoric to signal the possibility of nuclear escalation. Russia's strategic nuclear triad, NSNWs, and supporting nuclear complex and defense industrial base are undergoing modernization to ensure that Russia's nuclear capabilities remain a symbol of Russia's great power status as well as a formidable deterrent to a perceived threat of US and North Atlantic Treaty Organization (NATO) aggression.

What factors drive Russia's nuclear program?

Moscow views nuclear weapons as the ultimate guarantor of its security.[38] Russia's nuclear arsenal is an insurance policy to protect against nuclear and large-scale conventional attacks. In Russia's "strategic deterrence" framework, nuclear weapons play a role in deterring global and regional threats.[39] To Russia, a global threat is a nuclear attack from the United States or a large-scale war, and a regional threat is an escalating conventional conflict with the United States and NATO. This section briefly traces the history of Russia's nuclear program and discusses the rationales behind its strategic nuclear forces and NSNWs.

Russia inherited the Soviet Union's nuclear weapons program and strategic and nonstrategic nuclear arsenals following the dissolution of the Union of Soviet Socialist Republics (USSR). The primary motivations behind the Soviet Union's decision to acquire nuclear weapons were knowledge of the existence of foreign nuclear programs, a desire to elevate the position of the Soviet Union in the post–World War II period, and a desire to hedge against an uncertain

[38] Fink and Oliker, "Russia's Nuclear Weapons in a Multipolar World"; Sokov, *The Evolving Role of Nuclear Weapons in Russia's Security Policy*.

[39] Kofman, Fink, and Edmonds, *Russian Strategy for Escalation Management: Evolution of Key Concepts*.

future.[40] The Soviet Union's early nuclear program was facilitated by its intelligence services' espionage on the British bomb program and its spy nets within the US Manhattan Project.[41] It was reinvigorated by President Harry Truman announcing to Joseph Stalin at the Potsdam Conference that the US atomic bomb was completed, the US Trinity test of the first detonated nuclear weapon at Alamogordo, and the uses of the atomic bomb at Hiroshima and Nagasaki.[42]

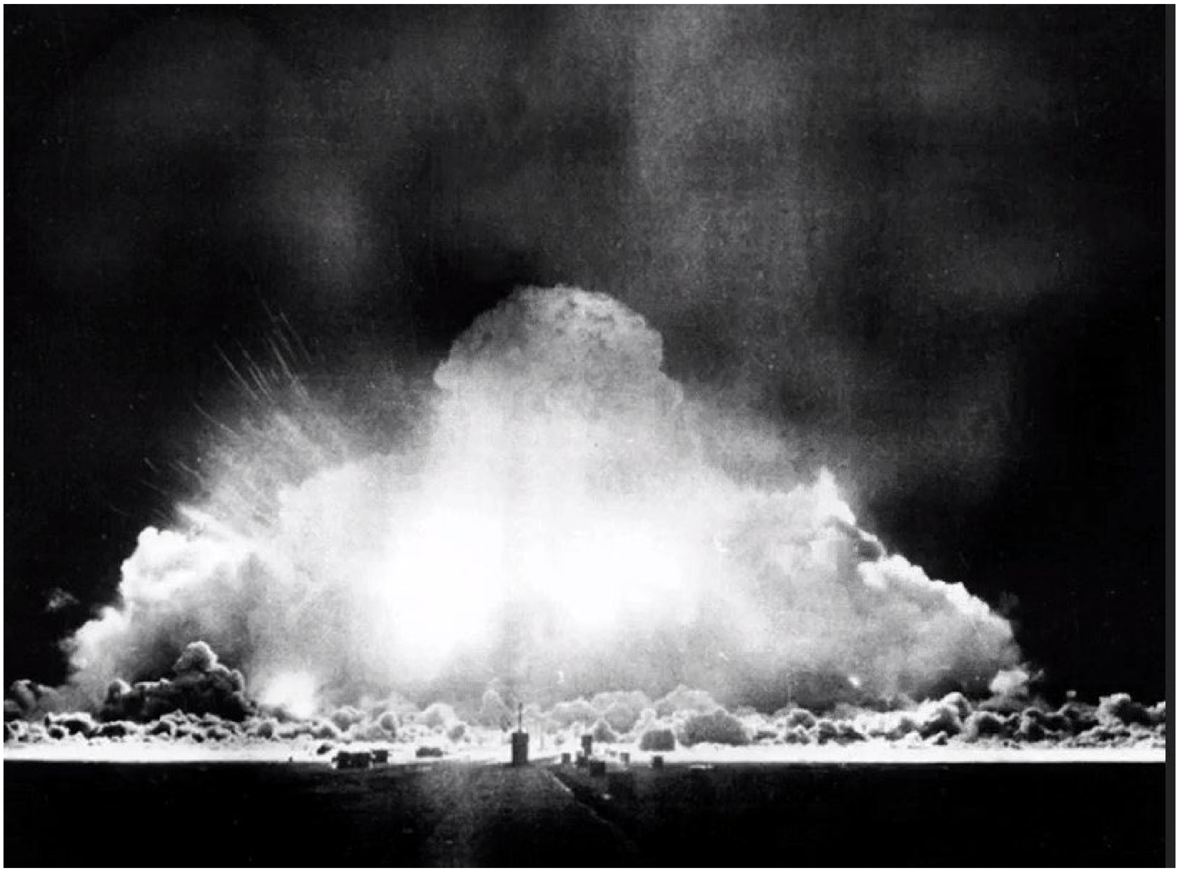
The Soviet Union officially acquired nuclear weapons in 1949, with the First Lightning/Joe-1 test, seen in Figure 1, at the Semipalatinsk test site, located in present-day Kazakhstan. It then gradually developed a triad of strategic nuclear forces consisting of strategic bombers, intercontinental ballistic missiles (ICBMs), and nuclear-powered ballistic missile submarines (SSBNs). Subsequent decades were marked by nuclear rivalry between the USSR and the United States, numerous nuclear crises, and quantitative and qualitative nuclear arms racing that resulted in both countries developing tens of thousands of weapons. Bilateral nuclear arms control, beginning in the 1970s, successfully reduced each country's arsenal of weapons from their peak during the Cold War while maintaining rough parity in strategic forces between these two nuclear powers.

[40] David Holloway, "Entering the Nuclear Arms Race: The Soviet Decision to Build the Atomic Bomb, 1939-45," *Social Studies of Science* 11, no. 2 (1981), https://www.jstor.org/stable/pdf/284865.pdf.

[41] Steven Zaloga, *The Kremlin's Nuclear Sword* (Washington, DC: Smithsonian Institution Press, 2022), pp. 5-7.

[42] Holloway, "Entering the Nuclear Arms Race: The Soviet Decision to Build the Atomic Bomb."

Figure 1. August 1949 test of the RDS-1 device (First Lightning/Joe-1 test)



Source: Rosatom, http://www.biblioatom.ru/evolution/dostizheniya-pervaya-atomnaya-bomba/002.jpg.

Today, as in the Cold War, Russia seeks to maintain approximate numerical parity of deployed strategic nuclear forces with the United States and ensure a capable and modernized second-strike force. US-Russian strategic arms control has kept Russian strategic nuclear forces at or slightly below the New START Treaty ceiling of 1,550 deployed warheads, per the counting rules of the treaty. However, Russia suspended its participation in New START in February 2023. It has also hedged against future technological uncertainty by developing novel nuclear-capable systems, including the Burevestnik nuclear-powered long-range nuclear-armed cruise missile, the Poseidon (Kanyon) nuclear-powered uninhabited underwater vehicle (UUV), the Kinzhal air-launched ballistic missile (ALBM), the Tsirkon ship-launched aero-ballistic missile, the Sarmat ICBM, and the Avangard hypersonic glide vehicle (HGV). (The last two systems were captured in New START.)

Some Western analysts argue that Russia's development of these systems reflects fears that advances in US ballistic missile defenses and improvement in space-based intelligence, surveillance, and reconnaissance may eventually leave Russian nuclear forces vulnerable or ineffective as a deterrent of a US attack, particularly if Russia tries to respond to a US first strike after its arsenal is heavily attrited by that attack.[44] In such a scenario, if US missile defenses intercepted a sizable portion of Russia's retaliatory strike, Moscow could have too few remaining penetrable nuclear weapons to inflict unacceptable damage on US targets.[45] Therefore, some of Moscow's novel systems may be intended to circumvent US missile defenses by adopting a less predictable non-ballistic trajectory. During the Cold War, the Soviet Union may have been concerned about the survivability of its nuclear forces and US counterforce innovations that could shift the nuclear

This chapter refers to some of Russia's nuclear capabilities as *nonstrategic*. This is a catchall term that includes all systems below the intercontinental range of 5,500 kilometers (3,400 miles). The terms ***nonstrategic***, ***tactical***, ***theater***, and ***battlefield*** all may refer to such shorter range or lower yield nuclear weapons. However, these terms are imprecise and lack agreed-upon definitions.[43]

[43] For more information, see Amy Woolf, *Nonstrategic Nuclear Weapons*, Congressional Research Service, Mar. 16, 2021, https://crsreports.congress.gov/product/pdf/RL/RL32572/43. Note that by contrast, strategic nuclear weapons are defined in the US-Russian bilateral nuclear arms control treaties, such as New START, which limit this category of weapon.

[44] Pavel Podvig, "Russia's Current Nuclear Modernization and Arms Control," *Journal for Peace and Nuclear Disarmament* 1, no. 2 (2018): 256-267, https://www.tandfonline.com/doi/full/10.1080/25751654.2018.1526629.

[45] Samuel Charap, et al., *Mitigating Challenges to US-Russia Strategic Stability*, RAND, 2022, https://www.rand.org/content/dam/rand/pubs/research_reports/RRA1000/RRA1094-1/RAND_RRA1094-1.pdf, p. 25.

balance.[46] Similar Russian concerns about superior US offensive *and* defensive capabilities could persist today.[47]

According to public US government estimates, Russia has around 2,000 warheads intended for its nonstrategic nuclear arsenal, and this stockpile may expand in the future.[48] A chief reason that Russia has maintained its NSNW is to offset its perceived conventional military inferiority against the United States and NATO in the European theater.[49] Moscow sees NATO as a sprawling, aggressive anti-Russian alliance that acts without regard for what it perceives as its legitimate security concerns.

In addition, Russian leaders use nuclear threats and signaling for coercive means by threatening escalation and manipulating risk. As part of its "strategic deterrence" approach, the Russian military envisions taking a variety of steps—from rhetoric and signaling to conventional and potentially even nuclear strikes—for escalation management.[50] For example, in the ongoing Russia-Ukraine war, Russian leadership has used nuclear rhetoric to forestall direct US/NATO military intervention. Western officials have been concerned about the possibility of Russian limited nuclear use in that conflict.[51]

Finally, Moscow views its nuclear weapons as proof that it is still a great power, as it was in the Cold War. Being one of the world's few declared nuclear weapons states under the Treaty on the Non-Proliferation of Nuclear Weapons—with quantity and capabilities matched only by the United States—earns Russia a "seat at the table" even if other markers of Russia's state

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[46] Brendan R. Green and Austin Long, "The MAD Who Wasn't There: Soviet Reactions to the Late Cold War Nuclear Balance," *Security Studies* 26, no. 4 (2017): 606–641, https://www.tandfonline.com/doi/abs/10.1080/09636412.2017.1331639?journalCode=fsst20; Austin Long, Testimony Before the House of Representatives Committee on Foreign Affairs, Subcommittee on Terrorism, Nonproliferation, and Trade, *Russian Nuclear Forces and Prospects for Arms Control*, June 21, 2018, https://www.rand.org/content/dam/rand/pubs/testimonies/CT400/CT495/RAND_CT495.pdf.

[47] Austin Long, "Red Glare: The Origin and Implications of Russia's 'New' Nuclear Weapons," War on the Rocks, Mar. 26, 2018, https://warontherocks.com/2018/03/red-glare-the-origin-and-implications-of-russias-new-nuclear-weapons/.

[48] Ashley, "Russian and Chinese Nuclear Modernization Trends."

[49] Ven Bruusgaard, "Russian Nuclear Strategy and Conventional Inferiority."

[50] Kofman, Fink, and Edmonds, *Russian Strategy for Escalation Management: Evolution of Key Concepts*.

[51] "Remarks by President Biden Before the 77th Session of the United Nations General Assembly," The White House, Sept. 21, 2022, https://www.whitehouse.gov/briefing-room/speeches-remarks/2022/09/21/remarks-by-president-biden-before-the-77th-session-of-the-united-nations-general-assembly/.

capacity, such as the size of its economy, fall short of those of other great powers.[52] Moscow's robust nuclear arsenal, along with its permanent seat in the United Nations Security Council, reinforces its perceived role as a counterweight to what it perceives as a unipolar American-led world order. The prestige and influence accorded to Russia as a result help fortify its position as a global power, and national pride associated with Moscow's nuclear arsenal may even strengthen the regime of Russia's President Vladimir Putin among domestic audiences.[53]

In summary, Russia's motivations for maintaining and modernizing its nuclear weapons arsenal include the following:

- To maintain mutual nuclear vulnerability and numerical parity of strategic nuclear forces with the United States to deter a US strategic attack on Russia
- To hedge against the emergence of new technologies and US technological breakthroughs that could detrimentally affect Russia's second-strike capability
- To offset US/NATO conventional superiority in the European theater
- To possess a coercive tool for escalation management purposes
- To preserve its geopolitical status as one of the great powers

What are Russia's nuclear weapons policies?

Russian documents and leadership statements highlight the role of nuclear weapons and discuss potential circumstances for the use of nuclear weapons. Russian nuclear declaratory policy focuses on the role Russia assigns to nuclear weapons and outlines conditions in which the Russian military could recommend, and the Russian political leadership could consider, employing nuclear weapons. But in practice, as the Russian statements in the current Russia-Ukraine war suggest, Russia's true nuclear threshold is ambiguous. This section highlights Russia's nuclear declaratory and employment policies. It draws on primary sources such as Russian nuclear doctrinal documents, leadership statements, and authoritative military writings.

[52] Michael Kofman, *Drivers of Russian Grand Strategy*, Frivarld, 2019, https://frivarld.se/wp-content/uploads/2019/04/Drivers-of-Russian-Grand-Strategy.pdf.

[53] Rose Gottemoeller, "Nuclear Necessity in Putin's Russia," *Arms Control Today* 34, no. 3 (Apr. 2004): 14–18.

Nuclear declaratory policy

Russian declaratory policy on nuclear weapons has traditionally been limited to several sentences in Russian military doctrine. The military doctrine—and the nuclear language contained within it—has undergone periodic revisions. In 2020, the Russian government expanded and clarified the language contained in the 2014 military doctrine. Current formal Russian declaratory policy on nuclear weapons is contained in the 2020 *Basic Principles of State Policy of the Russian Federation on Nuclear Deterrence.*[54]

Basic Principles outlines the role of nuclear weapons, discusses the essence of nuclear deterrence, and outlines military dangers that Russia considers essential to deter with its military means, including nuclear weapons. In addition, leadership speeches and statements—especially those by Russian President Vladimir Putin—reinforce and align with the policies outlined in *Basic Principles*.

Role of nuclear weapons and essence of nuclear deterrence

Basic Principles makes the following points, among others (emphasis in italics and notes in bold ours):

- **Nuclear weapons are just one part of the Russian deterrent**. "The guaranteed deterrence of a potential adversary from aggression against the Russian Federation and/or its allies is one of the highest state priorities. Deterrence of aggression is ensured by the *entire military strength* of the Russian Federation, including its nuclear weapons."
- "State policy on Nuclear Deterrence is defensive by nature, it is aimed *at maintaining the nuclear forces potential at the level sufficient for nuclear deterrence*, and guarantees protection of national sovereignty and territorial integrity of the State, and *deterrence of a potential adversary from aggression* against the Russian Federation and/or its allies. In the event of a military conflict, this Policy provides for *the prevention of an escalation of military actions and their termination on conditions that are acceptable for the Russian Federation* and/or its allies."

Basic Principles also discusses the essence of nuclear deterrence (emphasis in italics and notes in bold ours):

[54] Ministry of Foreign Affairs of the Russian Federation, *Basic Principles of State Policy of the Russian Federation on Nuclear Deterrence*; also see CNA unofficial translation of the document at https://www.cna.org/reports/2020/06/state-policy-of-russia-toward-nuclear-deterrence.

- "Nuclear deterrence is aimed to provide comprehension by a potential adversary of the *inevitability of retaliation* in the event of aggression against the Russian Federation and/or its allies."
- **Russian nuclear forces need to be able to strike at intended targets in even the worst case scenarios.** "Nuclear deterrence is ensured by the presence in the Armed Forces of the Russian Federation of the combat-ready forces and means that are capable to *inflict guaranteed unacceptable damage* on a potential adversary through employment of nuclear weapons in *any circumstances*, as well as by the readiness and resolve of the Russian Federation to use such weapons."
- **Russian nuclear forces are always on alert and practice nuclear deterrence.** "Nuclear deterrence is ensured *continuously* in peacetime, in periods of a direct threat of aggression and also in wartime, *up until the actual use of nuclear weapons*."

Military dangers

Basic Principles outlines military dangers that could develop into military threats that Russia plans to deter with nuclear weapons, including the following:

- "Build-up by a potential adversary of the general purpose forces groupings that possess nuclear weapons delivery means in the territories of the states contiguous with the Russian Federation and its allies, as well as in adjacent waters."
- "Deployment by states which consider the Russian Federation as a potential adversary, of missile defense systems and means, medium- and shorter-range cruise and ballistic missiles, non-nuclear high–precision and hypersonic weapons, strike unmanned aerial vehicles, and directed energy weapons."
- "Development and deployment of missile defense assets and strike systems in outer space."
- "Possession by states of nuclear weapons and (or) other types of weapons of mass destruction that can be used against the Russian Federation and/or its allies, as well as means of delivery of such weapons."
- "Uncontrolled proliferation of nuclear weapons, their delivery means, technology and equipment for their manufacture."
- "Deployment of nuclear weapons and their delivery means in the territories of non-nuclear weapon states."

Furthermore, the document points to concerns about NATO and specific capabilities:

- "The Russian Federation implements its nuclear deterrence with regard to individual states and military coalitions (blocs, alliances) that consider the Russian Federation as a potential adversary and that possess nuclear weapons and/or other types of weapons of mass destruction, or significant combat potential of general purpose forces."
- "While implementing nuclear deterrence, the Russian Federation takes into account the deployment by a potential adversary, in the territories of other countries, of offensive weapons (cruise and ballistic missiles, hypersonic aerial vehicles, strike unmanned aerial vehicles), directed energy weapons, missile defense assets, early warning systems, nuclear weapons and/or other weapons of mass destruction that may be used against the Russian Federation and/or its allies."

Principles of military deterrence and command

Basic Principles also lists the following principles of nuclear deterrence (emphasis ours):

- "Compliance with international arms control commitments."
- *"Continuity* of activities ensuring nuclear deterrence."
- *"Adaptability* of nuclear deterrence to military threats."
- *"Unpredictability* for a potential adversary in terms of scale, time and place for possible employment of forces and means of nuclear deterrence."
- *"Centralization of governmental control* over the activities of federal executive bodies and organizations involved in ensuring nuclear deterrence."
- "Rationality of structure and composition of nuclear deterrence forces and means and their *maintaining at the minimal level sufficient for implementing the tasks assigned."*
- "Maintaining *permanent readiness* of a designated fraction of nuclear deterrence forces and means for combat use."

It further notes that Russia's strategic nuclear forces are a triad: "The nuclear deterrence forces of the Russian Federation include land-, sea- and air-based nuclear forces."

Conditions for nuclear use

Basic Principles also outlines conditions in which the Russian leadership would consider nuclear employment (emphasis ours):

- "The Russian Federation reserves the right to use nuclear weapons in *response to the use of nuclear and other types of weapons of mass destruction* against it and/or its allies, as well as in the event of *aggression against the Russian Federation with the use of conventional weapons when the very existence of the state is in jeopardy*."

- The conditions that make it possible that Russia will employ nuclear weapons include the following:
  - "The arrival of reliable data on a launch of ballistic missiles attacking the territory of the Russian Federation and/or its allies."
  - "Use of nuclear weapons or other types of weapons of mass destruction by an adversary against the Russian Federation and/or its allies."
  - "Attack by adversary against critical governmental or military sites of the Russian Federation, disruption of which would undermine nuclear forces response actions."
  - "Aggression against the Russian Federation with the use of conventional weapons when the very existence of the state is in jeopardy."

The document also states that the nuclear employment decision rests with the Russian president: "The decision to use nuclear weapons is taken by the President of the Russian Federation."

As a result, the military may make plans and participate in the implementation of the order (as discussed in the Command and Control section below), but the nuclear employment decision is ultimately a political decision.

Figure 2. Russia's President Vladimir Putin with defense officials

Source: Press Service of the President of Russia, "Vladimir Putin at the National Defense Management Center," Russian Federation Ministry of Defense, Apr. 17, 2015, http://www.kremlin.ru/events/president/news/49268/photos.

Leadership speeches on declaratory policy

Statements made by Putin in 2022 suggest that his personal thinking is generally consistent with what is outlined in the *Basic Principles* document. The evolution of Russia's nuclear deterrent and its modernization have largely occurred on Putin's watch beginning in 1999. Putin has also consistently participated in strategic nuclear forces exercises, signaling that he is not removed from nuclear planning discussions.

In the ongoing Russia-Ukraine war, Putin has repeatedly used nuclear rhetoric that has been concerning to Western leaders and observers. Examples include the following (emphasis ours):

- In a February 24, 2022, speech, Putin stated: "As for military affairs, even after the dissolution of the USSR and losing a considerable part of its capabilities, *today's Russia* *remains one of the most powerful nuclear states.* Moreover, it has a certain advantage in several cutting-edge weapons. In this context, there should be no doubt for anyone that any potential aggressor will face defeat and ominous consequences should it directly attack our country."[55]

- On February 27, 2022, he announced a "special mode of combat duty" for the Russian deterrence forces.[56] Despite observers' concerns that this was an increase in Russian nuclear alert levels, it appears to have been merely an increase in manning.[57]
- On September 21, 2022, Putin stated: "In the event of a threat to the territorial integrity to our country and to defend Russia and our people, *we will certainly make use of all weapon systems available to us. This is not a bluff*."[58]
- In a September 30, 2022, speech, Putin proclaimed Ukraine's Luhansk, Donetsk, Zaporizhzhia, and Kherson regions to be part of Russia and stated, "*We will defend our land with all the forces and resources we have*." He also invoked the "precedent" of US use of nuclear weapons during World War II, implying perhaps that the United States should not be the one casting aspersions.[59]

Since February 2022, every major speech by the Russian leader has featured references to nuclear weapons. Other Russian officials such as former Russian President and now Deputy Chairman of the Security Council Dmitry Medvedev have engaged in even more explicit nuclear saber-rattling. A comprehensive analysis of these statements is beyond the scope of this paper. However, to date, Putin's principal aim appears to have been to signal the possibility of nuclear escalation in response to a direct Western military intervention on behalf of Ukraine that (in his view) poses a threat not just to Russia's unjust war against Ukraine but also to Russia itself.

55 "Address by the President of the Russian Federation," President of Russia, Feb. 24, 2022, http://en.kremlin.ru/events/president/news/67843.

56 "Putin Orders 'Special Service Regime' in Russia's Deterrence Force," TASS, Feb. 27, 2022, https://tass.com/defense/1412575.

57 "RF Deterrence Forces Have Started to Carry Out Combat Duty with Higher Manning" [Силы сдерживания ВС России приступили к несению боевого дежурства усиленным составом], TASS, Feb. 28, 2022, https://tass.ru/armiya-i-opk/13897773.

58 "Address by the President of the Russian Federation," President of Russia, Sept. 21, 2022, http://en.kremlin.ru/events/president/news/69390.

59 "Signing of Treaties on Accession of Donetsk and Lugansk People's Republics and Zaporozhye and Kherson Regions to Russia," President of Russia, Sept. 30, 2022, http://en.kremlin.ru/events/president/news/69465.

Analysts, however, have been concerned that the Russian leader could consider nuclear employment for war termination, among other reasons.[60]

Nuclear employment policy

Doctrinally, Russian strategic nuclear forces are intended for a response to existential threats to the nuclear deterrent or state that would in turn inflict unacceptable damage on an aggressor. Russia would launch this retaliatory strike after its early warning systems detect an incoming strategic nuclear missile attack. This launch would be a retaliatory-meeting strike (*otvetno-vstrechnyi udar*)—in essence, a launch on warning. Russia also has plans for the worst case scenario: a launch after an adversary's nuclear strikes have already taken place on Russian territory. This launch would be a retaliatory strike (*otvetnyi udar*)—in essence, a launch under attack. According to authoritative military writings, Russia's silo-based ICBMs are instrumental in launch on warning, whereas its mobile ICBMs and SSBNs with submarine-launched ballistic missiles (SLBMs) are central to launch under attack.[61] Russia's silo-based ICBMs may also be used in a first strike.[62]

> Russian strategic nuclear forces could be used in a ***retaliatory-meeting strike****,* which is a second strike after early warning systems receive notifications of an adversarial launch, or in a ***retaliatory strike***, which is conducted after adversary missiles have impacted Russian territory.

As noted earlier, Russia also has an extensive variety of NSNWs and dual-capable systems. Partly because of the cost-effectiveness of NSNWs vis-à-vis conventional capabilities, the Russian military intends them to play an important role in deterring aggression in a regional conventional contingency and help with signaling, escalation management, and, if deterrence fails, warfighting.[63] The most recent version of the Russian military doctrine, released in 2014, states that "nuclear weapons will remain an important factor preventing nuclear war and

[60] For example, Scott Sagan, "The World's Most Dangerous Man," *Foreign Affairs*, Mar. 16, 2022, https://www.foreignaffairs.com/articles/russian-federation/2022-03-16/worlds-most-dangerous-man.

[61] V. F. Lata, "Present and Future of the Strategic Missile Forces as the Guarantor of the Defense and Security in Russia" (Настоящее и будущее РВСН как гаранта оборонной безопасности России), *Vestnik Akademii Voennykh Nauk*, Feb. 2018.

[62] S.V. Karakaev, "On the Issue of Employment of Strategic Rocket Forces in Wars of the Future" (К вопросу о применении Ракетных войск стратегического назначекия в войнах будущего), *Voennaya Mysl'*, Feb. 2023.

[63] Kofman, Fink, and Edmonds, *Russian Strategy for Escalation Management: Evolution of Key Concepts*.

military conflicts with the use of conventional weapons [in large-scale and regional wars]."[64] This and the *Basic Principles* document suggest an emphasis on planning against the US/NATO.

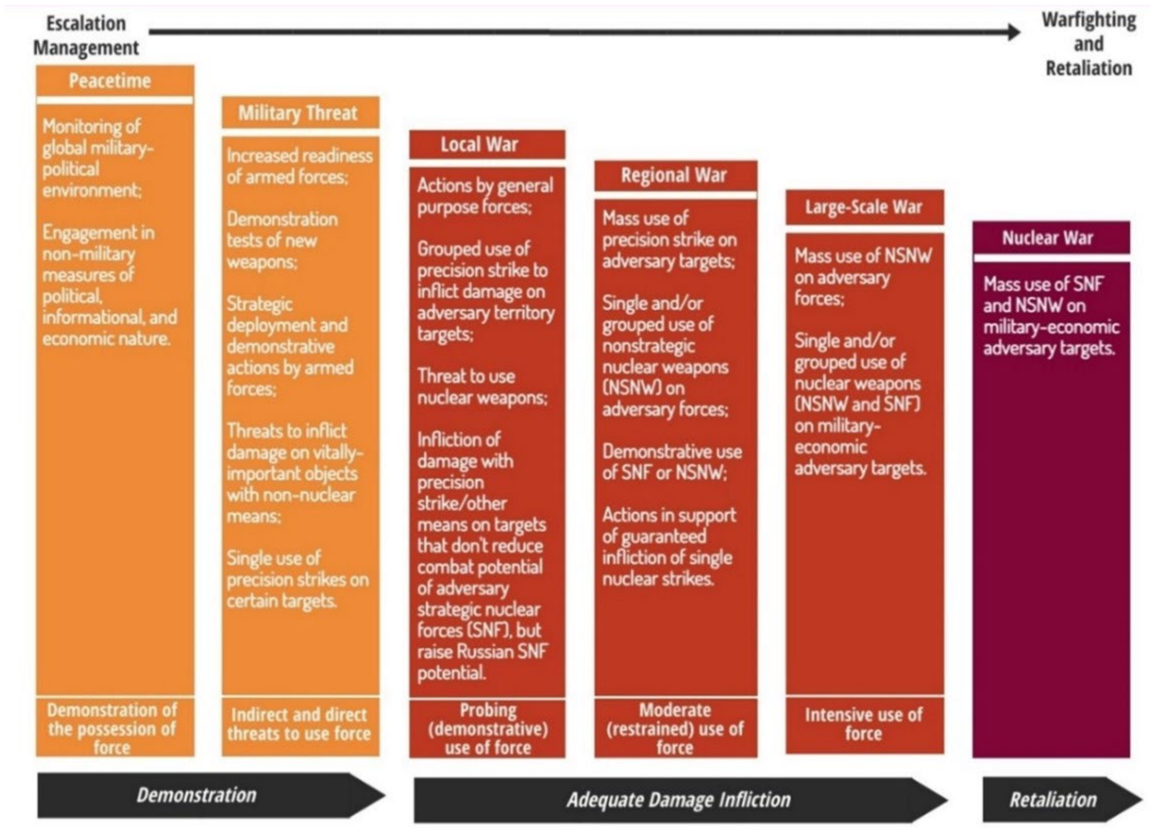
For decades, NSNWs were Russia's primary solution to the prospect of a massed Western aerospace attack on critical targets in Russia. Authoritative Russian military writings analyzed by CNA suggest that nuclear weapons are central to Russia's theory of escalation management.[65] As outlined in Figure 3, at certain points in a regional conflict, Russia may engage in limited use of NSNWs for the purposes of coercing the adversary or forestalling further conflict escalation.

Some argue that Russia has an "**escalate to de-escalate**" doctrine, referring primarily to potential Russian NSNW use in a regional conflict. Official and authoritative Russian sources do not use this terminology. However, the Russian military does appear to envision the possibility of limited NSNW use for escalation management potentially following activities like conventional precision missile strikes or cyberattacks on adversary critical targets.

[64] "Military Doctrine of the Russian Federation," unofficial translation, 2014, https://thailand.mid.ru/en/military-doctrine-of-the-russian-federation.

[65] Kofman, Fink, and Edmonds, *Russian Strategy for Escalation Management: Evolution of Key Concepts*.

Figure 3. Russian military approaches to escalation management



Source: Michael Kofman, Anya Fink, and Jeffrey Edmonds, *Russian Strategy for Escalation Management: Evolution of Key Concepts*, CNA, Apr. 2020, https://www.cna.org/archive/CNA_Files/pdf/drm-2019-u-022455-1rev.pdf.

Before the Russia-Ukraine war, Russian officials seemed to desire to reduce reliance on NSNWs in favor of more credible nonnuclear deterrence options (including counterspace and cyber capabilities).[66] Russia views conventional precision strike systems (or strategic nonnuclear weapons) as increasingly important for the purposes of fighting local wars and managing the escalation and warfighting of regional and large-scale conflicts, as seen in Figure 3. These

[66] "Statement by Chief of the RF General Staff" (Выступление начальника Генерального штаба Вооруженных Сил Российской Федерации), Russian Federation Ministry of Defense, Nov. 7, 2017, https://function.mil.ru/news_page/country/more.htm?id=12149743@egNews.

systems enable kinetic strikes on key nodes of adversary critical infrastructure for operational and psychological effects, including strikes as part of a special strategic operation.[67] Prospective Russian operational concepts suggest that conventional and nuclear weapons are becoming more tightly integrated, potentially as part of a strategic deterrent forces operation that relies on conventional precision strike and limited nuclear employment.[68]

How does Russia command and control its nuclear forces?

Although secrecy surrounds Russia's nuclear command and control procedures, many aspects are at least partially understood in the public domain. This section discusses the security of nuclear weapons before focusing on early warning and command and control of nuclear forces.

Nuclear command and control refers to the exercise of authority and direction, through established command lines, over nuclear weapon operations by the leadership of a country.[69] A central theme of nuclear command and control is the "always/never" principle: nuclear forces must always carry out assigned missions in response to orders from national leader(s) with nuclear release authority, but nuclear capabilities must never be employed or accidentally detonated under any other circumstances.[70] Nuclear command and control must function before, during, and after a conflict.[71] Chronologically, nuclear command and control involves four aspects: (1) the detection and characterization of an incoming attack, (2) nuclear decision-making, (3) the passing of orders through the chain of command to employment, and (4) the ability to maintain control even under attack.[72] Although different countries will approach these tasks differently, the basic ideas that animate nuclear command and control are common across all nuclear-armed states.

[69] This definition is slightly modified from Office of the Deputy Assistant Secretary of Defense for Nuclear Matters, "Nuclear Weapons Employment Policy, Planning and NC3," in *Nuclear Matters Handbook 2020 [Revised],* accessed Sept. 20, 2021.

[70] Peter Feaver. *Guarding the Guardians: Civilian Control of Nuclear Weapons in the United States*. (Ithaca, NY: Cornell University Press, 1992).

Launch authority and procedures

As discussed in the doctrine section above, the president of the Russian Federation is the supreme commander and the only doctrinally designated political nuclear decision-maker.[73] Russia's equivalent of the US "nuclear football"—the communications terminal in a portable briefcase that allows the US President to transmit nuclear orders down the command structure—is called the *Cheget*. Unlike the United States, Russia may have up to three of these briefcases: one is with the president of the Russian Federation (currently Putin), another is with the minister of defense (currently Sergey Shoigu), and the third is with the chief of the General Staff (currently Valeriy Gerasimov).[74]

Several analysts argue that these additional two *Cheget* terminals likely act as links in the chain of command required to transmit the president's orders to the ranks—essentially forming a "triple key."[75] However, there is disagreement about how many of the *Cheget* terminals are needed to authenticate the political orders; some accounts state that only two (rather than three) terminals need to provide authentication to authorize a launch.[76] In either case, the president, minister of defense, and chief of the General Staff seem to be expected to jointly

[69] This definition is slightly modified from Office of the Deputy Assistant Secretary of Defense for Nuclear Matters, "Nuclear Weapons Employment Policy, Planning and NC3," in *Nuclear Matters Handbook 2020 [Revised],* accessed Sept. 20, 2021.

[70] Peter Feaver. *Guarding the Guardians: Civilian Control of Nuclear Weapons in the United States*. (Ithaca, NY: Cornell University Press, 1992).

[71] John Harvey, *US Nuclear Command and Control for the 21st Century*, Technology for Global Security, May 23, 2019, https://securityandtechnology.org/wp-content/uploads/2020/07/john_harvey_u.s._nuclear_command_and_control_for_the_21st_century_IST.pdf.

[72] These four functions are derived from "Command and Control of U.S. Nuclear Forces," in *Managing Nuclear Operations in the 21st Century*, ed. Charles Glaser, Austin Long, and Brian Radzinski (Brookings Institution Press, 2022).

[73] Ministry of Foreign Affairs of the Russian Federation, *Basic Principles of State Policy of the Russian Federation on Nuclear Deterrence*.

[74] Valery E. Yarynich, *C3: Nuclear Command, Control Cooperation* (Center for Defense Information, 2003), p. 150.

[75] David E. Hoffman, "The Russian Nuclear Button," *Foreign Policy*, May 27, 2010, https://foreignpolicy.com/2010/05/27/the-russian-nuclear-button-2/.

[76] Jeffrey G. Lewis and Bruno Tertrais, *Finger on the Button: The Authority to Use Nuclear Weapons in Nuclear-Armed States*, Center for Nonproliferation Studies, Feb. 2019, https://www.nonproliferation.org/wp-content/uploads/2019/02/Finger-on-the-Nuclear-Button.pdf; Leonid Ryabikhin, *Russia's NC3 and Early Warning Systems*, Nautilus Institute, July 11, 2019, https://nautilus.org/napsnet/napsnet-special-reports/russias-nc3-and-early-warning-systems/?view=pdf; Yarynich, *C3: Nuclear Command, Control and Control Cooperation*, p. 151.

prepare the authorization of the political orders.[77] A secure, highly survivable communications system allows the senior leaders to discuss nuclear orders.[78]

Given that the *Cheget* terminals are assigned to military leaders, in addition to the civilian commander-in-chief, a notable Russian military analyst has raised concerns about the level of civilian control over the country's nuclear weapons, particularly if the president is incapacitated.[79] If the Russian president is incapacitated, the prime minister would assume all presidential duties, but whether these duties include nuclear launch authority is not explicit. What happens if the prime minister is also incapacitated is also unclear, although some argue that the chair of the Federation Council is possibly next in the line of authority.[80]

There is no evidence of pre-delegation of political authority from the civilian leadership to the military. Although the Russian military likely plans for the scenario of a surprise attack on Russia's nuclear forces, a much more probable planning scenario is a nuclear escalation of a conventional conflict. In this case, Russia's nuclear forces will likely be in a state of heightened alert before nuclear employment is authorized. An increase in alert levels is similarly a political decision. A raised alert level could lead to the dispersal of mobile nuclear systems and warhead loading operations.[81]

Security

According to an authoritative account of a former Soviet military officer, Russia maintains a high degree of centralization over each leg of its strategic nuclear forces, meaning it enforces tight custody and security measures with the goal of preventing unauthorized use.[82] Two people are required to launch Russian nuclear weapons as a rule.[83] Since the Soviet days, the Russian military has reportedly used electronic systems that allow authorities to disable the

[77] Yarynich, *C3: Nuclear Command, Control and Control Cooperation*, p. 153; Lewis and Tertrais, *Finger on the Button: The Authority to Use Nuclear Weapons in Nuclear-Armed States*.

[78] Yarynich, *C3: Nuclear Command, Control and Control Cooperation*, p. 150.

[79] Alexey Arbatov in Hoffman, "The Russian Nuclear Button."

[80] Lewis and Tertrais, *Finger on the Button: The Authority to Use Nuclear Weapons in Nuclear-Armed States*, p. 12.

[81] Pavel Podvig, Oleg Bukharin, and Frank N. von Hippel, *Russian Strategic Nuclear Forces* (MIT, 2001).

[82] Yarynich, *C3: Nuclear Command, Control and Control Cooperation*, p. 205; Lewis and Tertrais, *Finger on the Button: The Authority to Use Nuclear Weapons in Nuclear-Armed States*, p. 12.

[83] Yarynich, *C3: Nuclear Command, Control and Control Cooperation*, p. 206.

use of nuclear weapons by unauthorized individuals.[84] Furthermore, according to analysts, launch procedures require special access codes to unblock.[85]

The 12th GUMO, the 12th Chief (or "Main") Directorate of the Ministry of Defense (MOD) provides security for Russian warheads. Its personnel are responsible for storing, maintaining, and transporting the weapons to and from storage facilities and handling the warheads at Russia's nuclear test site in Novaya Zemlya (see Figure 13). The Russian military is believed to have 12 national-level storage sites for warheads and more than 30 smaller base-level storage sites that, in turn, receive warheads from national-level sites when necessary for deployment.[86]

A warhead leaves 12th GUMO custody only once it is mounted on its launcher.[87] Personnel from the 12th GUMO are present in units of Russian military forces that have nuclear warheads mated to delivery systems, and they are responsible for the physical security of the warheads. Owing to their readiness status, only ICBMs on duty and SSBNs on patrol have warheads mated, according to some reports.[88] As part of Cooperative Threat Reduction (CTR) activities, the US Department of Defense (DOD) previously worked with the 12th GUMO on enhancing the physical security of Russian warheads.[89]

Early warning

Detection of an attack begins with Russia's early warning system, which consists of a network of satellites, two ground control stations, and more than a dozen ground-based radars. The satellites include five of a planned constellation of second-generation EKS OiBU satellites in

[84] Yarynich, *C3: Nuclear Command, Control and Control Cooperation*, p. 208; for more reading on control measures, see Yarynich, *C3*.

[85] Pavel Podvig, *Russian Strategic Nuclear Forces* (Center for Arms Control, Energy and Environmental Studies at the Moscow Institute of Physics and Technology, 2004), pp. 53, 57.

[86] Pavel Podvig and Javier Serrat, *Lock Them Up: Zero Deployed Non-Strategic Nuclear Weapons in Europe*, UNIDIR, 2017, pp. 14–19, https://unidir.org/sites/default/files/publication/pdfs/lock-them-up-zero-deployed-non-strategic-nuclear-weapons-in-europe-en-675.pdf.

[87] Podvig and Serrat, *Lock Them Up: Zero Deployed Non-Strategic Nuclear Weapons in Europe*.

[88] Podvig and Serrat, *Lock Them Up: Zero Deployed Non-Strategic Nuclear Weapons in Europe*.

[89] William M. Moon, "The Story Behind U.S. Access to Russian Nuclear Warhead Storage Sites," Stimson Center, Feb. 4, 2021, https://www.stimson.org/2021/the-story-behind-u-s-access-to-russian-nuclear-warhead-storage-sites/.

highly elliptical orbits and geostationary orbits.[90] Upgrades to the space-based portion of Russia's early warning system have been proceeding slowly.[91] In contrast, Russia successfully modernized its early warning and space surveillance ground-based radars located in Russia, Kazakhstan, and Belarus.[92]

Since the end of the Cold War, the US and Russia have periodically discussed cooperation on early warning and missile defense as a way to improve strategic stability. These discussions included the idea of a joint data exchange center[93] and the concept of a radar that would be operated jointly in Azerbaijan.[94] However, these proposals were not successful.

Nuclear command, control, and communications

Early warning systems signals and other attack indicators are confirmed and transmitted to the command center of the Strategic Rocket Forces and the National Defense Management Center (NDMC) in Moscow, among other command points. As seen in Figure 4, the NDMC was founded in 2014 and is a key entity involved in nuclear command, control, and communications (NC3).[95] If these signals and indicators are preceded by a crisis that leads to heightened alert levels, steps are taken during that process to transfer the battle management systems to combat mode and improve NC3 resilience.[96]

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90 Anatoly Zak, *Russian Military and Dual Purpose Spacecraft: Latest Status and Operational Overview*, CNA, June 2019, https://www.cna.org/archive/CNA_Files/pdf/iop-2019-u-020191-final.pdf; Anatoly Zak, "Russia Launches a Missile-Detection Satellite," Russianspaceweb.com, Dec. 14, 2021, http://russianspaceweb.com/eks5.html.

91 "Russian Strategic Nuclear Forces: Early Warning," RussianForces.org, Aug. 7, 2021, https://russianforces.org/sprn/.

92 "Russian Strategic Nuclear Forces: Early Warning."

93 US Department of State," Memorandum of Agreement Between the United States of America and the Russian Federation on the Establishment of a Joint Center for the Exchange of Data from Early Warning Systems and Notifications of Missile Launches (JDEC MOA)," June 4, 2000, https://2009-2017.state.gov/t/avc/trty/187151.htm.

94 "Bush Says Azerbaijan Radar Proposal 'Interesting,'" RFE/RFL, June 11, 2007, https://www.rferl.org/a/1077056.html.

95 Leonid Ryabikhin, *Russia's NC3 and Early Warning Systems*.

96 Podvig, Bukharin, and von Hippel, *Russian Strategic Nuclear Forces*.

Figure 4. Inside Russia's National Defense Management Center

Source: Press Service of the President of Russia, "National Defense Management Center of the Russian Federation," Dec. 19, 2014, http://www.kremlin.ru/news/47256.

If an incoming attack is detected and confirmed, the president discusses the possibility of a nuclear launch with the chief of the General Staff and minister of defense. Should the president choose to launch nuclear weapons, the command would be communicated through the *Cheget* to the General Staff, who would issue the order through a special communications system.[97] Next, the armed forces (the Strategic Rocket Forces, the Aerospace Forces, the Navy, or all three) would receive the orders through a series of redundant terminals, and they would then carry out the orders.[98] According to an authoritative account of a former Soviet military officer, these terminals transmit information quickly, and the forces can receive the orders in as little

[97] Podvig, Bukharin, and von Hippel, *Russian Strategic Nuclear Forces*.

[98] Hoffman, "The Russian Nuclear Button"; Lewis and Tertrais, *Finger on the Button: The Authority to Use Nuclear Weapons in Nuclear-Armed States*.

as 30 seconds after they are issued.[99] NC3 operations can reportedly also be conducted via a series of secure road or rail mobile and airborne command posts with two-way communications, each of which is equipped to receive early warning signals.[100] According to authoritative analysts, Russia's nuclear battle management system includes a component called *Perimetr*.[101] Some argue that this system can even function as a "dead hand" switch that can launch a retaliatory attack with Russian strategic nuclear forces even if the decision-making body has been incapacitated by an adversary's strike.[102] This system was introduced in 1986, went through several rounds of modernization, and was reportedly re-operationalized in 2011.[103] Although reliable open-source information about the system is scant, *Perimetr* appears to involve a set of command rockets that would transmit orders directly to strategic launchers.[104] Some describe the system as operating in the following manner:

> *Perimetr* may be alerted in two ways. In the first, it can be alerted by a human. The second way is for *Perimetr* to alerted [sic] itself because of data received that confirms a nuclear attack, based on information from land-, sea-, air- and space-based sensors. The system then requires a yes or no responses [sic] from the General Staff of the Armed Forces. If the supreme commander (now the president of Russia) survives the first strike and is reachable, the General Staff addresses the request from the *Perimetr* system to him or her, and then forwards the decision to the *Perimetr* system. If *Perimetr* receives no response from the General Staff, it requires a yes or no response from the so-called nuclear briefcase '*Cheget*.'...If there is no response from the nuclear briefcase, *Perimetr* requests a yes or no response from any command center of the

[99] Yarynich, *C3: Nuclear Command, Control and Control Cooperation*, p. 154.

[100] Yarynich, *C3: Nuclear Command, Control and Control Cooperation*, p. 150.

[101] Podvig, Bukharin, and von Hippel, *Russian Strategic Nuclear Forces*.

[102] Defense Intelligence Agency, *Russia Military Power*, 2017, https://www.dia.mil/Portals/110/Images/News/Military_Powers_Publications/Russia_Military_Power_Report_2017.pdf. Ryabikhin writes, "In 2011 General S. Karakayev, Commander-in-Chief of the Russian [Strategic Rocket Forces], confirmed in an interview with one of the central Russian newspapers that 'Perimeter' exists and continues to be on combat duty." Ryabikhin, *Russia's NC3 and Early Warning Systems*.

[103] Vincent Boulanin, ed., *The Impact of Artificial Intelligence on Strategic Stability and Nuclear Risk, Volume I, Euro-Atlantic Perspectives* (Stockholm International Peace Research Institute, 2019), https://www.sipri.org/publications/2019/other-publications/impact-artificial-intelligence-strategic-stability-and-nuclear-risk-volume-i-euro-atlantic.

[104] Podvig, Bukharin, and von Hippel, *Russian Strategic Nuclear Forces*.

> Strategic Rocket Forces. Only after receiving no response from any of these sources is *Perimetr* designed to initiate retaliation.[105]

Some have written that the launch orders from *Perimetr* would then be delivered to human-controlled command units, meaning that humans remain "in the loop" (i.e., the system is not fully automated).[106] However, there are debates about the nature of the system among experts with insights into Russian nuclear forces.[107]

How is Russia's nuclear program funded?

The Russian government does not publicly disclose detailed defense spending information. In the past, researchers have deduced information on spending based on budget documents. In October 2021, the reporting of defense spending amounts, alongside other types of military information, by Russian media became an infraction that could result in a "foreign agent" designation in Russia.[108] Since the beginning of the Russia-Ukraine war, media reporting on any military matters has also been severely curtailed, further challenging defense spending estimates.[109] Some defense estimates were made public by state agencies only to later be removed from their websites.[110] This section focuses on our understanding of Russian defense and nuclear spending and procurement.

Defense and nuclear spending priorities

Before the Russia-Ukraine war, Putin and Russia's Defense Minister Sergey Shoigu maintained that Russia would not get involved in quantitative arms races that would increase the defense

[105] Boulanin, *The Impact of Artificial Intelligence on Strategic Stability and Nuclear Risk*.

[106] Jeffrey Edmonds et al., *Artificial Intelligence and Autonomy in Russia*, CNA, May 2021, https://www.cna.org/reports/2021/05/Artificial-Intelligence-and-Autonomy-in-Russia.pdf.

[107] Podvig, Bukharin, and von Hippel, *Russian Strategic Nuclear Forces*; Yarynich, *C3: Nuclear Command, Control and Control Cooperation*.

[108] See types of information the disclosure of which could result in a "foreign agent" designation. Order 379, Sept. 28, 2021, http://publication.pravo.gov.ru/Document/View/0001202109300048.

[109] Al Tompkins, "Russia Outlaws Spreading 'Fake News' About the Russian Military with Fines and Prison," Poynter, Mar. 7, 2022, https://www.poynter.org/business-work/2022/russia-outlaws-spreading-fake-news-about-the-russian-military-with-fines-and-prison/.

[110] Julian Cooper, *Implementation of the Russian Federal Budget During January-July 2022 and Spending on the Military*, Stockholm International Peace Research Institute, Oct. 2022, https://www.sipri.org/sites/default/files/2022-10/bp_2210_russianmilex.pdf.

burden; rather, it would focus defense spending on improving the quality of the weapons.[111] Russian defense procurement priorities are informed by Russia's political leaders and championed by the MOD, with other actors such as the Ministry of Finance participating in the interagency push and pull of figuring out spending and balancing competing priorities.

Estimates of defense spending vary. According to one authoritative analyst, Russian spending on the military in 2021 was approximately $64 billion. However, using the purchasing power parity exchange rate that more accurately reflects what a ruble can buy in the context of the Russian economy, estimates are closer to $165 billion. Before the Russia-Ukraine war, Russian defense spending was expected to rise further in 2022 to $68 billion (or $173 billion in purchasing power parity terms).[112]

As a result of the Russia-Ukraine war, Russia's defense budget has grown to account for wartime spending. Estimates, including those of actual 2022 spending, are still unreliable, but the upward trend is evident.[113] According to Russian reports, the proposed Russian budget for 2023 to 2025 will see a further increase in the "National Defense" section of the budget.[114] Military expenditure may reach $91 billion at current market exchange rates (or $218 billion at purchasing power parity) in 2023.[115] Much of this spending increase, however, will likely go toward the Russia-Ukraine war and toward mobilization, procurement of munitions, and efforts to substitute or illicitly procure sanctioned Western microelectronics.[116] The true levels of spending will depend on the state of the Russian economy, which is anticipated to face ever-increasing stress given oil price caps and Western sanctions.

Nuclear weapons have an important role in Russia's procurement plans. Russia initiated its current State Armament Program (SAP), SAP-2027, in 2018 and saw the stated levels of

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111 For example, see Putin's statements in "Defense Ministry Board Meeting" Dec. 18, 2018, http://en.kremlin.ru/catalog/keywords/91/events/59431. See also Shoigu's statements in "Defense Ministry Board Meeting," Dec. 24, 2019, http://en.kremlin.ru/catalog/keywords/91/events/62401.

112 Richard Connolly, *Russian Defense Industry Analysis,* RSI Research Report #13, Feb. 2022.

113 Cooper, *Implementation of the Russian Federal Budget During January-July 2022 and Spending on the Military*.

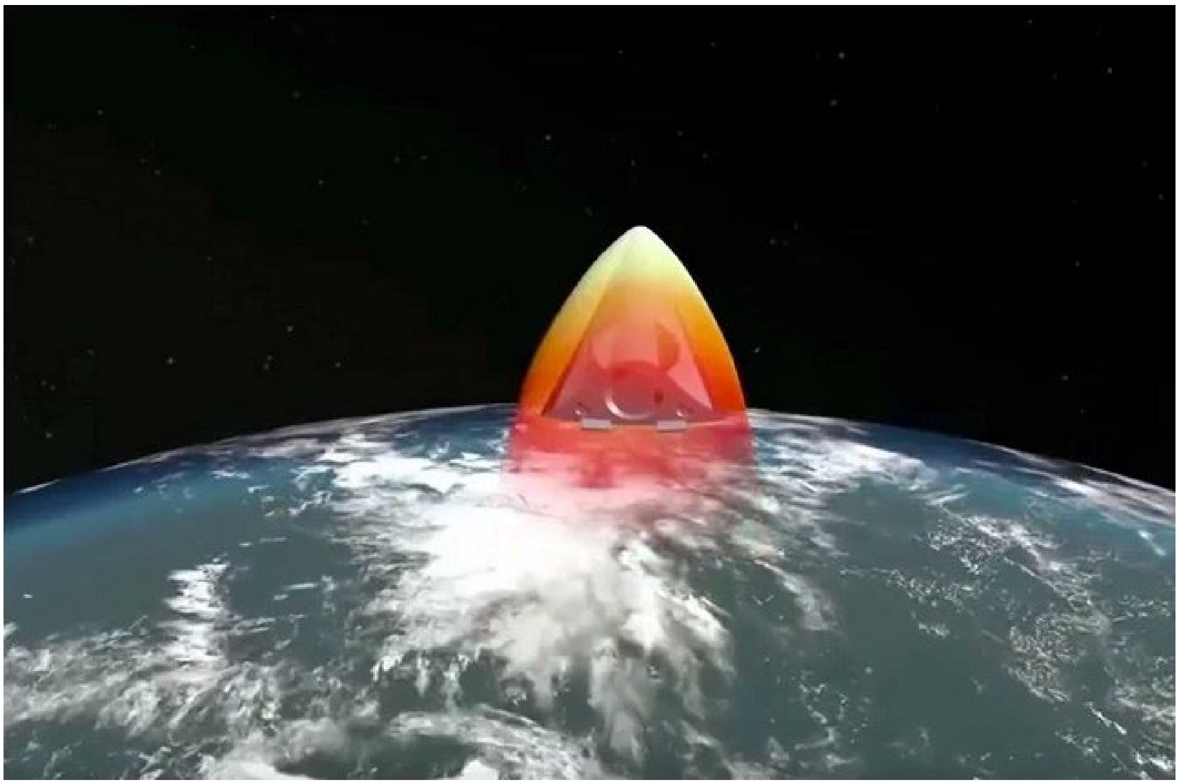
114 "Budget Proposal Calls for More Than 13.7 tln Rubles for Russia's Defense in 2023-2025," TASS, Sept. 28, 2022, https://tass.com/defense/1514879.

115 Author conversation with Richard Connolly, Jan. 9, 2023.

116 "Financing of the Special Military Operation Can Decay the Military," *Nezavisimoe Voennoe Obozrenie*, Nov. 8, 2022, https://www.ng.ru/armies/2022-11-08/1_8584_monetization.html.

modern equipment rise to more than 60 percent by 2020.[117] In addition to continuing modernization across the ground, aerospace, and naval forces, SAP-2027 prioritized procurement throughout all three legs of Russia's nuclear triad and its aerospace capabilities with platforms like the S-500 as well as systems like the Avangard HGV, seen in Figure 5.[118]

Figure 5. "Avangard" hypersonic glide vehicle



Source: Russian Federation Ministry of Defense, Mar. 1, 2018, https://www.youtube.com/watch?v=o-5UEq32-wc.

The future SAP, SAP-2033, is currently under development. According to MOD officials, this SAP was intended to address the requirements of the "intellectualization of weapons" as well

[117] Julian Cooper, "Prospects for Russia's Defense Spending," *Russian Analytical Digest* (June 21, 2019), https://css.ethz.ch/content/dam/ethz/special-interest/gess/cis/center-for-securities-studies/pdfs/RAD237.pdf.

[118] See Julian Cooper, *The Russian State Armament Programme, 2018-2027*, NATO Defense College, May 2018.

as the deployment of unmanned and robotic systems.[119] In late 2022, Russian source reporting suggested that the implementation of some elements of SAP-2027 and the development of SAP-2033 were halted to prioritize procurement efforts in the Russia-Ukraine war.[120]

In addition to spending on the modernization and procurement of launchers for Russian nuclear forces as well as funding maintenance and operations, Russia has been undertaking a massive effort to recapitalize its nuclear and defense complex to ensure its ability to modernize and perform deterrent missions.

Nuclear program spending and trends

According to Western estimates, Russia devotes about 13.5 to 16 percent of its defense spending on its nuclear weapons program, depending on the year and the scale of procurement.[121] This estimated percentage range includes spending for warheads production, handling, and security as well as for the development, procurement, and operations of Russia's nuclear triad and other nuclear systems.[122]

Reports from 2021 suggested that spending for nuclear weapons would increase in 2022 in part because of the need to develop new warheads and continue the procurement of ICBMs, SLBMs, and other systems.[123] Data from August 2022 indicate that the budget for the "nuclear complex" for 2022 was 49 billion rubles.[124] An additional 8 billion rubles were budgeted for the formerly closed cities that carry out work on nuclear warheads and parts of the fuel cycle.[125] Although spending for 2023 is estimated to be similar to that for 2022, budget documents suggest that nuclear spending may rise substantially beginning in 2024.[126]

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[119] See a statement by the head of the MOD Main Directorate for Weapons A.V. Gulyaev, Apr. 10, 2020, http://mil.ru/army2020/statements/more.htm?id=12297890@egNews.

[120] "The State Armament Program is Essentially Halted" (Государственная программа вооружений фактически приостановлена), Nov. 13, 2022, https://bmpd.livejournal.com/4611787.html.

[121] Cooper, "Russia's Spending on Nuclear Weapons in a Comparative Perspective."

[122] Relevant budget categories include "National Defense" and "National Nuclear Complex" and in the past, data have also included funding for Russia's formerly closed nuclear cities, which form the backbone of the nuclear complex.

[123] "Russian Nuclear Weapons Stand Out in Defense Budget Request."

[124] Cooper, *Implementation of the Russian Federal Budget During January-July 2022 and Spending on the Military*.

[125] Cooper, *Implementation of the Russian Federal Budget During January-July 2022 and Spending on the Military*.

[126] Author conversation with Richard Connolly, Jan. 9, 2023.

What activities is Russia's nuclear program engaged in?

As a mature nuclear weapons state, Russia has an expansive fissile material production and nuclear weapons complex as well as potentially the world's largest stockpile of fissile materials. The US and Russia jointly hold about 90 percent of the global stockpiles of HEU and plutonium.[127] Russia has invested funds into domestically manufacturing missiles and launchers for its nuclear modernization as well as designing and producing nuclear warheads.

Fissile material production

Russia's nuclear civilian and military complex is managed by Rosatom State Atomic Energy Corporation (Rosatom). Much like its Soviet predecessor Minatom, Rosatom oversees the nuclear energy and applied nuclear science programs; nuclear warhead design, production, and maintenance; nuclear research and development (R&D) institutes; and the nuclear icebreaker fleet.

As will be discussed in greater detail in later sections, Russia mines, processes, and enriches uranium for nuclear fuel; fabricates nuclear fuel; constructs power and research reactors; and exports its reactor technology. It has reprocessing capabilities and is pursuing a closed nuclear cycle, in which spent nuclear fuel can be reprocessed for reuse.[128] Many key fissile material production enterprises are located in formerly closed nuclear cities, including four gas centrifuge uranium enrichment facilities (in Seversk, Angarsk, Novouralsk, and Zelenogorsk), one active reprocessing facility (in Mayak), and a new reprocessing center currently under development (in Zheleznogorsk).

According to some estimates, Russia holds the world's largest stocks of HEU and plutonium. Unlike some Western countries, Russia has not declassified historical records and has not publicly declared the size of its stockpiles. Nongovernmental estimates—which are generally based on historical documents about the Soviet fissile material production infrastructure, the

[127] International Panel on Fissile Materials, *Global Fissile Material Report 2022*, 2022, https://fissilematerials.org/library/gfmr22.pdf.

[128] "Russia's Nuclear Fuel Cycle," World Nuclear, Dec. 2021, https://world-nuclear.org/information-library/country-profiles/countries-o-s/russia-nuclear-fuel-cycle.aspx.

capabilities of the Russian nuclear complex to use up or dispose of some of these materials, and US-Russian CTR agreements—have significant uncertainties.[129]

As of 2022, Russia does not engage in the production of fissile materials for nuclear weapons.[130] Its last plutonium production reactor was shut down in 2010 as part of US-Russian CTR efforts under the Elimination of Weapons Grade Plutonium Production program.[131] Russia may produce some HEU for naval fuel and research and other reactors.[132] According to an assessment by the International Panel on Fissile Materials, perhaps the most authoritative nongovernmental assessment available, as of the beginning of 2021, Russia was estimated to possess about 191 megatons (MT) of separated plutonium (of which about 88 MT were available for the military program, 40 MT were unavailable for the military program, and 63 MT were for civilian use) and 678 MT ± 120 MT of HEU (of which 90 MT were in the active stockpile of assembled nuclear weapons, 40 MT were in weapons awaiting dismantlement, and as much as 580 MT remained for military or civilian uses).[133]

Russia's nuclear stockpile and nuclear weapons complex have shrunk, and their security has been improved since the end of the Cold War because of US-funded CTR programs and Russia's own efforts. In the last 15 years, US-Russian engagement to reduce nuclear threats has steadily deteriorated; thus, direct US government insights into the state of Russia's nuclear complex as well as its security have diminished. Russia's 2014 invasion of Ukraine resulted in the end of long-running lab-to-lab engagement between Russia and the US and contributed to the collapse of other programs.[134] (One of these programs, efforts to assist in dismantling Soviet nuclear weapons, is depicted in Figure 6.)

[129] Anatoli Diakov, "The History of Plutonium Production in Russia," *Science & Global Security* 19 (2011): 28–45, https://scienceandglobalsecurity.org/archive/sgs19diakov.pdf; Oleg Bukharin, "Security of Fissile Materials in Russia," *Annual Review of Energy and the Environment* 21 (1996): 467–496, https://www.annualreviews.org/doi/pdf/10.1146/annurev.energy.21.1.467.

[130] International Panel on Fissile Materials, *Global Fissile Material Report 2022*.

[131] Diakov, "The History of Plutonium Production in Russia."

[132] International Panel on Fissile Materials, *Global Fissile Material Report 2022*.

[133] International Panel on Fissile Materials, *Global Fissile Material Report 2022*, pp. 40–42.

[134] Anton Khlopkov, *Russia's Nuclear Security Policy: Priorities and Potential Areas for Cooperation*, Stanley Foundation, May 2015, https://stanleycenter.org/publications/pab/KhlopkovPAB515.pdf.

Figure 6. Worker destroying an SS-18 missile as part of Cooperative Threat Reduction

Source: DTRA.

Beginning in 1991, the US Congress funded Nunn-Lugar CTR programs to reduce the threat that unemployed or underemployed scientists and engineers in the newly independent Russia might sell their nuclear and missile knowledge and skills to would-be proliferator states or that fissile materials in Russia's nuclear complex might be trafficked to terrorist organizations. After the Cold War, US CTR efforts assisted Russia in destroying some of its nuclear weapons and production infrastructure.

Other past bilateral cooperative efforts included the Megatons to Megawatts program, through which a private-public partnership used HEU from former Soviet nuclear warheads to generate electricity in US nuclear power plants, and the Plutonium Management and Disposition

Agreement, through which both countries agreed to disposition certain quantities of weapons-origin plutonium. However, Russia has also been committed to decommissioning legacy Soviet infrastructure and dispositioning some fissile materials on its own.[135]

Nuclear weapons work

Russia's work on nuclear warheads takes place in several types of facilities: nuclear weapons design centers, component design and production centers, and assembly/disassembly facilities (in Ozersk, Seversk, Sarov, Shezhinsk, Zarechny, Trekhgorny, and Lesnoy). US government assessments suggest that Russia is designing new warheads, including "new high-yield and earth-penetrating warheads to attack hardened military targets."[136]

As with fissile material production facilities, the footprint of the warhead production complex has shrunk since the Cold War.[137] However, the capabilities of Russia's warhead production complex are greater than those of the United States because Russia has a different approach to warhead management that involves routinely refurbishing and rebuilding nuclear warheads. Russia's warhead production complex is always in motion, but analysts suggest that estimating its surge capacity is challenging.

[135] Khlopkov, *Russia's Nuclear Security Policy: Priorities and Potential Areas for Cooperation*.

[136] Ashley, "Russian and Chinese Nuclear Modernization Trends."

[137] Oleg Bukharin, "Downsizing Russia's Nuclear Warhead Production Infrastructure," *The Nonproliferation Review* (Spring 2001): 116–130, https://www.nonproliferation.org/wp-content/uploads/npr/81bukh.pdf; Oleg Bukharin, "The Changing Russian and US Nuclear Warhead Production Complexes," in *SIPRI Yearbook: Non-Proliferation, Arms Control, Disarmament, 2001* (2001), pp. 585-597, https://www.sipri.org/sites/default/files/10C%20.pdf.

Nuclear weapons testing

The Soviet Union had an extensive nuclear testing program from 1949 to 1989 conducted primarily at the Semipalatinsk test site located in present-day Kazakhstan. The testing program included the 1961 test of the most powerful nuclear weapon ever built, the Tsar Bomba (as seen in Figure 7), at 50 MT of TNT. As a successor to the USSR, Russia is a signatory to numerous Cold War treaties that ban nuclear testing, and it is also a party to the Comprehensive Nuclear-Test-Ban Treaty (CTBT).

Russian officials have stated that Russia conducts subcritical (nonnuclear explosive) experiments similar to those conducted by the US.[138] In other words, these tests may be nonnuclear or even use up a small amount of nuclear material that is not enough to generate a self-sustaining chain reaction. Further experiments to ensure the reliability of Russia's nuclear arsenal are carried out by supercomputers in Russia's nuclear and defense ministry institutes.

Figure 7. October 1961 test of Tsar Bomba hydrogen bomb

Source: Rosatom, http://www.biblioatom.ru/evolution/dostizheniya-samaya-moshnaya-vodorodnaya-bomba/001.jpg.

However, Russia may be engaged in activities that the US intelligence community assesses to be in contravention of its CTBT obligation of generating "zero yield" during nuclear tests.[139] US officials allege that Russia may be conducting tests that create low nuclear yields. Some

[138] Yuriy Gavrilov, "Ministry of Defense Discusses Nonnuclear Experiments at Novaya Zemlya" (В Минобороны рассказали о неядерных экспериментах на Новой Земле), *Rossiyskaya Gazeta*, June 6, 2021, https://rg.ru/2021/06/06/reg-szfo/v-minoborony-rasskazali-o-neiadernyh-eksperimentah-na-novoj-zemle.html.

[139] Daryl G. Kimball, "US Questions Russian CTBT Compliance," *Arms Control Today*, July/Aug. 2019, https://www.armscontrol.org/act/2019-07/news/us-questions-russian-ctbt-compliance.

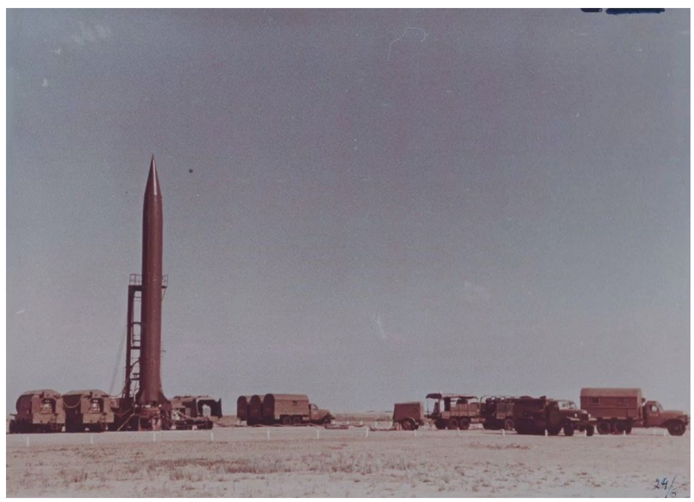
US observers have been concerned that Russia therefore has an unfair advantage over the United States.[140] Assessing this concern via open-source reporting is challenging because of the differences in approaches to warhead production between the two countries and the higher quality of US supercomputing capabilities. The US relies heavily on cutting-edge supercomputers to conduct modeling that aids in the maintenance of a reliable, effective nuclear arsenal without having to conduct real-world nuclear tests. One motivation for Russia to conduct very low-yield nuclear tests (if it is in fact doing so) may be to compensate for the limits of its own supercomputing capabilities. Russian officials maintain that Russia is fully in compliance with its CTBT obligations. [141]

Nuclear weapons delivery system work

Russia has possessed strategic-range ICBMs since the 1950s (Figure 8). More recently, Russia has been modernizing its strategic nuclear forces at a steady pace for more than two decades. These efforts have extended to all three legs of the Russian nuclear triad and its related nuclear, production, and early warning infrastructure.

As of the end of 2021, nearly 90 percent of equipment across the strategic nuclear forces was

Figure 8. 1956 test of Soviet R-5M missile warhead



Source: https://mil.ru/files/files/kapyar/photos/index.html.

[140] Mark B. Schneider, "Yes, the Russians Are Testing Nuclear Weapons and It Is Very Important," RealClearDefense, Aug. 8, 2019, https://www.realcleardefense.com/articles/2019/08/08/yes_the_russians_are_testing_nuclear_weapons_and_it_is_very_important_114651.html.

[141] “Not Contravening Agreements Russia Will Resume Subcritical Nuclear Experiments” (Не нарушая договора Россия возобновит подкритические ядерные испытания), Lenta.ru, Oct. 4, 2012, https://lenta.ru/articles/2012/10/04/object700/; "Novaya Zemly: Central Nuclear Test Site," TV Zvezda, 2021, https://tvzvezda.ru/schedule/programs/201412231323-1cpc.htm/2021651534-5wicv.html/player/.

deemed modern.[142] This section briefly overviews systems across various elements of the Russian armed forces.

Russian Strategic Rocket Forces

More than 60 percent of Russia's warheads for strategic nuclear forces are part of the land-based ICBM leg of its nuclear triad, under the command of the Strategic Rocket Forces.[143] According to Strategic Rocket Forces' Commander Sergey Karakayev, the force's ever-dominant role in the Russian nuclear triad is "determined by the largest number of nuclear launchers, the number and yield of nuclear warheads and countermeasures."[144]

At present, the Strategic Rocket Forces' posture incorporates ICBMs carrying a single warhead and others carrying multiple independently targetable reentry vehicles (MIRVs), with a relatively even split between silo-based and mobile missiles.[145] The force currently includes the following:

- The solid-fuel RS-12M Topol-M (RS-SS-27 Mod1) and the RS-24 Yars (RS-SS-27 Mod2), as seen in Figure 9.
- The liquid-fuel Sarmat heavy ICBM, which is intended to replace the R-36/RS-20 (RS-SS-18 Satan) (MIRV x 10).
- Some of the Sarmat ICBMs will carry the Avangard HGV. After a testing program, the HGV's deployment (initially on the UR-100NUTTKh (RS-SS-19 Stiletto Mod 4) ICBM) began in 2019, and the system was also exhibited under New START.[146]
- Another novel capability is the Burevestnik nuclear-powered very-long-range nuclear-armed cruise missile, which could potentially loiter for an extended time before striking.

[142] "Expanded Meeting of the MOD Collegium" (Расширенное заседание коллегии Минобороны) President of Russia, Dec. 21, 2021, http://kremlin.ru/events/president/news/67402.

[143] Roman Biruylin and Dmitry Andreev, "Russia's Unquestionable Argument" (Бесспорный аргумент России), *Krasnaya Zvezda*, Dec. 17, 2021.

[144] Biruylin and Andreev, "Russia's Unquestionable Argument."

[145] Biruylin and Andreev, "Russia's Unquestionable Argument."

[146] Pavel Podvig, "Russia Shows Avangard System 'to Maintain Viability' of New START," *Russian Strategic Nuclear Forces (blog)*, Nov. 27, 2019, https://russianforces.org/blog/2019/11/russia_shows_avangard_system_t.shtml.

Figure 9. "Yars" ICBM

Source: Russian Federation Ministry of Defense, Feb. 27, 2018, https://xn--80ahclcogc6ci4h.xn--90anlfbebar6i.xn--p1ai/images/upload/2017/4%2848%29.JPG.

Russian navy

Nuclear deterrence is a key part of the mission of the Russian navy, although Russia's SSBNs patrol irregularly.[147] The modernization of the undersea leg of Russia's strategic nuclear forces has been slow and characterized by delays in the development of new platforms and their principal weapons systems. At the same time, Russia's guided missile submarines (SSGNs) can

[147] See Michael Kofman, "The Role of Nuclear Forces in Russian Maritime Strategy," in *The Future of the Undersea Deterrent: A Global Survey,* ed. Rory Medcalf, Katherine Mansted, Stephan Frühling and James Goldrick (Canberra: Australian National University, 2020).

conduct long-range precision strikes with NSNWs and nonnuclear systems and also participate in escalation management.[148]

The naval force currently includes the following:

- The Borey (Project 955) and Borey-A (Project 955A) vessels and their accompanying SLBM: the RSM-56 Bulava (RS-SS-N-32). The current plan is to have 10 of the new SSBNs, likely 5 each at the Northern and Pacific Fleet bases.
- The Delta IV SSBNs, which carry the older R-29RMU2 Sineva and R-29RMU2.1 Lainer (RS-SS-N-23 Skiff) (MIRV x 4), as seen in Figure 10.
- One unconventional new capability is the Poseidon/Kanyon/Status-6 large UUV. The first submarine designed to host this weapon, the *Belgorod*, was inducted into service in July 2022.[149]
- Another novel capability is the Tsirkon, an allegedly scramjet-powered aero-ballistic missile that is currently finishing up trials.[150]

Figure 10. "Delta IV" ballistic missile submarine participates in the Umka-2021 exercise

Source: Russian Federation Ministry of Defense, Mar. 2021, https://eng.mil.ru/en/news_page/country/more.htm?id=12351055@egNews.

[148] Kofman, "The Role of Nuclear Forces in Russian Maritime Strategy."

[149] "Belgorod Sub Has Been Transferred to the Navy" (Подлодку «Белгород» передали Военно-морскому флоту РФ) Bel.ru, July 8, 2022, https://bel.ru/news/2022-07-08/podlodku-belgorod-peredali-voenno-morskomu-flotu-rf-353225.

[150] "Tsirkon Hypersonic Missile State Trials for Naval Carriers Successfully Completed—Source," TASS, May 30, 2022, https://tass.com/defense/1458187.

- Russia is continuing construction of new *Yasen*-M class SSGNs that can carry Kalibr and Tsirkon cruise missiles.

Russian Aerospace Forces

Numerous tasks of Russia's Aerospace Forces touch on the nuclear deterrence mission.

In addition to the obvious mission of Long-Range Aviation bombers, these tasks include intelligence, surveillance, and reconnaissance; detection and early warning; participation in countering adversarial attacks; and point defense of strategic nuclear forces and other critical targets.[151] Some of the developments in Long-Range Aviation include the following:

Figure 11. Tu-95 strategic bomber during exercises

Source: Russian Federation Ministry of Defense, Sept. 16, 2022, https://xn--80ahclcogc6ci4h.xn--90anlfbebar6i.xn--p1ai/images/upload/2019/vks5-169-1200_2.JPG.

- Two strategic bombers, the Tu-160 and the Tu-95 (seen in Figure 11) have been mainstays of the Russian triad since the Cold War and feature the new dual-capable Kh-101/102 (RS-AS-23A/B).
- The future of Russia's new generation strategic bomber, the PAK DA, is uncertain. Although this bomber is in development, Russia also recently restarted the construction of the Tu-160 fleet, which may cut into its ability to execute on the PAK DA.
- Russia has several Beriev airborne early warning and control aircraft, and it is also in the process of developing a next-generation aircraft for this purpose.[152]

[151] A. B. Palitsyn and D. B. Zhilenko, "Analysis of Traditional and Future Goals of the Systems of Aerospace Defense of Russia: Issues and Possible Aolutions" (Анализ традиционных и перспективных задач системы воздушно-космической обороны России: проблемы и пути их решения) *Voennaya mysl'* 9 (Sept. 30, 2020).

[152] "Russia's Cutting-Edge A-100 Long-Range 'Flying Radar' to Complete Flight Tests in 2022," TASS, Feb. 10, 2022, https://tass.com/defense/1400809.

- The novel dual-capable Kinzhal ALBM could be deployed on modified MiG-31K or Tu-22M3.

Russian ground forces

Several precise capabilities of Russia's ground forces are intended for use at the operational-tactical level. These systems have concerned US allies because they are highly mobile and can carry out conventional and nuclear missions. They have also been at the center of US allegations of Russia's noncompliance with the Intermediate-Range Nuclear Forces Treaty.

- The Iskander-M (RS-SS-26 Stone) solid-fuel short-range ballistic missile is intended as a replacement for the Tochka-U (RS-SS-21 Scarab).
- Another system is a ground-launched cruise missile of intermediate range designated 9M729 (RS-SSC-8 Screwdriver).[153]

Nuclear weapons and delivery system testing and exercises

For Russia, displays and demonstrations of its nuclear capabilities are part of exercising strategic deterrence. These generally include Victory Day (May 9) parades that incorporate strategic nuclear forces, as seen in Figure 12, and the following activities:

- The Grom exercise has taken place three times (once in 2019 and twice in 2022, in part because of COVID-19 delays). The most recent Grom exercise took place in October 2022 amid tensions between Russia and the West due to Russia's invasion of Ukraine. The exercise featured launches of ballistic and cruise missiles of all three branches of Russia's nuclear triad and sought to assess command and control of nuclear forces.[154] The exercise script featured a mass retaliatory nuclear strike and the participation of all three individuals with reported roles in implementing the launch of a nuclear strike: Putin, Shoigu, and Gerasimov.[155]
- Large-scale annual military exercises, such as the Zapad or the Vostok, may include a nuclear component.

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[153] NASIC, *Ballistic and Cruise Missile Threat*, 2020, https://irp.fas.org/threat/missile/bm-2020.pdf.

[154] "Supreme Commander Carried Out Exercises of Strategic Deterrence Forces," President of Russia, Oct. 26, 2022, http://kremlin.ru/events/president/news/69680.

[155] "Supreme Commander Carried Out Exercises of Strategic Deterrence Forces."

- Branch-specific exercises usually follow a predictable pattern. For example, the Strategic Rocket Forces carry out trainings every summer and winter.
- Authoritative Russian military writings suggest the possibility of a nuclear demonstration or a test as part of a spectrum of escalation management activities.[156]
- As part of its nuclear modernization process, Russia periodically tests strategic missiles and launchers. The United States is usually notified of these tests as part of cooperative agreements.

Figure 12. Strategic Rocket Forces at the May 9 Victory Day Parade

Source: Vitaly V. Kuzmin, "Topol-M missile system TEL," May 2013, https://www.vitalykuzmin.net/.

Under agreements signed in 1988 and 1989, the United States and Russia have agreed to notify the other in advance of launches of strategic-range ballistic missiles (ICBMs and SLBMs), as well as one major strategic exercise involving heavy bombers per year. The two states have

156 Kofman, Fink, and Edmonds, *Russian Strategy for Escalation Management: Evolution of Key Concepts*.

also concluded politically binding agreements whereby they have agreed (but are not legally obligated to) provide each other with information about other (but not all) missile tests and space launches. Furthermore, Russia has a legally binding obligation to host a designated number of onsite inspections each year at bases hosting declared strategic nuclear forces. In addition, the US and Russia exchange some telemetry data during missile tests to confirm the correctness of warhead numbers and to serve as a bilateral confidence-building measure.[157]

What nuclear weapons–related R&D has Russia undertaken?

Russia's nuclear forces are supported by a substantial nuclear complex that has been modernized and optimized since the collapse of the Soviet Union. Russia also has a vast network of defense institutes and enterprises that support the government's procurement and employment planning of missiles and nuclear weapons–relevant systems and platforms. This section draws on English- and Russian-language open sources to provide a sketch of nuclear and missile R&D efforts and procurement architectures.

Fissile material production

During the 1990s, the Russian nuclear weapons complex was in a state of turmoil because of Russia's economic situation and the change toward a less hostile US-Russian relationship that dramatically shifted defense priorities. The economic situation was so dire that the US government was concerned about the proliferation of materials, technology, and know-how from Russian nuclear and missile scientists to their counterparts in states like Iran and North Korea.[158] Additional US government concerns included the state of the Russian nuclear material, protection, control, and accounting system, which was upgraded as part of US-Russian lab-lab cooperation under CTR beginning in the mid-1990s.[159] Over the last decade,

[157] Rose Gottemoeller, "The New START Verification Regime: How Good Is It?" *Bulletin of the Atomic Scientists*, May 1, 2020, https://carnegieendowment.org/2020/05/21/new-start-verification-regime-how-good-is-it-pub-81877.

[158] See, for example, John C. Baker, "Improving Minatom's Export Policies," *The Adelphi Papers* 37, no. 309 (1997): 55–78, https://www.tandfonline.com/doi/abs/10.1080/05679329708449425; Igor Khripunov, "Russia's MINATOM Struggles for Survival: Implications for US-Russian Relations," *Security Dialogue* 31, no. 1 (March 2000): 55–69, https://www.jstor.org/stable/26296625.

[159] See, for example, Siegfried S. Hecker, ed., *Doomed to Cooperate: How American and Russian Scientists Joined Forces to Avert Some of the Greatest Post–Cold War Nuclear Dangers* (Bathtub Row Press, 2016).

Rosatom has focused on reducing the large footprint of the formerly expansive Soviet nuclear production complex and modernizing it to sustain Russia's nuclear weapons and nuclear energy programs.[160]

As noted earlier, Russia does not engage in the production of fissile materials for its nuclear weapons, according to open sources. It engages in some small-scale production of HEU for naval fuel and for export, as discussed below. Russia has an extensive commercial enrichment program that supplies fuel for light water reactors for Russia's domestic market and clients abroad, as well as reprocessing capabilities. Fissile material production enterprises include four gas centrifuge uranium enrichment facilities, one active reprocessing facility, and a new reprocessing center currently under development, as discussed in detail in the facilities section.

Nuclear weapons design

The Russian nuclear complex engages in activities to ensure that the Russian stockpile is reliable and safe. Warheads are designed, assembled, evaluated, refurbished, life extended, dismantled, and remanufactured. This work is carried out in a handful of design, production, and testing facilities discussed in greater detail later in this section. The dismantlement usually occurs at the original assembly facility.[161]

The 1999 NATO bombing of the former Yugoslavia highlighted to the Russian political leadership the importance of its nuclear deterrent and the key role of the nuclear complex in its preservation. In this context, the Russian government also focused on preparing the nuclear complex for the eventual entry into force of the CTBT, which Russia signed in 1996, and preparing Minatom (now Rosatom) to develop the capabilities to certify that Russia's nuclear weapons are safe and effective without nuclear testing.[162]

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[160] Khlopkov, "Russia's Nuclear Security Policy: Priorities and Potential Areas for Cooperation."

[161] Bukharin, "Downsizing Russia's Nuclear Warhead Production Infrastructure."

[162] "Domestic Nuclear Complex Is Collapsing" (Отечественный ядерный комплекс разваливается) *Nezavisimaya Gazeta,* Apr. 30, 1999; "Priority National Interest of Russia (Приоритетный госинтерес России) *Nezavisimoe voennoe obozrenie*, 17 (1999).

Figure 13. Belushaya Guba settlement on Novaya Zemlya

Source: TV Zvezda show *Voennaya Priemka* on Central Nuclear Test Site, June 2021, https://tvzvezda.ru/schedule/programs/201412231323-1cpc.htm/2021651534-5wicv.html/player/.

Leaders in Russia's nuclear complex have persistently expressed concerns that they would be unable to ensure weapons safety without testing and lamented the political leadership's decision process regarding testing.[163] A 2000 interview with a Minatom official suggested that the 1991 decision by the Soviet Union to implement a nuclear testing moratorium came as a surprise to the nuclear complex, which at the time was working on changing the explosives in Russia's nuclear weapons. He lamented that the US and France joined the moratorium only after they resolved this same issue.[164] The official further noted that Russia was several orders of magnitude behind the United States with regard to relevant supercomputing power, even

[163] Michael Jasinski, Cristina Chuen, and Charles Ferguson, "Renewed US-Russian Controversy over Nuclear Testing," James Martin Center for Nonproliferation Studies, May 27, 2002, https://nonproliferation.org/renewed-us-russian-controversy-over-nuclear-testing/.

[164] "Our Shield Is Not a Fig Leaf" (Наш щит не фиговый листок), *Vek* 25 (2000).

though it was desperately trying to catch up.[165] He further stated that "if the state of our arsenal raises national security concerns, underground nuclear testing may be necessary," also arguing that "the decision to withdraw from the moratorium or from the [CTBT] under such circumstances will be taken by us at the highest level of government."[166] In 2002, officials in the US government were concerned that Russia was preparing to conduct underground nuclear tests, which Russian government officials maintained would be subcritical and thus not restricted by the CTBT.[167]

Over the next decade, the Russian government and Putin personally prioritized the improvement of the nuclear complex, aiming to improve the technological base and attract workers. In 2010, as part of a nuclear base modernization program, Russian nuclear research institutes received additional funding to modernize their supercomputing capabilities.[168] In 2014, Gerasimov wrote:

> The strategy for the development of the nuclear weapons complex is currently determined by the need to maintain a nuclear arsenal based on a qualitatively new scientific and technical base, which includes powerful computers, mathematical and physical modeling, powerful X-ray, laser, electrophysical and irradiation installations that simulate the effect of a nuclear explosion. The improvement of nuclear weapons is primarily aimed at increasing their reliability and safety.[169]

However, statements by Russian nuclear complex officials suggest that some view testing—particularly of the nonnuclear components of weapons—as instrumental to safety and are generally not satisfied with an approach reliant purely on supercomputers.[170]

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165 "Our Shield Is Not a Fig Leaf."

166 "Our Shield Is Not a Fig Leaf."

167 Jasinski, Chuen, and Ferguson, "Renewed US-Russian Controversy over Nuclear Testing."

168 "Vladimir Putin Signed Addendum for Long-Term Program for Development of Nuclear Armament Complex" (Владимир Путин подписал дополнение к долгосрочной программе развития ядерного оружейного комплекса), *Rossiyskaya Gazeta*, June 10, 2010, https://rg.ru/2010/06/10/atom.html.

169 Valeriy Gerasimov, "The First Main Test" (Первое главное испытание), *VPK* 32 (Sept. 3, 2014).

170 "Russia Is Conducting Nonnuclear-Explosive Experiments" (Россия проводит неядерно-взрывные эксперименты), Vesti, Sept. 4, 2010, https://www.vesti.ru/article/2035342; Michael Albertson, "Russia's Approach to Stockpile Modernization," in *Stockpile Stewardship in an Era of Renewed Competition,* ed. Brad Roberts (Livermore, CA: CGSR, 2022), https://cgsr.llnl.gov/content/assets/docs/CGSR_Occasional_Stockpile-Stewardship-Era-Renewed-Competition.pdf.

Russia's nuclear complex is always in a state of churn regarding nuclear warheads. Some suggest that Russian warheads have less complex and more conservative designs than their US counterparts and that Russia deals with any problems resulting from age by remanufacturing weapons.[171] Little open-source information about the life cycle of Russian warheads is available. According to an authoritative account by a Russian expert:

> Russian warheads are reported to have a shelf life of approximately 10 years (with newer warheads having a life of 15 years), presumably because the warheads' conventional high explosives degrade and their fissile components deteriorate. The deployment cycle for Russian warheads is reported to be three years long. After three years of deployment, warheads are removed from their delivery systems and shipped to a serial production facility for modernization and refurbishment. Refurbished warheads are placed in storage prior to a new cycle of operational deployment.[172]

In the early 2000s, the nuclear complex was in the midst of an effort to modernize and develop new warheads for the Topol-M ICBM.[173] Then, a Minatom official outlined the extensive scope of work facing the complex with respect to warheads: Russia had many different warheads because "historically, [it] developed [its] own nuclear weapon for almost every type of carrier" and many of these were close to the end of their service lives.[174] Recent reports suggest that the Russian nuclear complex is in the midst of a multiyear effort to develop new warheads to replace those produced in the 1980s and 1990s, particularly for the Sarmat ICBM.[175]

One limiting factor for Russian warheads may be plutonium pit production. Unlike the United States, Russia reportedly must continuously remanufacture its plutonium pits because of a limited 10- to 15-year service life and does not appear to have reserve pits.[176] Although two facilities in Russia have the capability to produce plutonium pits, this work likely takes place at just one of them.

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[171] Bukharin, "Downsizing Russia's Nuclear Warhead Production Infrastructure."

[172] Oleg Bukharin, "A Breakdown of Breakout: US and Russian Warhead Production Capabilities," *Arms Control Today*, Oct. 2002, https://www.armscontrol.org/act/2002-10/features/breakdown-breakout-us-russian-warhead-production-capabilities.

[173] "Our Shield Is Not a Fig Leaf."

[174] "Our Shield Is Not a Fig Leaf."

[175] "Russian Nuclear Weapons Stand Out in Defense Budget Request."

[176] Oleg Bukharin, "A Breakdown of Breakout: US and Russian Warhead Production Capabilities."

Nuclear weapons delivery systems

Russia has focused on developing a diverse and survivable nuclear force that will also allow a hedge in an uncertain political and military-technological future.

Russia's strategic nuclear forces have been steadily modernizing for more than two decades. These efforts have extended to all three legs of the Russian nuclear triad and its related nuclear, production, and early warning infrastructure. Modernization has focused on preservation of a retaliatory capability and development of asymmetric capabilities that could hedge against a US breakthrough in missile defense technologies. These have included multipurpose undersea systems, a nuclear-propelled cruise missile, and an HGV that could be placed on an ICBM.

Modernization of ICBMs and SLBMs has involved both solid- and liquid-fuel technologies, and silo and mobile missiles, for a diverse arsenal set designed and produced by different design bureaus and factories. The current force has both MIRVed missiles and single-warhead ones, but the Russian ICBM force is trending toward greater MIRVing.

Figure 14. Museum at the Strategic Rocket Forces Academy

Source: https://varvsn.mil.ru/upload/site12/document_images/OdyGJyhZxi.jpg.

Russia to date has declined to pursue rail-based systems that the Soviet Union once possessed, resolving the budget debate in favor of the Avangard ICBM-launched hypersonic weapon system, but the designs for a Yars ICBM based on rail still exist.

Moscow has also prioritized the development and fielding of dual-capable systems that could provide coverage of targets in Europe and systems particularly based on and under the sea for escalation management and NSNW missions.

What sites or facilities does Russia use for nuclear weapons–related R&D?

Most of the facilities involved in nuclear weapons work are located across Russia in so-called closed cities. Russia's nuclear complex has shrunk substantially since the days of the Soviet Union through CTR assistance from the United States and other Western states and Russia's own efforts. Over the last 30 years, Rosatom has engaged in deliberate efforts to consolidate nuclear weapons–related work, improve security, convert facilities to civilian activities, and shutter old weapons production infrastructure. Russia's nuclear weapons infrastructure remains comparatively vast, as the following sections detail. The complex has been well resourced and upgraded over the last several decades.

Regarding the design, testing, and production of missiles, Russia has an advanced defense industry with numerous design bureaus and state-owned enterprises that manufactures armaments for domestic use and export abroad. Most work on Russia's ballistic and cruise missiles as well as launch platforms is performed in established teams of design and development facilities, as discussed in this section.

Fissile material production facilities

The Soviet Union had an extensive fissile material production infrastructure, with numerous production reactors across six facilities. Today, because of its large stocks of fissile materials, Russia does not produce plutonium and may enrich only small amounts of HEU for niche uses, such as naval propulsion fuel.[177] It also engages in some HEU production for export to foreign clients, such as Germany.[178] Recent reports suggest that Russia may also be supplying HEU to China.[179]

Although Russia no longer produces weapons-grade fissile material, the key facility in Russia's production infrastructure is the Production Association "Mayak" in Ozersk (Chelyabinsk-65). Established in 1948, Mayak produced components for the Soviet Union's first nuclear device. According to some descriptions, "at different times, it operated five plutonium production

[177] International Panel on Fissile Materials, *Global Fissile Material Report 2022*.

[178] Alexander Glaser and Pavel Podvig, "Production of New Highly Enriched Uranium in Russia for the FRM-II in Germany," *IPFM Blog*, Nov. 8, 2017, https://fissilematerials.org/blog/2017/11/production_of_new_highly_.html.

[179] US Department of Defense, "Russia Reportedly Supplying Enriched Uranium to China."

reactors, five tritium production reactors, several reprocessing plants, a plutonium metallurgy plant, and various supporting facilities."[180]

Figure 15. First plutonium separation facility at Mayak in 1948

Source: PO Mayak website, "22 December 1948 startup of weapons grade plutonium separation facility," https://www.po-mayak.ru/about/history/history_in_dates/22_dekabrya_1948_goda_vveden_v_ekspluatatsiyu_radiokhimicheskiy_zavod_po_vydeleniyu_oruzheynogo_plut/.

Mayak is probably a storage site for significant amounts of both weapons-grade plutonium and HEU.[181] The plant likely continues to be engaged in the fabrication of warhead components, including work on plutonium pits. Reactors at the site also produce tritium for Russia's nuclear weapons. A new multipurpose reactor is currently under construction at Mayak to replace the

[180] Pavel Podvig, *Consolidating Fissile Materials in Russia's Nuclear Complex*, IPFM, 2009, https://fissilematerials.org/library/rr07.pdf.

[181] Podvig, *Consolidating Fissile Materials in Russia's Nuclear Complex*.

two currently in operation that are used for tritium production, among other purposes.[182] The facility is also involved in civilian commercial activities.

Another key facility is the Siberian Chemical Combine in Seversk (Tomsk-7). Established in 1953, it produced HEU and plutonium for the Soviet nuclear program and fabricated warhead components. Today, the site likely stores weapons-grade plutonium and HEU stocks and potentially retains the capability for warhead component production. The facility is also involved in civilian commercial activities. Table 1 details the past and contemporary roles of Soviet and Russian fissile material production facilities.

In addition, some studies suggest that Russia also has extensive fissile material storage sites in Zheleznogorsk, Sarov (see the following section), and Snezhinsk (see the following section).[183]

Table 1. Soviet and Russian fissile material production facilities

Facility and Location	Role in Soviet Complex[a]	Present-Day Role[b,c]
Production Association "Mayak" in Ozersk (Chelyabinsk-65)	Production of Pu and tritium and fabrication of warhead components	Pu reprocessing, production of tritium, fabrication of warhead components (plutonium pits), storage of HEU and Pu, and fissile component dismantlement. Extensive civilian processing and storage work.
Siberian Chemical Combine in Seversk (Tomsk-7)	Production of HEU and Pu and fabrication of warhead components	Civilian uranium activities and materials storage. No longer produces HEU or Pu (old weapons material production infrastructure shuttered). Unclear whether it is formally engaged in fabrication of warhead components. However, it potentially remains a site for storage and handling of nuclear weapons materials and components.

[182] A. A. Yukhimchuk, "Tritium-Related Activities in the Russian Federation," *Fusion Science and Technology* 76, no. 4 (2020), https://www.tandfonline.com/doi/abs/10.1080/15361055.2020.1728174.

[183] Podvig, *Consolidating Fissile Materials in Russia's Nuclear Complex*.

Facility and Location	Role in Soviet Complex[a]	Present-Day Role[b,c]
Mining and Chemical Combine in Zheleznogorsk (Krasnoyarsk-26)	Pu production	Old weapons material production infrastructure shuttered but potentially stores weapons-usable fissile materials. New reprocessing center currently under development.
Angarsk Electrolysis and Chemical Plant in Angarsk	Uranium enrichment (never produced HEU)	LEU enrichment and related activities.
Urals Electro-Chemical Combine in Novouralsk (Sverdlovsk-44)	HEU production	LEU enrichment and related activities.
Electro-Chemical Plant in Zelenogorsk (Krasnoyarsk-45)	HEU production	LEU enrichment and related activities. Some HEU production, including for export.[d]

Sources: [a] Oleg Bukharin and Thomas B. Cochran, *New Perspectives on Russia's Ten Secret Cities*, NRDC, 1999, https://nuke.fas.org/norris/nuc_10019901a_208b.pdf; [b] NTI facilities collection, https://www.nti.org/education-center/facilities; [c] Podvig, *Consolidating Fissile Materials in Russia's Nuclear Complex*; [d] Glaser and Podvig, "Production of New Highly Enriched Uranium in Russia for the FRM-II in Germany."
Note: LEU = low enriched uranium; Pu = plutonium.

Nuclear weapons design facilities

The Soviet Union had an extensive nuclear enterprise devoted to the design, testing, production, and maintenance or remanufacture of nuclear weapons. Since the collapse of the USSR, many of these facilities have been shut down. However, the remaining facilities retain the capability and capacity to support Russia's nuclear forces. Today, the following are two key facilities:

- Best understood as the Los Alamos of the Soviet Union, VNIIEF, based in Sarov, was the Soviet Union's first nuclear weapons design center (established in 1947) and developed the first Soviet explosive device as well as the Tsar Bomba—the highest yield nuclear explosive test in history—and the warhead for the SS-18, among others.[184] The institute works on "the increase in effectiveness, safety, and reliability of the warheads," related mathematical and computer modeling, nuclear physics (both

[184] Oleg Bukharin and Thomas B. Cochran, *New Perspectives on Russia's Ten Secret Cities*, NRDC, 1999, https://nuke.fas.org/norris/nuc_10019901a_208b.pdf.

theoretical and applied), and other related fields.[185] It houses a new laser (Figure 16) that Russian scientists compare to the National Ignition Facility based at the Lawrence Livermore National Laboratory.[186] It is also the home for the newly inaugurated National Center of Physics and Mathematics, which has extensive ambitions in terms of developing Russian scientific capacity overall.[187]

- A competitor to VNIIEF, VNIITF, based in Snezhinsk, was the nuclear institute created second, in 1955. It worked primarily on miniaturization and low-yield systems and developed warheads for SLBMs, cruise missiles, and artillery.[188] It also continues to work on warhead design.

[185] "Activities" (Деятельность), VNIIEF, http://vniief.ru/researchdirections/.

[186] "UFL-2M Laser Machine," TAdviser, https://tadviser.com/index.php/Product:VNIIEF:_UFL-2M_laser_machine.

[187] Aleksandr Mekhanik and Aleksandr Sergeev, "The Center for the Quick Development of Science and Technologies" (ЦЕНТР ДЛЯ БЫСТРОГО РАЗВИТИЯ НАУКИ И ТЕХНОЛОГИЙ), *Ekspert* 5 (2023).

[188] О РФЯЦ – ВНИИТФ http://vniitf.ru/article/o-vniitf.

Figure 16. UFL-2M laser at VNIIEF in Sarov

Source: https://strana-rosatom.ru/2021/08/24/yadernyj-centr-v-sarove-narastit-dolju-g/.

In addition to these weapons design facilities, the Soviet Union possessed and now Russia possesses an expansive complex of other facilities that provide nonnuclear components of nuclear weapons, testing and diagnostics, warhead assembly and disassembly, and other support functions. These facilities are detailed in Table 2.

Table 2. **Soviet and Russian nuclear weapons development and assembly/disassembly facilities**

Facility and Location	Role in Soviet Complex[a]	Present-Day Role[b,c]
Institute of Experimental Physics, VNIIEF in Sarov, Nizhniy Novgorod (Arzamas-16)	Nuclear warhead design Stockpile support	Nuclear warhead design Stockpile support
Institute of Technical Physics, VNIITF in Snezhinsk (Chelyabinsk-70)	Nuclear warhead design Stockpile support	Nuclear warhead design Stockpile support
Institute of Automatics, VNIIA in Moscow	Nuclear warhead design Design of nonnuclear components	Nuclear warhead design Design of nonnuclear components
Institute of Impulse Technologies, VNII IT in Moscow	Nuclear test diagnostics	Nuclear test diagnostics Part of VNIIA
Institute of Measurement Systems, NII IS in Nizhniy Novgorod	Design of nonnuclear components and support equipment	Design of nonnuclear components and support equipment Part of VNIIEF
Design Bureau of Road Equipment, KB ATO in Mytischy, Moscow region	Nuclear warhead transportation and handling equipment	Nuclear warhead transportation and handling equipment[d]
Electrochimpribor in Lesnoy (Sverdlovsk-45)	Nuclear warhead assembly/disassembly	One of two sites for assembly/disassembly work
Device-Building Plant in Trekhgorny (Zlatoust-36)	Nuclear warhead assembly/disassembly	One of two sites for assembly/disassembly work
Electromechanical Plant "Avangard" in Sarov (Arzamas-16)	Nuclear warhead assembly/disassembly	Presumably no longer involved in nuclear weapons work[e]
Production Association "Start" in Zarechny (Penza-19)	Nuclear warhead assembly/disassembly	Presumably no longer involved in nuclear weapons work
Production Association "Sever" in Novosibirsk	Production of nonnuclear weapon components for nuclear weapons	One of two sites for production of nonnuclear components for nuclear weapons
Urals Electromechanical Plant in Yekaterinburg	Production of nonnuclear weapon components for nuclear weapons	One of two sites for production of nonnuclear components for nuclear weapons

Facility and Location	Role in Soviet Complex[a]	Present-Day Role[b,c]
Production Association “Molnia” in Moscow	Production of nonnuclear weapon components for nuclear weapons	Presumably no longer involved in nuclear weapons work[e]
Nizhneturinsky Mechanical Plant in Nizhnyaya Tura	Production of nonnuclear weapon components for nuclear weapons	Presumably no longer involved in nuclear weapons work[e]
Kuznetsk Machine-Building Plant in Kuznetsk	Production of nonnuclear weapon components for nuclear weapons	Presumably no longer involved in nuclear weapons work[e]
Bazalt		Beryllium production facility[e]
Novaya Zemlya test site	Nuclear weapons testing facility	Nuclear weapons testing facility
Semipalatinsk test site	Nuclear weapons testing facility	Located in present-day Kazakhstan, shuttered

Sources: Bukharin and Cochran, *New Perspectives on Russia's Ten Secret Cities*; [b] NTI facilities collection, https://www.nti.org/education-center/facilities; [c] Podvig, *Consolidating Fissile Materials in Russia's Nuclear Complex*; [d] Vyacheslav Khryashchev, "FSUE Design Bureau of Vehicular Equipment," Rosatom Library, 2007, http://elib.biblioatom.ru/text/oruzhie-i-tehnologii-rossii_v14_2007/go,212/; [e] Pavel Podvig, "Presidential Decree Lists Russia's Military Nuclear Facilities," *Russian Strategic Nuclear Forces (blog)*, July 10, 2007, https://russianforces.org/blog/2007/07/presidential_decree_lists_russ.shtml.

Nuclear weapons are tested by scientists from VNIIEF and VNIITF at the Central Test site of the Russian Federation, which is in Novaya Zemlya. According to reports, the site is maintained in a state of readiness to conduct nuclear testing that both does and does not generate yield.[189] The site is managed by the 12th GUMO. The 12th GUMO is supported by a separate MOD research institute located in the Moscow Region. This institute, the 12 TsNII, focuses on issues relevant to the 12th GUMO, such as testing, nuclear weapons security, and the resilience of weapons to nuclear effects.[190]

[189] "Not Contravening Agreements Russia Will Resume Subcritical Nuclear Experiments."

[190] "12 TsNII of the MOD" (12 Центральный научно-исследовательский институт Министерства обороны Российской Федерации), Russian MOD, https://ens.mil.ru/science/SRI/information.htm?id=12008@morfOrgScience.

Figure 17. Nuclear effects testing facility at the 12 TsNII

Source: TV Zvezda show *Voennaya Priemka* on the Central Nuclear Test Site, June 2021, https://tvzvezda.ru/schedule/programs/201412231323-1cpc.htm/2021651534-5wicv.html/player/.

Nuclear weapons delivery system facilities

Russia has an advanced defense industry with numerous design bureaus and state-owned enterprises that manufacture armaments for domestic use and export abroad. Most work on Russia's ballistic and cruise missiles as well as launch platforms is performed in established teams of design and development facilities.

Key facilities supporting the development of ballistic missiles include the following:

- Moscow Institute of Thermal Technology was founded in 1946 and is a key designer of solid-fuel SSBNs (Bulava) and ICBMs (Topol/Yars), launch vehicles, and the Avangard HGV.

- Votkinsk Machine Building Plant was originally founded in 1795 as an ironworks plant and is today a key manufacturer of solid-fuel SSBNs (Bulava) and ICBMs (Topol/Yars), launch vehicles, and the Avangard HGV.
- Makeev Design Bureau, part of Roskosmos, was founded in 1947 and is a key designer of liquid-fuel SSBNs (Sineva) and ICBMs (Sarmat) as well as launch vehicles (see Figure 18).
- Krasnoyarsk Machine-Building Plant, part of Roskosmos, was founded in 1932 and is the production facility for Russia's liquid-fuel SSBNs (Sineva) and ICBMs (Sarmat) as well as launch vehicles.
- KB Mashinostroyeniya, part of Rostec, was founded in 1942 and designs theater ballistic missiles such as the Tochka tactical ballistic missile and the Iskander.
- The Russian MOD maintains numerous test sites for missiles. The key facility is the Plesetsk Cosmodrome, created in 1957, an ICBM test launch and space launch site. Other test sites include Kapustin Yar and Kura (the latter is usually used as a target for missile tests).

Figure 18. Test stand at Makeev used for testing of the Sarmat ICBM

Source: TV Zvezda show *Voennaya Priemka* on the Sarmat ICBM, June 5, 2022, https://www.youtube.com/watch?v=jF1jACw32aI.

Key facilities supporting the development of the air and sea (and undersea) nuclear weapons capabilities include the following:

- MKB Raduga, today part of the Tactical Missile Corporation, was created in 1946 and is the designer for Russia's "Kh" cruise missile series, including the Kh-55 and Kh-101/2.
- The storied design bureau Tupolev, founded in 1922 and today part of the United Aircraft Corporation, is now a large Russian defense firm. Tupolev designed, produced, and modernized the Russian Blackjack and Bear strategic bombers and serves as the lead for the PAK DA new-generation bomber.
- NPO Novator, today part of Almaz Antey, was created in 1947 and is the designer for some of Russia's anti-ballistic missiles (A-135) and the Kalibr missile family.
- NPO Mashinostroyeniya, today part of the Tactical Missile Corporation, is a missile design bureau founded in 1944. It is best known for its anti-ship missiles, including the Tsirkon hypersonic cruise missile.
- Rubin design bureau, created in 1900 and today part of the United Shipbuilding Corporation, is responsible for designing nuclear-powered submarines, including the Borey SSBN and the Belgorov special purpose submarine intended to carry the Poseidon torpedo, also of Rubin design. (Another design bureau, Malakhit, created in 1948, is responsible for some other nuclear submarines, including the 855 Yasen class.)
- Sevmash shipyard, created in 1936 and today part of the United Shipbuilding Corporation, is Russia's largest shipbuilding enterprise and is responsible for producing nuclear-powered submarines.
- Several Rosatom research institutes work on naval nuclear propulsion. These include the Afrikantov Experimental Design Bureau for Mechanical Engineering, A.P. Aleksandrov Scientific Research Technological Institute, and N.A. Dollezhal Scientific Research and Design Institute of Energy Technologies.

How knowledgeable, educated, and skilled are the scientific and technical personnel who make up Russia's nuclear weapons program?

Russia has invested significant government funding into the improvement of the state of its science and technology ecosystem and the growth of human capital necessary for innovation. As evidenced by international rankings of Russian physics and engineering programs and publications data, these efforts have met with mixed results.

Sanctions imposed on Russia in the wake of its invasion of Ukraine have cut off some avenues for international collaboration for Russian scientists. Despite this situation, Rosatom has pushed ahead with an ambitious drive to develop technologies and human capital in the nuclear field, as evidenced from Russian open sources. If successful, these efforts will ensure that Russia retains a relatively high-quality scientific talent pool that is capable of modernizing and advancing its nuclear weapons program.

Efforts to stimulate nuclear science and engineering

Like many states, Russia views science and technology as a key driver of economic development. Russian efforts to increase spending, grow human capital, and kick-start government programs focused on innovation in specific science, technology, engineering, and mathematics (STEM) sectors have been met with mixed results. Russia continues to lag behind the US, China, and a handful of states in Europe and Asia with respect to R&D spending, patents, and scientific publications.[191] The Russian government's innovation development strategies have had to account for sanctions beginning in 2014 after the annexation of Crimea. In a 2016 Organisation for Economic Co-operation and Development (OECD) report that laid out benchmarks for OECD states in science and technological innovation, Russia's indicators ranked in the bottom half.[192]

One of the major challenges faced by Russian science and technology is human capital. Russian researchers point out that salaries for scientists remain low, scientist positions are not

[191] Klepach, Vodovatov, and Dmitrieva, "Russian Science and Technology: Rise or Progressive Lag (Part I)."

[192] "Russian Federation," in *OECD Science, Technology and Innovation Outlook 2016*, https://read.oecd-ilibrary.org/science-and-technology/oecd-science-technology-and-innovation-outlook-2016/russian-federation_sti_in_outlook-2016-83-en#page5.

considered prestigious in society, and there is a shortage of modern equipment.[193] More recently, sanctions and other restrictions on Russia have affected international collaborations, and concerns about being mobilized by the Russian armed forces have exacerbated the brain drain—the mass departure of well-educated Russians to other countries—particularly in the information technology sector.[194] The extent to which these challenges apply to the nuclear sphere is not entirely clear from open sources.

Figure 19. Rosatom personnel promotional image

Source: Rosatom, https://www.atomic-energy.ru/news/2023/01/19/132102.

Rosatom, Russia's state-owned nuclear corporation, has taken a very active role in the development of human capital and infrastructure in nuclear-related disciplines and specialties. Rosatom, which currently employs 330,000 people, estimates that it will need to hire up to

[193] Klepach, Vodovatov, and Dmitrieva, "Russian Science and Technology: Rise or Progressive Lag (Part I)."

[194] For a great overview, see Krystyna Marcinek and Eugeniu Han, *Russia's Asymmetric Response to 21st Century Strategic Competition Robotization of the Armed Forces*, RAND, 2023, https://www.rand.org/pubs/research_reports/RRA1233-5.html.

100,000 new professionals in physics, chemistry, math, information technology, and other areas by 2030.[195] As part of its effort to develop human capital to meet this demand, Rosatom has spearheaded numerous initiatives, including in the 28 towns and locations that are centers for nuclear energy, nuclear weapons, or industry and science.[196] These initiatives have included the *Professionalitet* project, which seeks to increase the cooperation between educational institutions and potential employers.[197] For example, the Mayak Production Association, a key nuclear production enterprise, is a key partner for educational efforts in Ozersk as part of this program.[198]

Rosatom's efforts have also extended to growing the next generation of scientists. The corporation has a close connection to National Research Nuclear University MEPhI and plans to increase the number of relevant graduate students at the university to 25,000 by 2030, with plans for Rosatom to hire 40 percent of graduates in nuclear-related disciplines.[199] Other Rosatom efforts include the support of Lomonosov Moscow State University's branch in Sarov and VNIIEF to conduct summer schools focused on high-energy physics and other nuclear-relevant topics taught by scholars and scientists from numerous Russian nuclear labs.[200] As discussed earlier in this paper, VNIIEF is the home of a budding National Center of Physics and Mathematics and a repository of supercomputing capability that seeks to attract highly educated scientists, engineers, and other skilled professionals (see Figure 20).

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195 "Rosatom Is Planning to Attract 100,000 New Specialists by 2030" (Росатом до 2030 года планирует привлечь еще 100 тысяч новых специалистов).

196 "Moscow Hosts VII Forum on Nuclear Cities" (В Москве прошел VII Форум городов атомной отрасли), Atomnaya Energiya, Mar. 20, 2023, https://www.atomic-energy.ru/news/2023/03/20/133717.

197 "Education-Enterprise Centers Will Be Created as Part of Professionalists Project in Ozersk" (В Озерске в рамках федерального проекта «Профессионалитет» будут созданы образовательно-производственные центры), Rosatom, Apr. 29, 2022, https://www.rosatom.ru/journalist/news/v-ozerske-v-ramkakh-federalnogo-proekta-professionalitet-budut-sozdany-obrazovatelno-proizvodstvenny/.

198 "Ozersk Will See the Creation of Two Super Colleges for Future Nuclear Staff" (В Озерске создадут два суперколледжа для будущих атомщиков), Rosatom, June 14, 2022, https://strana-rosatom.ru/2022/06/14/v-ozerske-perezagruzyat-profobrazova/.

199 "MEPhi Nuclear Center May Take 20% of World Market of Nuclear-Related Education" (НИЯУ МИФИ к 2030 году может занять 20% мирового рынка ядерного и смежного образования), Atomnaya Energiya, Mar. 15, 2023, https://www.atomic-energy.ru/news/2023/03/15/133581.

200 "National Center of Physics and Mathematics Conducted the First All-Russian School on Gaseous Dynamics and Physics of Explosions" (НЦФМ провел в Сарове I Всероссийскую школу по газодинамике и физике взрыва) Atomnaya Energiya, Mar. 17, 2023, https://www.atomic-energy.ru/news/2023/03/17/133683.

Figure 20. Supercomputing modeling class at the National Center of Physics and Mathematics

Source: Rosatom, https://www.atomic-energy.ru/news/2022/12/12/131108.

Rosatom maintains that its educational and grant-giving efforts have resulted in the increase of young science and technology graduates employed in its nuclear-related research institutes and labs from 21 percent in 2017 to 36 percent in 2022, a number it argues is greater than that in the US and comparable to that in China.[201] These data are challenging to validate, but other data points also suggest that Rosatom's efforts have been slowly bearing fruit. VNIIEF has said

[201] "Systematic Work in Hiring Youth into Science Has Increased Number of Scientists in Rosatom by 15 Percent" (Системная работа по привлечению молодежи в науку обеспечила 15%-й рост количества ученых в Росатоме), Atomnaya Energiya, Oct. 12, 2022, https://www.atomic-energy.ru/news/2022/10/12/129182.

that Rosatom's efforts between 2016 and 2023 have resulted in the hire of 1,650 new specialists from 48 universities in 86 areas or professions relevant to the lab.[202]

Rosatom has also proceeded with an expansion of its nuclear energy and research infrastructure. The *Proryv* (Breakthrough) initiative's objective is to grow the share of nuclear power in energy generation, including through fast neutron reactors and enabling a closed nuclear cycle.[203] If Rosatom's reports are to be believed, this initiative has contributed to a hiring spree. For example, the Siberian Chemical Combine, which employs about 3,350 people across its programs, plans to hire an additional 1,000 people in the next several years, many of these to operate the BREST fast neutron reactor that is currently under construction.[204]

Foreign collaborations across the nuclear field have suffered significantly since Russia invaded Ukraine, with Western institutions severing links to Russian counterparts. For example, the European Organization for Nuclear Research is set to terminate its agreement with Russia in 2024 and will no longer host Russian scientists.[205] However, Russia remains a major participant in and Rosatom enterprises a major technology contributor to ITER, a multinational effort based in France to research fusion energy.[206] Sanctions notwithstanding, Russia's nuclear energy research institutes have sought to attract staff with experience in international collaboration. For example, the Joint Institute for Nuclear Research in Dubna has sought to hire 15 postdocs in nuclear energy–adjacent areas for a salary of $2,300 monthly.[207]

[202] "VNIIEF, NIIIS, and RPRAYeP Adopted a Three Year Collective Agreement" (РФЯЦ-ВНИИЭФ, НИИИС и РПРАЭП приняли новый трехлетний коллективный договор), Atomnaya Energiya, Jan. 13, 2023, https://www.atomic-energy.ru/news/2023/01/13/132002.

[203] A nuclear fuel cycle is considered "closed" if spent fuel is reprocessed and at least partly reused.

[204] "Siberian Chemical Combine to Hire Almost 1,000 People in Next Two Years" (Сибирский химкомбинат в ближайшие два года примет на работу почти 1 тыс. человек), Strana Rosatom, Mar. 29, 2023, https://strana-rosatom.ru/2023/03/29/sibirskij-himkombinat-v-blizhajshie-dv/.

[205] "CERN Council Declares Its Intention to Terminate Cooperation Agreements with Russia and Belarus at Their Expiration Dates in 2024," CERN, June 17, 2022, https://home.cern/news/news/cern/cern-council-cooperation-agreements-russia-belarus.

[206] "ITER: Russian Poloidal Field Coil Arrives at Construction Site," World Nuclear News, Feb. 13, 2023, https://www.world-nuclear-news.org/Articles/ITER-Russian-poloidal-field-coil-arrives-at-constr; Goda Naujokaitytė, "Russian Participation in ITER Nuclear Fusion Project 'Not an Easy Subject' in Wake of Invasion," Science Business, Mar. 15, 2022, https://sciencebusiness.net/russian-participation-iter-nuclear-fusion-project-not-easy-subject-wake-invasion.

[207] "15 New JINR Postdocs Will Receive $2,300 Monthly" (15 новых участников Программы постдоков ОИЯИ будут получать $2300 долларов ежемесячно), Atomnaya Energiya, Mar. 2, 2023, https://www.atomic-energy.ru/news/2023/03/02/133202.

(For reference, Russia's median salary is between $500 and $1,000 monthly as of this writing.[208]) Because of Russia's export of nuclear technology abroad, there are usually numerous foreign students and researchers in Russia studying nuclear-related fields.

University rankings in nuclear-relevant fields

According to QS World University Rankings, Times Higher Education (THE), and Academic Ranking of World Universities (ARWU), Russian institutions offering programs in physics and astronomy and engineering and technology rank lower than their counterparts in the US, Europe, and China. Table 3 shows the top five Russian universities' physics and astronomy departments, ranked among 611 global schools, and engineering and technology departments, ranked among 533 global schools, in 2022 according to QS. THE ranked Russian universities with physics and astronomy departments among 1,227 global schools but did not list rankings for engineering and technology departments. ARWU ranked Russian university physics programs alongside those of 500 other universities worldwide.

Table 3. Rankings of Russian universities, 2022

Russian University	Subject	Ranking Globally	Year
Lomonosov Moscow State University	Physics and astronomy	34,[a] 95,[b] 76-100[c]	2022
	Engineering and technology	57[a]	2022
Moscow Institute of Physics and Technology (MIPT/ Moscow Phystech)	Physics and astronomy	41,[a] 71,[b] 151-200[c]	2022
	Engineering and technology	150[a]	2022
National Research Nuclear University MEPhI (Moscow Engineering Physics Institute)	Physics and astronomy	73,[a] 101-125,[b] 151-200[c]	2022
	Engineering and technology	287[a]	2022
Novosibirsk State University	Physics and astronomy	102,[a] 251-300,[b] 101-150[c]	2022

[208] "Salaries in Russia" (Зарплаты в России), TAdviser, accessed Apr. 5, 2023, https://www.tadviser.ru/index.php/Статья:Зарплаты_в_России.

Russian University	Subject	Ranking Globally	Year
ITMO University	Physics and astronomy	151-200[a] 401-500[b]	2022
	Engineering and technology	116[a]	2022

Sources: [a] "QS World University Rankings by Subject 2022: Engineering & Technology: Russia," QS World University Rankings, accessed Mar. 31, 2023, https://www.topuniversities.com/university-rankings/university-subject-rankings/2022/engineering-technology?&countries=ru; [b] "World University Rankings 2021 by Subject: Physical Sciences: Russia," Times Higher Education, accessed Mar. 31, 2023, https://www.timeshighereducation.com/world-university-rankings/2022/subject-ranking/physical-sciences#!/page/0/length/25/locations/RUS/subjects/3060/sort_by/rank/sort_order/asc/cols/stats; [c] "2022 Global Ranking of Academic Subjects in Physics," Shanghai Ranking, accessed Apr. 5, 2023, https://www.shanghairanking.com/rankings/gras/2022/RS0102.

These positions in the rankings may seem dismal for Russian science. However, even according to Russian sources, Russia's scientists have always been relatively weak on international scientific publications and patents.[209] In fact, Russia had a government program that sought to improve the standing of its institutions in international rankings, including QS, THE, and ARWU, called Project 5-100 that sought to, inter alia, boost publication rates.[210] No matter how dismal, the positions in the rankings have not stopped Russia from maintaining nuclear parity with the United States or holding commanding positions on the global nuclear reactor market.

Although these rankings do not provide specific data on nuclear physics and engineering, a handful of universities connected to Rosatom and its enterprises show up in Western and Russian rankings.[211] Most of these, such as Lomonosov Moscow State University, National Research Nuclear University MEPhI, and Tomsk Polytechnic University, are participants in the 18-school Rosatom core universities consortium and have close relationships with Russia's nuclear labs.

[209] Klepach, Vodovatov, and Dmitrieva, "Russian Science and Technology: Rise or Progressive Lag (Part I)."

[210] See "Project 5-100," accessed Apr. 5, 2023, https://www.5top100.ru/en/.

[211] "10 Best Universities for Nuclear Engineering in Russia," EduRank, accessed Apr. 5, 2023, https://edurank.org/engineering/nuclear/ru/; "13 Best Universities for Nuclear Engineering in Russia," EduRank, accessed Apr. 5, 2023, https://edurank.org/physics/nuclear/ru/; "Subject Ratings: Nuclear Physics and Technologies" (Предметные рейтинги: ядерные физика и технологии), RAEX Rating Review, accessed Apr. 5, 2023, https://raex-rr.com/education/universities/subject_ranking_Nuclear_Physics.

Russian scholars studying abroad in nuclear-relevant fields

We do not have current data on Russian students studying abroad in nuclear-relevant fields. Numbers of those who do so, and their rate of return home, are likely small. The number of Russian students in the United States is insignificant. For example, in the 2021–2022 academic year, the last year data were available, there were about 4,000 Russian students out of a total of more than 20 million international students in the US.[212] The number has likely decreased since then given the suspension of US visa nonimmigrant services at the embassy and consulates in Russia in response to Russian restrictions on locally hired staff in 2021.[213] Although some Russian students have traveled to Europe, European Union restrictions on Russia could be interpreted as prohibiting education in technical fields of study.[214] There are no good data on Russian students studying in China, but entry to China for many Russian students was curtailed by the COVID-19 pandemic until late 2022.[215]

Publication volume and quality in nuclear-relevant fields

As discussed above, Russian publications in international journals are one of the reasons that Russian universities perform poorly in international rankings. According to the Scimago database of Russian publications in six nuclear-related fields, Russian scholars' publication numbers rank much better than Russian universities (see Table 4).[216]

[212] "All Places of Origin," Opendoors, accessed Apr. 5, 2023, https://opendoorsdata.org/data/international-students/all-places-of-origin/.

[213] Alexander Marrow, Dmitry Antonov, and Dmitry Antonov, "Moscow Decries 'Unfriendly Actions' as US Ends Visa Services for Most Russians," Reuters, Apr. 30, 2021, https://www.reuters.com/world/us-embassy-moscow-reduce-consular-services-over-ban-hiring-local-staff-ifax-2021-04-30/.

[214] "EU Restrictive Measures Against Russia," EASA, accessed Apr. 5, 2023, https://www.easa.europa.eu/en/the-agency/faqs/eu-restrictive-measures-against-russia.

[215] "Russian Students Travel to China to Study After 3 Years of Pandemic" (Студенты из РФ едут учиться в КНР после 3 лет пандемии), RIA, Dec. 20, 2022, https://ria.ru/20221220/kitay-1839943769.html.

[216] "Scimago Journal and Country Rank," accessed Apr. 5, 2023, https://www.scimagojr.com/countryrank.php.

Table 4. Russia's Scimago 2021 rankings

Field	Ranking	Behind	Year	Comments
Atomic and molecular physics and optics	4	China, US, India	2021	China's no. of documents is orders of magnitude different from US (25,000 vs. 7,000)
Condensed matter physics	4	China, US, India	2021	China's no. of documents is orders of magnitude different from US (50,000 vs. 16,000)
Nuclear and high- energy physics	5	US, China, Germany, India	2021	
Physics and astronomy (miscellaneous)	2	China	2021	46,000 vs. 20,000
Radiation	3	US, China	2021	1,575 (US) vs. 731 (Russia)
Statistical and non-linear physics	3	China, US	2021	2,836 (China) vs. 931 (Russia)

Source: "Scimago Journal and Country Rank," https://www.scimagojr.com/countryrank.php.

Insights from US visits to Russia's nuclear weapons facilities

As discussed earlier in this paper, after the end of the Cold War, the United States sought to reduce the threat of proliferation of nuclear knowledge by underemployed Russian scientists to states such as Iran and North Korea. The result was the creation of the CTR lab-to-lab program between the two countries, in which the US Department of Energy National Nuclear Security Administration and personnel from US national laboratories engaged in cooperative activities with their Russian counterparts at Rosatom and the Russian nuclear labs.[217] Similar engagements took place on the mil-mil side. For example, as part of CTR, US DOD previously worked with the 12th GUMO on enhancing the physical security of Russian warheads.[218] Such

[217] See Hecker, *Doomed to Cooperate: How American and Russian Scientists Joined Forces to Avert Some of the Greatest Post-Cold War Nuclear Dangers*; Matthew Bunn, *Securing the Bomb* reports, NTI, https://www.nti.org/about/programs-projects/project/Securing-bomb/.

[218] Moon, "The Story Behind U.S. Access to Russian Nuclear Warhead Storage Sites," Stimson Center, Feb. 4, 2021, https://www.stimson.org/2021/the-story-behind-u-s-access-to-russian-nuclear-warhead-storage-sites/; William M. Moon, "What It's Like to Visit a Russian Nuclear Warhead Storage Site," Stimson Center, Apr. 1, 2021, https://www.stimson.org/2021/what-its-like-to-visit-a-russian-nuclear-warhead-storage-site/.

engagements provided the US with a collateral understanding of the state of Russian human capital, facilities, and procedures. Before the 2014 invasion of Ukraine, there were ongoing efforts to develop cooperation between the two countries in areas of mutual interest, such as nuclear energy, and to transform the relationship from donor-recipient to a partnership. Following that invasion, this cooperation ceased.[219]

Figure 21. 12th GUMO servicemembers participate in NBC environment training

Source: Russian MOD, May 19, 2022, https://eng.mil.ru/en/news_page/country/more.htm?id=12422281@egNews.

[219] Khlopkov, *Russia's Nuclear Security Policy: Priorities and Potential Areas for Cooperation*.

What nuclear weapons and delivery systems does Russia possess, where are they deployed, and how capable are they?

Strategic Rocket Forces

As discussed earlier in this paper, Russia's Strategic Rocket Forces are the dominant leg of the Russian triad, and their modernization has been ongoing. Russia's ICBM force, which is becoming increasingly MIRVed, is key to Russia's retaliatory strike.

Multiple independently targetable reentry vehicle, or **MIRV**, refers to the ability of some ballistic missiles to carry more than one nuclear warhead. Some estimates state that the Russian Sarmat could load up to 10 large or 16 small warheads.[220] As the name suggests, these different warheads can be programmed to hit individual targets across a given area. The total payload could be a mix of real warheads and countermeasures designed to evade missile defense.

They are deployed in the 27th Guards Missile Army (HQ in Vladimir), the 31st Missile Army (Orenburg), and the 33rd Guards Missile Army (Omsk). These three missile armies, in turn, consist of 12 missile divisions.[221] A regiment usually comprises 6 to 10 silos or 9 mobile launchers.[222]

- 27th Guards Missile Army (HQ in Vladimir)
  - Tatishchevo: 60th MD (Tatishchevo-5, Svetlyy) consists of six regiments of SS-27 Mod 1 (silo)/RS-12M2 (Topol-M).
  - Kozelsk: 28th GMD consists of three regiments of SS-27 Mod 1 (silo)/RS-12M2 (Topol-M).
  - Vypolzovo: 7th GMD (Ozernyy, Bologoye-4) consists of one regiment of SS-27 Mod 2 (mobile)/RS-24 (Yars) and one regiment of SS-25 Sickle/RS-12M (Topol).

220 "RS-28 Sarmat," Missile Threat, CSIS, Missilethreat.csis.org/missile/rs-28-sarmat.

221 Pavel Podvig, "Strategic Rocket Forces" *Russian Strategic Nuclear Forces (blog)*, accessed Apr. 5, 2023, https://russianforces.org/missiles/; Hans M. Kristensen and Matt Korda, "Nuclear Notebook: How Many Nuclear Weapons Does Russia Have in 2022?" *Bulletin of the Atomic Scientists*, Feb. 23, 2022, https://thebulletin.org/premium/2022-02/nuclear-notebook-how-many-nuclear-weapons-does-russia-have-in-2022/; International Institute for Strategic Studies, "Russia and Eurasia," in *The Military Balance 2023* (Taylor and Francis, 2023), https://www.routledge.com/The-Military-Balance-2023/IISS/p/book/9781032508955.

222 International Institute for Strategic Studies, "Russia and Eurasia," p. 184.

- Teykovo: 54th GMD (Krasnyye Sosenki) consists of two regiments of SS-27 Mod 1 (mobile)/RS-12M1 (Topol-M) and two regiments of SS-27 Mod 2 (mobile)/RS-24 (Yars).
- Yoshkar-Ola: 14th MD consists of three regiments of SS-27 Mod 2 (mobile)/RS-24 (Yars).

- 31st Missile Army (Orenburg)
  - Dombarovsky: 13th MD (Yasnyy) consists of four regiments of SS-18 M6 Satan/RS-20V.
  - Nizhniy Tagil: 42nd MD (Verkhnyaya Salda, Nizhniy Tagil-41, Svobodnyy) consists of three regiments of SS-27 Mod 2 (mobile)/RS-24 (Yars).
- 33rd Guards Missile Army (Omsk)
  - Uzhur: 62nd MD (Uzhur-4, Solnechnyy) consists of three regiments of SS-18 M6 Satan/RS-20V and one regiment of SS-X-29 (silo)/RS-28 (Sarmat).
  - Novosibirsk: 39th GMD (Novosibirsk-95, Pashino, Gvardeiskiy) consists of three regiments of SS-27 Mod 2 (mobile)/RS-24 (Yars).
  - Irkutsk: 29th GMD (Zelenyy) consists of three regiments of SS-27 Mod 2 (mobile)/RS-24 (Yars).
  - Barnaul: 35th MD (Sibirskiy-2) consists of four regiments of SS-27 Mod 2 (mobile)/RS-24 (Yars).

Table 5 provides an overview of these capabilities. Russia also previously developed other missile capabilities, including a new rail-mobile ICBM, but this and other programs were postponed or canceled in the 2017–2018 time frame to prioritize the development of the Avangard HGV and other systems.

Table 5. Strategic Rocket Forces' nuclear systems

Name/Type	Launcher	Year Deployed	Characteristics	Totals
SS-18 M6 Satan/RS-20V	40-46	1988	10 x 500/800 (MIRV)	400-460
SS-19 M3 Stiletto/RS-18 (UR-100NUTTH)	Up to 20	1980	6 x 400 (MIRV)	Being withdrawn
SS-19 M4? (Avangard HGV)	6	2019	1 x HGV	6
SS-25 Sickle/RS-12M (Topol)	9	1988	1 x 800	9
SS-27 Mod 1 (mobile)/RS-12M1 (Topol-M)	18	2006	1 x 800	18

Name/Type	Launcher	Year Deployed	Characteristics	Totals
SS-27 Mod 1 (silo)/RS-12M2 (Topol-M)	60	1996	1 x 800	60
SS-27 Mod 2 (mobile)/RS-24 (Yars)	153-162	2010	3 or 4 x 100? (MIRV)	486-612
SS-27 Mod 2 (silo)/RS-24 (Yars)	18-20	2014	3 or 4 x 100? (MIRV)	54-80
SS-X-29 (silo)/RS-28 (Sarmat)	—	2023?	10 x 500? (MIRV)	—

Sources: Kristensen and Korda, "Nuclear Notebook: How Many Nuclear Weapons Does Russia Have in 2022?"; "Strategic Weapons Systems," Jane's Sentinel Security Assessment—Russia and the CIS, Feb. 9, 2023, https://customer.janes.com/display/CISA028-CIS; International Institute for Strategic Studies, "Russia and Eurasia."

Strategic Fleet

As discussed earlier in this paper, the undersea leg of the Russian triad has also undergone extensive modernization. Russia has deployed its new class of SSBNs, the Borey, since 2012 with the SS-N-32/RSM-56 (Bulava) SLBM. Six of these boats have been commissioned as of this writing, one more is ready for commissioning, and three more are under active construction. A total of 12 boats are planned by 2030, with 6 each in the Northern and Pacific Fleets. Russia currently also deploys several overhauled Delta IV SSBNs that will likely be retired as new Boreys enter service. All the Delta IV boats are in service with the Northern Fleet and carry the SS-N-23 M2/3 /RSM-54 (Sineva/Layner). Two of the Boreys are also with the Northern Fleet, with the rest in the Pacific.[223]

The Northern Fleet is based in Severomorsk and is Russia's fleet in the Arctic. The Pacific Fleet is based in Fokino in the Russian Far East. Table 6 provides an overview of the Strategic Fleet's capabilities.

[223] Pavel Podvig, "Strategic Fleet," *Russian Strategic Nuclear Forces (blog)*, accessed Apr. 5, 2023, https://russianforces.org/navy/.

Table 6. Strategic Fleet's nuclear systems

Name/Type	Launcher	Year Deployed	Characteristics	Totals
SS-N-23 M2/3 /RSM-54 (Sineva/Layner) on Delta IV SSBN	4-6/64-80	2007	4 x 100 (MIRV)	264–320
SS-N-32/RSM-56 (Bulava) on the Borey SSBN	5/80	2014	6 x 100 (MIRV)	480

Sources: Kristensen and Korda, "Nuclear Notebook: How Many Nuclear Weapons Does Russia Have in 2022?"; "Strategic Weapons Systems"; International Institute for Strategic Studies, "Russia and Eurasia."

Long-Range Aviation

As discussed earlier in this paper, Russia's Long-Range Aviation consists of two types of bombers: the modernized Tu-95 and the modernized Tu-160. These bombers also perform conventional missions. Russia intends to eventually field the PAK DA new-generation bomber, which can carry long-range air-launched cruise missiles (ALCMs) derived from the AS-15 Kent. Table 7 provides an overview of these capabilities, which are deployed as follows:

- The 6950th Guards Air Base in Engels (Saratov oblast): the 121st Guards regiment of Tu-160 bombers and the 184th regiment of Tu-95MS bombers.
- The 6952nd Air Base in Ukrainka (Amurskaya oblast): the 79th regiment and 182nd Guards regiments of Tu-95MS bombers.[224]

Table 7. Long-Range Aviation's nuclear systems

Name/Type	Launcher	Year Deployed	Characteristics	Totals
Bear-H6/16 Tu-95MS6/MS16/MSM	55-60 bombers	1984/2015	6-16 x AS-15A (Kh-55) ALCMs or 14 x AS-23B (Kh-102) ALCM	448+?

[224] Pavel Podvig, "Strategic Aviation," *Russian Strategic Nuclear Forces (blog)*, accessed Apr. 5, 2023, https://russianforces.org/aviation/.

Name/Type	Launcher	Year Deployed	Characteristics	Totals
Blackjack Tu-160/M	13-16 bombers	1987/2021	12 x AS-15B ALCMs or AS-23B ALCM bombs	132+?

Sources: Kristensen and Korda, "Nuclear Notebook: How Many Nuclear Weapons Does Russia Have in 2022?"; "Strategic Weapons Systems"; International Institute for Strategic Studies, "Russia and Eurasia."

Other systems

As discussed earlier in this paper, Russia also has an extensive variety of NSNWs and dual-capable systems. Partly because of the cost-effectiveness of NSNWs vis-à-vis conventional capabilities, the Russian military intends them to play an important role in deterring aggression in a regional conventional contingency and help with signaling, escalation management, and, if deterrence fails, warfighting. The numbers of warheads potentially assigned to these systems are presented in Table 8.

Table 8. Nonstrategic nuclear weapons

Name/Type	Launcher	Year Deployed	Characteristics	Totals
Bombers/fighters (Tu-22M3(M3M)/Su-24M/Su-34/MiG-31K)	~300	1974–2018	ASMs, ALBM, bombs	~500
S-300/S-400 (SA-20/SA-21)	~750	1992/2007	1 x low	~290
53T6 Gazelle	68	1986	1 x 10	68
SSC-1B Sepal (Redut)	8	1973	1 x 350	4
SSC-5 Stooge (SS-N-26) (K-300P/3M-55)	60	2015	(1 x 10)	25
SS-26 Stone SSM (9K720, Iskander-M)	144	2005	1 x 10-100	70
SSC-7 Southpaw GLCM (R-500/9M728, Iskander-M)	?	?	?	?
SSC-8 Screwdriver GLCM (9M729)	20	2017	1 x 10-100	20

Name/Type	Launcher	Year Deployed	Characteristics	Totals
Submarines/surface ships/air			LACM, SLCM, ASW, SAM, DB, torpedoes	~935

Sources: Kristensen and Korda, "Nuclear Notebook: How Many Nuclear Weapons Does Russia Have in 2022?"
Note: ASM = air-to-surface missile; ASW = antisubmarine weapon; DB = depth bomb; LACM = land-attack cruise missile; SAM= surface-to-air missile; SLCM = submarine-launched cruise missile.

Russia has also hedged against future technological uncertainty by developing novel nuclear-capable systems. These include the following:

- Burevestnik SSC-X-9 nuclear-powered long-range nuclear-armed cruise missile remains under development (see Figure 22).
- Poseidon (Kanyon) dual-capable nuclear-powered UUV remains under development, although the special purpose submarine intended to carry it was turned over to the navy in 2022.[225]
- Kinzhal (Killjoy) dual-capable ALBM, capable of being carried by either the Tu-22M3 or MiG-31K aircraft, has entered service with the Russian armed forces.
- Tsirkon (SS-N-33) dual-capable ship-launched aero-ballistic missile intended for surface ships and submarines is currently undergoing testing.[226]
- As noted in the Strategic Rocket Forces section above, the Sarmat ICBM and the Avangard HGV were captured in New START before Russia's announcement that it was suspending its participation in the treaty.

[225] International Institute for Strategic Studies, "Russia and Eurasia."

[226] International Institute for Strategic Studies, "Russia and Eurasia."

Figure 22. Burevestnik cruise missile

Source: Russian MOD, https://www.youtube.com/watch?v=okS76WHh6FI.

Conclusion

Russia is in a relationship of mutual nuclear vulnerability with the United States, and strategic arms control has until recently ensured quantitative parity in the number of deployed strategic nuclear forces. Russia has a diverse arsenal of strategic nuclear weapons mounted on a triad of delivery vehicles and NSNWs that could be launched from a variety of aircraft, vessels, and ground-launched cruise and ballistic missiles, among others. Russia also has an extensive nuclear complex that has shrunk since the end of the Cold War thanks to US and Western CTR assistance. Although it no longer produces fissile materials for nuclear weapons, Russia possesses an extensive stockpile of fissile materials and related production infrastructure.

Russia's strategic nuclear triad, its NSNWs, and its supporting nuclear complex and defense industrial base are all undergoing modernization to ensure that Russia's nuclear capabilities remain a symbol of its great power status as well as a formidable deterrent to a perceived threat of US and NATO aggression. As part of this modernization, Rosatom has pushed ahead with an ambitious drive to develop technologies and human capital in the nuclear field, as evidenced from Russian open sources. If successful, these efforts will ensure that Russia retains a relatively high-quality scientific talent pool that is capable of modernizing and advancing its nuclear weapons program.

China's Nuclear Program

The People's Republic of China (PRC) first became a nuclear power in 1964. Since the start of China's nuclear weapons program, China's leaders, official statements, and declaratory policy have all stated that China adheres to a no-first-use (NFU) policy for nuclear weapons—meaning that China will not be the first to use nuclear weapons in a conflict and will not use nuclear weapons against a nonnuclear state. PRC Foreign Ministry statements and government writings assert that although China is still relatively poor and the "world's largest developing country,"[227] China is a "medium nuclear power" (compared to "great nuclear powers" such as the US and Russia)[228] and that its nuclear force is intended to deter nuclear attacks against China and prevent coercion through the threat of nuclear attack by other countries.[229]

Any analysis of PRC nuclear forces and strategy takes place against the backdrop of opacity. China does not publish information on the composition, size, or scope of its nuclear arsenal. This ambiguity is described by PRC authors as "strategic transparency and tactical secrecy" and is used to maintain a credible deterrent for a nuclear power with fewer nuclear warheads and delivery systems than the US and Russia.[230]

For decades, China has maintained its nuclear deterrence capabilities to form a type of "asymmetric strategic stability" with other larger nuclear powers—particularly the US. This asymmetric strategic stability is characterized by "mutual vulnerability" to counterattack by the other, thereby diminishing each nation's incentive to launch a preemptive nuclear strike.[231]

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[227] "Foreign Ministry Spokesperson Wang Wenbin's Regular Press Conference on June 9, 2023," Ministry of Foreign Affairs of the People's Republic of China, June 9, 2023, https://www.fmprc.gov.cn/eng/xwfw_665399/s2510_665401/2511_665403/202306/t20230609_11094406.html.

[228] Hu Gaochen (胡高辰), "An Analysis of China-US Asymmetric Nuclear Stability and the US Strategic Opportunism" (中美不对称核稳定与美国战略机会主义论), *Journal of International Security Studies* (国际安全研) 2 (2021).

[229] Information Office of the State Council of the People's Republic of China, *China's National Defense in 2006*, Dec. 29, 2006, http://fas.org/nuke/guide/china/doctrine/wp2006.html.

[230] Zou Zhibo (邹治波) and Liu Wei (刘玮), "Constructing the Sino-US Nuclear Strategic Stability Framework: An Asymmetric Strategic Balance Approach" (构建中美核战略稳定性框架:非对称性战略平衡的视角), *Journal of International Security Studies* (国际安全研究) 1 (2019).

[231] Gaochen, "An Analysis of China-US Asymmetric Nuclear Stability and the US Strategic Opportunism."

Recent PRC writings, however, demonstrate a concern that global advancements in military technology may be eroding long-standing dynamics of strategic deterrence and thus China's ability to defend itself from nuclear attack or to ensure a second nuclear strike, particularly with advancements in US ballistic missile defense systems.[232] PRC writings argue that this shift in strategic deterrence dynamics could destroy the mutual vulnerability that underpins US-China asymmetric strategic stability.[233]

Since the early 2000s, the PRC has been modernizing, diversifying, and expanding its nuclear arsenal and delivery systems, presumably in response to these shifting concepts of strategic deterrence and perceived changes in the international security environment. More recently, authoritative PRC statements on China's nuclear forces suggest that China is pursuing a "strong system of strategic deterrence," likely alluding to a larger nuclear force as well as a suite of conventional capabilities that could have strategic effects.[234] Although the transition to this more robust posture remains in progress, it appears to involve acquiring a larger, more capable nuclear force, including a triad of ground-based, air-based, and submarine-based weapons, as well as perhaps the ability to maintain some of these forces at a higher level of readiness to enable launch on warning of an incoming nuclear strike.

What factors drive China's nuclear program?

The PRC began pursuing nuclear weapons capabilities in the mid-1950s. Generally, scholars agree that China's decision to acquire nuclear weapons was driven by the perceived threat from the United States during the Korean War and the 1950s Taiwan Strait crises and reinforced by growing tensions with the neighboring Soviet Union by the end of the decade.[235]

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[232] See, for example, Zhibo and Wei, "Constructing the Sino-US Nuclear Strategic Stability Framework: An Asymmetric Strategic Balance Approach," as discussed in Alison A. Kaufman and Brian Waidelich, *PRC Writings on Strategic Deterrence: Technological Disruption and the Search for Strategic Stability*, CNA, July 2022, DOP-2022-U-032923-1Rev.

[233] National Defense University, *Science of Military Strategy* (战略学) (Beijing: National Defense University Press (国防大学出版社), 2020), p. 384.

[234] Xi Jinping, *Hold High the Great Banner of Socialism with Chinese Characteristics and Strive in Unity to Build a Modern Socialist Country in All Respects*, Report to the 20th National Congress of the Communist Party of China, Oct. 16, 2022, https://english.news.cn/20221025/8eb6f5239f984f01a2bc45b5b5db0c51/c.html.

[235] Scott Sagan, "Why Do States Build Nuclear Weapons? Three Models in Search of a Bomb," *International Security* 21, no. 3 (Winter, 1996-1997): 58–59; Eric Heginbotham et al., *China's Evolving Nuclear Deterrent: Major Drivers and Issues for the United States*, RAND, 2017, https://www.rand.org/pubs/research_reports/RR1628.html.

According to secondary source analyses, PRC leaders directed China's first nuclear scientists to develop a small nuclear arsenal capable of surviving an initial strike by an enemy with the ability to retaliate with a second strike. In 1954, Chairman of the Chinese Communist Party (CCP) Mao Zedong requested assistance from the Union of Soviet Socialist Republics (USSR) for China's nascent nuclear weapons program. Even though Soviet leaders stated that "it was sufficient for the global socialist community to have a single nuclear umbrella,"[236] Mao doubted the reliability of USSR extended deterrence and viewed an independent Chinese nuclear capability as critical for the country's security. After a few years of initial scientific support from the USSR, which ended in 1959, China officially acquired nuclear capability in 1964 with its first successful detonation of an enriched uranium fission bomb at the Lop Nur site in Western China.[237] By the early 1960s, China and the Soviet Union had broken off relations, and Mao came to fear a Soviet nuclear attack, prompting the relocation of key industries away from the Sino-Soviet border.[238] In response to this perceived security environment, PRC leaders pursued nuclear weapons both to deter nuclear attacks on the country and to prevent other countries from practicing nuclear coercion against China (i.e., using the threat implicit in one's nuclear arsenal as political leverage).[239]

[236] Xu Weidi, "China's Security Environment and The Role of Nuclear Weapons," in *Understanding Chinese Nuclear Thinking*, ed. Li Bin and Tong Zhao (Carnegie Endowment for International Peace, 2016), p. 23.

[237] "16 October 1964 – First Chinese Nuclear Test: CTBTO Preparatory Commission," CTBTO Preparatory Commission, Oct. 16, 1964; Weidi, "China's Security Environment and the Role of Nuclear Weapons," p. 23; Ashley J. Tellis, *Striking Asymmetries: Nuclear Transitions in Southern Asia* (Carnegie Endowment, 2022), p. 10.

[238] Scott Sagan, "Why Do States Build Nuclear Weapons? Three Models in Search of a Bomb"; Heginbotham et al., *China's Evolving Nuclear Deterrent: Major Drivers and Issues for the United States*.

[239] M. Taylor Fravel, *Active Defense: China's Military Strategy Since 1949*, (Princeton, NJ: Princeton University Press, 2019); Heginbotham et al., *China's Evolving Nuclear Deterrent: Major Drivers and Issues for the United States*, p. 16; Tellis, *Striking Asymmetries: Nuclear Transitions in Southern Asia*, pp. 10–11.

In a statement issued on the day of that test, the PRC government implied that China's basic approach to developing its nuclear weapons program was one of reluctance and unavoidable necessity, asserting that "China cannot remain idle and do nothing in the face of the ever-increasing nuclear threat posed by the United States. China is forced to conduct nuclear tests and develop nuclear weapons."[240]

Figure 23. Model of the PRC's first atomic bomb

Source: Photo by Max Smith via Wikimedia Commons.

Historically, the goal of Chinese deterrence has required that China maintain a nuclear arsenal that can survive a first strike and reliably threaten an adversary with retaliation—thus eroding the adversary's incentive to engage in a preemptive strike. This approach, which is labeled *mutual vulnerability* by scholars of nuclear policy within the PRC and more broadly across the field, does not require that nuclear powers achieve parity in their nuclear forces. Rather, it requires only that enough of the weaker side's forces survive and can retaliate against a nuclear strike.[241]

Previously, China has declared in its defense white papers that it has a "lean and effective" nuclear arsenal—possessing fewer nuclear weapons than other nuclear powers such as the US and Russia but maintaining enough nuclear capability to deter attack by assuring a retaliatory second strike. PRC government documents have made this point consistently over time. For example, the PRC's 2006 Defense White Paper declared that the PRC "aims at building a lean and effective nuclear force capable of meeting national security needs"—terminology that was reiterated as recently as the 2015 PRC Defense White Paper.[242] PRC writings, much like Western discourse on the topic, characterize the end state of this deterrence as creating

[240] "Statement of the Government of the People's Republic of China (October 16, 1964)" (中华人民共和国政府声明 (1964年10月16日), Government of the People's Republic of China, accessed Sept. 8, 2022, http://www.gov.cn/gongbao/shuju/1964/gwyb196414.pdf.

[241] Gaochen, "An Analysis of China-US Asymmetric Nuclear Stability and the US Strategic Opportunism.

[242] Information Office of the State Council of the People's Republic of China. *China's National Defense in 2006*.

strategic stability, a state in which there is no rational reason for the main actors of a regional or global system to use military force against each other.[243]

China's concept of what constitutes an effective strategic deterrent may be changing, however. In line with the PRC's goals of modernizing its military force to "fight and win wars," China is actively modernizing its nuclear arsenal, making robust qualitative and quantitative improvements to its capabilities.[244] With rapid modernization and expansion of its nuclear forces, China aspires to deter challenges from the US and other great power competitors as the CCP seeks "the great rejuvenation of the Chinese nation" by 2049.

A major security concern driving the retention and modernization of China's nuclear arsenal appears to be the perception that the international strategic landscape is fundamentally changing. For example, China's 2019 National Defense White Paper states that "international strategic competition is on the rise" and "growing hegemonism, power politics, and unilateralism" are undermining the international security system.[245] China views the US-led international order as a force that will try to contain China's growth and capacity and challenge its interests in the Asia-Pacific region.[246]

China's geographic location intensifies its security concerns. The PRC is surrounded by 14 countries on its land borders, including nuclear powers Russia, Pakistan, and North Korea, as well as India, a nuclear-armed regional rival with which China has had ongoing border disputes for half a century.[247] China's eastern coast boasts long maritime borders as well as proximity to US allies South Korea and Japan.[248] In addition, China has maritime disputes with five countries and Taiwan in the South China Sea. China's 2019 Defense White Paper states that the

[243] For an in-depth analysis on this topic, see Kaufman and Waidelich, *PRC Writings on Strategic Deterrence: Technological Disruption and the Search for Strategic Stability*.

[244] Office of the Secretary of Defense, US Department of Defense, *Military and Security Developments Involving the People's Republic of China*, Annual Report to Congress, 2021, p. 94.

[245] "Full Text: China's National Defense in the New Era," State Council Information Office of the People's Republic of China, July 24, 2019, http://www.xinhuanet.com/english/2019-07/24/c_138253389.htm.

[246] David Santoro and Robert Gromoll, *On the Value of Nuclear Dialogue with China*, Pacific Forum, Nov. 2020, p. 9, https://pacforum.org/wp-content/uploads/2020/11/issuesinsights_Vol20No1.pdf; Tellis, *Striking Asymmetries,* p. 19.

[247] Heginbotham et al., *China's Evolving Nuclear Deterrent: Major Drivers and Issues for the United States*, p. xii; Larry M. Wortzel, *China's Nuclear Forces: Operations, Training, Doctrine, Command, Control*, US Army War College, May 1, 2007, p. 5.

[248] Tellis, *Striking Asymmetries*, p. 19.

"Asia-Pacific region has become a focus of major country competition, bringing uncertainties to regional security."

It is noteworthy that Japan is embarking on a five-year plan, including a 25 percent increase in military spending, to boost its defense capabilities because of perceived threats from China and North Korea.[249] South Korean President Yoon Suk Yeol stated that his country would consider developing a nuclear capability or asking the US to redeploy nuclear weapons on South Korea's territory if the North Korean threat increased.[250] In his April 26, 2023, meeting with President Biden, however, Yoon recommitted to extended deterrence, and the two leaders agreed to close consultation on any redeployment of nuclear weapons in South Korea.[251]

The PRC's changing assessment of the international balance of nuclear capabilities is a key factor in its shifting view of effective deterrence. According to Western scholars, China perceives the United States as its main threat and key competitor in the nuclear balance (as in many others).[252] PRC leaders and official documents express fears that the US will continue increasing its nuclear and anti-ballistic missile capabilities, either directly threatening China's nuclear arsenal or rendering it ineffective by eliminating China's second-strike capability.[253]

Recent PRC writings argue that China's ability to maintain its asymmetric strategic stability through mutual vulnerability has been eroded by new technologies, advancements in tactical nuclear weapons, and the rise of conventional weapons with the ability to inflict such damage as to cause strategic effects. For example, PRC scholars have expressed concerns regarding the survivability and penetration effectiveness of China's nuclear forces given US advancements in striking precision, robust missile defense capabilities, and intelligence, surveillance, and

[249] Isabel Reynolds, "Japan Begins Defense Upgrade with 26% Spending Increases for 2023," Bloomberg, Dec. 23, 2022, https://www.bloomberg.com/news/articles/2022-12-23/japan-begins-defense-upgrade-with-26-spending-increase-for 2023#:~:text=Japan%20will%20hike%20its%20defense,China%2C%20North%20Korea%20and%20Russia.

[250] Choe Sang-Hun, "In a First, South Korea Declares Nuclear Weapons an Option," *New York Times*, Jan. 12, 2023, https://www.nytimes.com/2023/01/12/world/asia/south-korea-nuclear-weapons.html.

[251] The White House, "Washington Declaration," Apr. 26, 2023, https://www.whitehouse.gov/briefing-room/statements-releases/2023/04/26/washington-declaration-2/#:~:text=The%20United%20States%20commits%20to,infrastructure%20to%20facilitate%20these%20consultations.

[252] Heginbotham et al., *China's Evolving Nuclear Deterrent: Major Drivers and Issues for the United States*, p. xii; Wortzel, *China's Nuclear Forces: Operations, Training, Doctrine, Command, Control*, p. 3.

[253] George Perkovich et al., *China-US Cyber-Nuclear C3 Stability*, Carnegie Endowment for International Peace, Apr. 2021, https://carnegieendowment.org/2021/04/08/china-u.s.-cyber-nuclear-c3-stability-pub-84182.

reconnaissance.[254] PRC authors have particularly argued against US deployment of missile defense systems, which they believe undermine the effectiveness of China's second-strike deterrent and may embolden the US to take more assertive military actions against China.[255] For example, in 2018 a scholar associated with China's Academy of Military Sciences (a People's Liberation Army (PLA) research academy under the direct leadership of the Central Military Commission (CMC)) stated:

> The United States is [now] trying to [gain] an absolute advantage in both offensive and defensive fields in the strategic deterrence system. It has improved its missile defense capabilities from the terminal stage of missile flight to the booster stage of the flight trajectory…This strategic advantage places the United States in a position to avoid strategic retaliation by adversaries.[256]

Because of these US improvements, and because China has relatively few nuclear weapons compared to the US and Russia, China's calculation of what forms a "credible deterrent" has changed. Recent statements by PRC strategists suggest that the PRC's definition of a credible strategic deterrence has moved away from its previous emphasis on a "lean and effective" force and is expanding to incorporate other nonnuclear capabilities that could generate strategic effects.

The most notable such statement occurred on October 16, 2022, when CCP General Secretary Xi Jinping delivered his report at the opening session of the 20th National Congress of the Chinese Communist Party. This report contained a section on military affairs that provided a

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[254] Sun Xiangli, "The Development of Nuclear Weapons in China," in *Understanding Chinese Nuclear Thinking*, ed. Li Bin and Tong Zhao (Carnegie Endowment for International Peace, 2016), http://www.jstor.org/stable/resrep26903.8, p. 91; Fiona S. Cunningham and M. Taylor Fravel, "Assuring Assured Retaliation: China's Nuclear Posture and US-China Strategic Stability," *International Security* 40, no. 2 (Fall 2015): 15; David Logan, "Making Sense of China's Missile Forces," in *Chairman Xi Remakes the PLA: Assessing Chinese Military Reforms,* ed. Phillip C. Saunders, Arthur S. Ding, Andrew Scobell, Andrew N.D. Yang, and Joel Wuthnow (Washington, DC: National Defense University Press, 2019), https://ndupress.ndu.edu/Portals/68/Documents/Books/Chairman-Xi/Chairman-Xi_Chapter-11.pdf?ver=2019-02-08-112005-803; Congressional Research Service, *China's Military: The People's Liberation Army (PLA)*, June 4, 2021, https://crsreports.congress.gov/product/pdf/R/R46808, p. 37.

[255] Fan Jishe (樊吉社), "The Logic and Evolution of China's Nuclear Policy" (中国核政策的基本逻辑与前景), *Foreign Affairs Review* (外交评论(外交学院学报) 5 (2018).

[256] Luo Xi (罗曦), "The Adjustments of US Strategic Deterrence System and Their Implications to Sino-US Strategic Stability" (美国战略威慑体系的调整与 中美战略稳定性), *Journal of International Relations* (国际关系研究) 6 (2017): 47–48.

list of nearly three dozen areas for future focus and modernization. One focus area was the need to

> establish a *strong system of strategic deterrence* [emphasis added], increase the proportion of new-domain forces with new combat capabilities, speed up the development of unmanned, intelligent combat capabilities, and promote coordinated development and application of the network information system.[257]

Xi Jinping's use of the word *system* suggests a more expansive view of strategic deterrence as enabled by a suite of capabilities that includes not only an expanded nuclear weapons arsenal but also high-end conventional weapons such as hypersonics, missile defense systems, and cyber and space capabilities with strategic effects. Xi's statement suggests that this view, which had been evident in PRC scholarly writings for several years before the 2022 speech, has now been adopted by the highest levels of PRC leadership.[258] This seemingly subtle change from a "lean and effective" nuclear force to a "strong system of strategic deterrence" is actually quite consequential because it relates to the nuclear forces that the PRC will field and how and when it will plan to employ those forces.

[257] Jinping, *Hold High the Great Banner of Socialism with Chinese Characteristics and Strive in Unity to Build a Modern Socialist Country in All Respects.*

[258] See, for example, Kaufman and Waidelich, *PRC Writings on Strategic Deterrence: Technological Disruption and the Search for Strategic Stability*.

The PRC has historically used the term *lean and effective* to describe the composition of its nuclear arsenal. This term alludes to the PRC possessing fewer nuclear warheads than other nuclear powers, such as the US and Russia, while maintaining enough of a nuclear arsenal to achieve asymmetric strategic deterrence and assured second strike capability. The PRC's 2015 Defense White Paper made reference to *lean and effective* but the term was dropped from the 2019 version.

The US Department of Defense (DOD) estimates that in 2021 China's operational warhead stockpile surpassed 400; if China continues its current pace of nuclear modernization, it will likely field at least 1,500 deliverable warheads on various systems by 2035.[259] In other words, China would nearly match US and Russian warhead levels set by START II.

This change has raised concerns among analysts and the US government that China may be moving away from its historical "lean and effective" deterrence force structure toward one suited for a more robust nuclear strategy.[260] Even so, some Western analysts argue that the PRC's perspective on the purpose of nuclear weapons has largely remained unchanged from its 1950s motivations to prevent nuclear coercion and deter nuclear attack through a credible retaliatory capability.[261]

What are China's nuclear weapons policies?

China has rigidly adhered to an official declaratory policy of NFU since the day of its first nuclear test. This policy has been reiterated by PRC leaders and in official statements countless times and has shaped decisions about nuclear posture and readiness. However, China's ongoing nuclear modernization suggests that the PLA intends to move toward a higher

[259] Office of the Secretary of Defense, US Department of Defense, *Military and Security Developments Involving the People's Republic of China*, 2022, p. 94.

[260] US Department of Defense, *2022 Nuclear Posture Review*, 2022.

[261] Fravel, *Active Defense: China's Military Strategy Since 1949*; Office of the Secretary of Defense, US Department of Defense, *Military and Security Developments Involving the People's Republic of China,* 2021; Cunningham and Fravel, "Assuring Assured Retaliation."

readiness Launch on Warning (LOW) posture.[262] This posture would require at least parts of China's nuclear force to be ready for launch within minutes of receiving an order to do so. Such a policy would represent both a major policy shift as well as a major shift in how the PRC operates its nuclear forces on a day-to-day basis. The 2019 Defense Intelligence Agency report *China Military Power* states that "the PLA is implementing a launch-on-warning posture" and likely believes that a LOW posture is consistent with its defensive NFU policy.[263] The logical justification is that if China responded to an incoming missile attack by choosing to launch its own missiles before it was struck, it would not be the first country to have "used" its nuclear weapons.

Nuclear declaratory policy

On October 16, 1964, the day of China's first successful atomic bomb test, the PRC government issued a statement declaring that the "PRC government hereby solemnly declares that China will never at any time and under any circumstances be the first to use nuclear weapons."[264]

In the decades following China's debut as a nuclear-armed state, PRC leaders declared their country a supporter of nuclear nonproliferation, joining the International Atomic Energy Agency (IAEA) in 1984.[265] In 1991, PRC Premier Li Peng met with IAEA Director General Hans Blix, stating "China's position is clear-cut, that is, China won't practice nuclear proliferation.

[262] The Defense Intelligence Agency characterizes LOW as "an approach to deterrence that uses heightened readiness, improved surveillance, and streamlined decision-making processes to enable a more rapid response to enemy attack." Defense Intelligence Agency, *China Military Power: Modernizing a Force to Fight and Win*, 2019, https://www.dia.mil/Portals/110/Images/News/Military_Powers_Publications/China_Military_Power_FINAL_5MB_20190103.pdf, p. 37; Office of the Secretary of Defense, US Department of Defense, *Military and Security Developments Involving the People's Republic of China,* 2021, p. 91; Fiona S. Cunningham, *Nuclear Command and Control and Communications Systems of the People's Republic of China*, Nautilus Institute for Security and Sustainability, July 18, 2019, https://nautilus.org/napsnet/napsnet-special-reports/nuclear-command-control-and-communications-systems-of-the-peoples-republic-of-china/.

[263] Fravel, *Active Defense: China's Military Strategy Since 1949*; Office of the Secretary of Defense, US Department of Defense, *Military and Security Developments Involving the People's Republic of China*, 2021, p. 91; Defense Intelligence Agency, *China Military Power: Modernizing a Force to Fight and Win*.

[264] "Statement of the Government of the People's Republic of China (October 16, 1964)"; for a complete translation of the Chinese document, see, "October 16, 1964, Statement of the Government of the People's Republic of China," Wilson Center, accessed Nov. 3, 2022, https://digitalarchive.wilsoncenter.org/document/134359.pdf?v=b1e04ac05705.

[265] Mingquan Zhu, "The Evolution of China's Nuclear Nonproliferation Policy," *The Nonproliferation Review* 45 (1997).

Meanwhile, we are against the proliferation of nuclear weapons by any other country."[266] At the same time, US officials harbored suspicions that beginning in the 1960s and persisting into the mid-1990s, the PRC was providing or had provided clandestine assistance for Pakistan's nuclear weapons program in contravention of its stated nonproliferation commitments.[267]

PRC leaders maintain adherence to their stated NFU nuclear doctrine and nonproliferation policy to this day.[268] On October 19, 2022, Chinese Ambassador for Disarmament Affairs Li Song gave a speech at the Thematic Discussion on Nuclear Weapons of the 77th Session of the United Nations General Assembly First Committee, stating that China "adheres to no first use of nuclear weapons at any time."[269]

Nuclear employment policy

Very little is known about China's nuclear employment policy because China does not publish information detailing employment of its nuclear forces. PRC writings describe this opacity as grounded in the concept of asymmetric nuclear deterrence. This understanding of deterrence presupposes that "the stronger side often reveals their nuclear forces," whereas the weaker side is more likely to "conceal their nuclear forces" to increase uncertainty and fear in the other side.[270] What can be gleaned from PRC public documents speaks in broad terms about China's concepts for national defense and the theoretical role of nuclear weapons and other conventional weapons with strategic effects in deterrence. The language employed in China's

266 Zhu, "The Evolution of China's Nuclear Nonproliferation Policy."

267 William Burr, "China, Pakistan, and the Bomb: The Declassified File on US Policy, 1977-1987," *National Security Archive Electronic Briefing Book No. 114*, Mar. 5, 2004.

268 "Full Text: China's National Defense in the New Era."

269 "Amb. Li Song's Speech at UNGA Thematic Discussion on Nuclear Weapons," China Global Television Network, Oct. 16, 2022, http://eng.chinamil.com.cn/view/2022-10/19/content_10193473.htm. No other country maintains an NFU policy except for India, although India's policy also has a conditionality clause. See Jasmine Owens and Tara Drozdenko, "Q&A: No First Use of Nuclear Weapons," Outrider, Mar. 19, 2019, https://outrider.org/nuclear-weapons/articles/qa-no-first-use-nuclear-weapons.

270 Wang Zhengda (王政达), "The Mechanism of Nuclear Deterrence: Capabilities, Signaling and Psychological Game (核威慑机理：实力基础、信号传递和心理博弈), *International Forum* (国际论坛) 1 (2022), as quoted in Kaufman and Waidelich, *PRC Writings on Strategic Deterrence: Technological Disruption and the Search for Strategic Stability*, p. 24.

Defense White Papers suggests that the PRC's nuclear employment policy is fundamentally based on deterrence through assured counterattack.[271]

For example, since 1964, PRC official documents and leaders' statements have emphasized that China maintains a nuclear force for self-defense and will use nuclear weapons only as a countermeasure in response to a nuclear attack. The PRC's 2019 Defense White Paper states that "China pursues a nuclear strategy of self-defense, the goal of which is to maintain national strategic security by deterring other countries from using or threatening to use nuclear weapons against China."[272] There is much debate among Western analysts whether China's retaliatory nuclear attack would be launched against military targets (counterforce) or against civilian targets (countervalue). While PRC official statements and public documents do not explicitly state the PRC's policy on counterforce versus countervalue targeting in a counterstrike scenario, thus lending to the Western debate, key Chinese military writings on nuclear deterrence discuss the role of counterforce and counter-military targeting in a second nuclear strike, not limiting the PRC to only countervalue options.[273]

In line with China's stated defensive nuclear employment policy, some Western analysts assess that China formerly maintained a low nuclear alert level for its nuclear arsenal because the PLA was believed to store the *majority* of its nuclear warheads separately from its missiles, which would need to be mated in preparation for a retaliatory strike.[274] The 2022 US DOD annual report to Congress on China's national defense states, however, that the PRC probably seeks to keep at least some of its nuclear force, particularly the new silo-based intercontinental ballistic missile (ICBM) units in Western China, on a higher alert level with a LOW posture.[275] China's posture is unlike the postures of the US or Russia, who keep many of their nuclear weapons on

[271] "Full Text: China's National Defense in the New Era."

[272] "Full Text: China's National Defense in the New Era."

[273] See for example Xue Xinglin, ed., Campaign Theory Study Guide (战役理论学习指南), Beijing: National Defense University Press (国防大学出版社), 2001, pp. 384–393; Zhao Xijun, ed., Deterrence Warfare: A Comprehensive Discussion of Missile Deterrence (慑战:导弹威慑综合谈) National Defense University Press (国防大学出版社), 2005, as quoted in M. Taylor Fravel and Evan S. Medeiros, "China's Search for Assured Retaliation-The Evolution of Chinese Nuclear Strategy and Force Structure," *International Security*, Vol. 35, No. 2 (2010), pp. 48–87.

[274] See for example, CSIS China Power Team, "How Is China Modernizing Its Nuclear Forces?" China Power, Dec. 10, 2019, updated Oct. 28, 2020, accessed Dec. 1, 2022, https://chinapower.csis.org/china-nuclear-weapons/; Gregory Kulacki, *China's Military Calls for Putting Its Nuclear Forces on Alert*, Union of Concerned Scientists, Jan. 2016, http://www.ucsusa.org/ChinaHairTrigger, p. 2.

[275] Office of the Secretary of Defense, US Department of Defense *Military and Security Developments Involving the People's Republic of China,* 2022, p. 99.

high alert with warheads mated to missiles in preparation for nuclear launch. If enacted, this change to a higher alert level would bring the PRC into closer alignment with the US and Russia regarding the high alert and readiness levels of their nuclear forces.[276]

However, authoritative PRC writings on military strategy suggest that there may be a debate within China about increasing the overall alert level of its strategic weapons. For example, the 2020 *Science of Military Strategy*, the PRC National Defense University's core textbook on military strategy, states that because China's nuclear employment policy is one of self-defense and assured retaliation, rapid response time is critical. The text states, "To improve the rapid response capability, it is necessary to increase the alertness of the strategic missile force and always maintain a high alert state."[277] This language suggests a possible move toward a posture in which nuclear warheads and delivery systems are mated and ready to be employed promptly.

How is China's nuclear program funded?

PRC defense spending, planning, and prioritization is opaque. The PRC does not publicly release its nuclear weapons program funding, specific figures for planned future defense spending, or a breakdown of defense spending priorities. However, the PRC does publish data on its yearly defense spending. By examining past defense budgets, growth in spending, and methodologies developed by nongovernmental organizations (NGOs) outside of China, we can make some informed estimates of the PRC's spending and priorities for its nuclear program—assuming that past patterns persist. For example, in 2021 the NGO International Campaign to Abolish Nuclear Weapons estimated that the PRC spent $11.7 billion that year developing its nuclear arsenal, or approximately 4 percent of its annual military spending.[278] The following sections summarize what we know about China's nuclear funding priorities and trends.

[276] National Defense University, *Science of Military Strategy*, p. 383.

[277] National Defense University, *Science of Military Strategy*, p. 383.

[278] The 11.7 billion USD is based on a percentage estimate of the PRC's overall 2021 defense budget and assumes that the PRC spends 4 percent of its budget on nuclear forces. Different estimates of the overall budget or nuclear spending levels could substantially alter this estimate. ICAN, *2021 Global Nuclear Weapons Spending Report*, June 14, 2022, https://www.icanw.org/spending_report.

Nuclear and defense funding priorities

China focuses its defense spending on the modernization of its armed forces to fulfill growing domestic and international missions in support of its national security interests. The priorities that it sets for defense spending are based on its assessment of its current and future security environment. Analysis of recently published PRC official documents and statements, however, helps to clarify China's long-term defense spending priorities and nuclear program goals.

DOD has determined that part of the PRC's military modernization efforts will focus on improving, updating, and increasing China's nuclear arsenal and delivery systems and building a survivable nuclear triad of ground-, air-, and sea-based nuclear weapons.[279]

The 2022 DOD National Defense Strategy assesses that the PRC continues to make dramatic advances in its conventional and nuclear-armed ballistic and hypersonic missile capabilities, "in many areas continu[ing] to close the gap with the United States…[and] to develop and expand its missile capabilities."[280]

Nuclear program spending and trends

China's defense spending has historically been pegged to a percentage of its gross domestic product (GDP), which was projected in 2020 to grow 4 to 5 percent annually over the next decade.[281]

According to its 2019 Defense White Paper, China spent on average 1.3 percent of its GDP each year on defense from 2012 to 2017.[282] Outside sources, however, estimate that China spends

[279] Office of the Secretary of Defense, US Department of Defense, *Annual Report to Congress: Military and Security Developments Involving the People's Republic of China,* 2022.

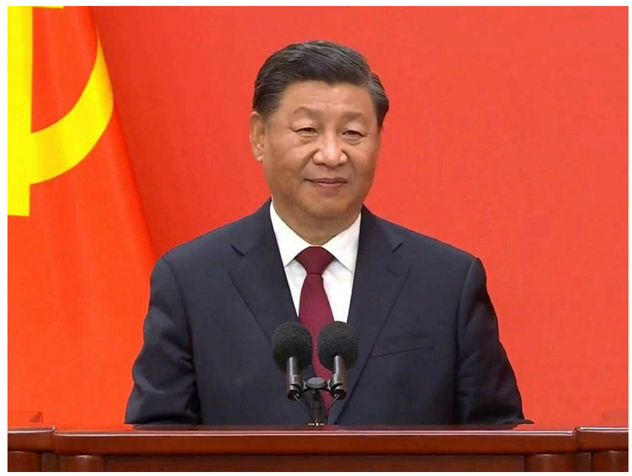
[280] US Department of Defense, *2022 National Defense Strategy of the United States of America*, 2022, https://media.defense.gov/2022/Oct/27/2003103845/-1/-1/1/2022-NATIONAL-DEFENSE-STRATEGY-NPR-MDR.PDF.

[281] Because China is a partially planned economy, China's government sets economic growth targets each year and then directs government spending at all levels toward meeting these targets. Defense spending is similarly planned and directed, and China's defense industrial base builds to meet annual defense spending targets. Such defense spending targets are set about four to six months ahead of major Communist Party meetings at which annual economic targets are announced, such as those that were announced at the 2020 Fifth Plenum of the 19th Central Committee of the Chinese Communist Party. See "Regular Press Conference of the Ministry of National Defense on November 26," China Military Online, Nov. 26, 2020, http://eng.chinamil.com.cn/view/2020-11/29/content_9944372.htm.

[282] "Full Text: China's National Defense in the New Era," p. 38.

more on defense than it publicly reports. The Office of the Secretary of Defense, for instance, notes that China omits from its official defense spending reports money spent on research and development (R&D) and foreign weapons procurement programs.[283] The Stockholm International Peace Research Institute estimates that from 2000 to 2019 China's defense spending was pegged at 2 percent of its annual GDP on average.[284]

Figure 24. Chinese President Xi Jinping



Source: Photo by China News Service via Wikimedia Commons.

Xi Jinping's 2022 speech referencing the importance of building a "strategic deterrence system" suggests that China's defense spending over the next five years will emphasize developing China's strategic deterrence capabilities. As China updates its nuclear arsenal, it seems likely to focus not only on maintaining second-strike survivability but also on gaining a technological edge through the development of advanced systems, such as nuclear-capable hypersonic glide vehicles (HGVs).[285]

During the March 2023 National People's Congress, PRC officials announced that China will increase defense spending by 7.2 percent in 2023.[286] This increase in military spending is slightly higher than the previous year's 7.1 percent growth increase and exceeds the government's 2023 economic growth target of around 5 percent. The PRC's continued uptick in military spending despite sluggish economic growth during the COVID-19 pandemic, with 2022 GDP growth estimated to have

283 Office of the Secretary of Defense, US Department of Defense, *Military and Security Developments Involving the People's Republic of China,* 2022.

284 "SIPRI Military Expenditure Database," Stockholm International Peace Research Institute, accessed Feb. 22, 2021, https://www.sipri.org/databases/milex.

285 "China," Nuclear Threat Initiative, https://www.nti.org/learn/countries/china/nuclear/.

286 "Update: China's 2023 Defense Budget to Rise by 7.2 pct, Remaining Single-Digit for 8th Year," Xinhua, Mar. 5, 2023, https://english.news.cn/20230305/dd575f79ce5b4f379e42a7b44fe8ed68/c.html.

fallen to 3 percent,[287] signals that the PRC continues to prioritize its military modernization and development under Xi Jinping.

What activities is China's nuclear program engaged in?

China's efforts to modernize and diversify its delivery systems involve using existing stockpiles of fissile material, producing new fissile material, building new nuclear weapons, and developing and testing new nuclear weapons delivery systems.

Fissile material stockpile and production

China's production of highly enriched uranium (HEU) and plutonium for nuclear weapons began in the 1960s, and China is reported to have halted production in the 1980s.[289] China's stockpile of fissile materials is estimated to include 14 ± 3 metric tons of HEU and 2.9 ± 0.6 metric tons of weapons-grade plutonium.[290] According to Western nuclear experts, China's current inventories can readily support a doubling of its nuclear weapons stockpile. However, if China wanted to triple or quadruple its inventory, it would need to produce more fissile material.[291] Given that China likely ended its military

> A fast breeder reactor is a type of nuclear reactor that creates more fissile material than it consumes while generating power. Civilian fast breeder reactors coupled with plutonium reprocessing plants could be used to produce weapons-usable plutonium.[288]

[287] "The World Bank in China," The World Bank, accessed June 27, 2023, https://www.worldbank.org/en/country/china/overview#:~:text=Following%20China's%20swift%20reopening%20after,in%20demand%2C%20particularly%20for%20services.

[288] Henry D. Sokolski, *China's Civil Nuclear Sector: Plowshares to Swords*, Nonproliferation Policy Education Center, 2021.

[289] Hui Zhang, *China's Fissile Material Production and Stockpile*, International Panel on Fissile Materials, 2018, accessed Nov. 4, 2022, https://fissilematerials.org/library/rr17.pdf; "Country Profile: China," International Panel on Fissile Materials, May 2, 2022, https://fissilematerials.org/countries/china.html.

[290] Zhang, *China's Fissile Material Production and Stockpile*.

[291] Hans M. Kristensen and Matt Korda, "Chinese Nuclear Weapons, 2021," *Bulletin of the Atomic Scientists* 77, no. 6 (2021): 318–336, doi: 10.1080/00963402.2021.1989208.

production of plutonium, nuclear experts assess that it is "reasonable to assume that beyond existing stocks, if China desired additional plutonium for weapons prior to 2030, it could turn to its civil reactors for additional plutonium."[292] This use of civil reactors for military purposes could be accomplished, in theory, under the PRC's "military-civil fusion" plan, a national strategy aimed at the "elimination of barriers between China's civilian research and commercial sectors, and its military and defense industrial sectors."[293]

In July 2016, the PRC's *13th Five Year National S&T Innovation Plan* outlined a list of National Science and Technology Megaprojects, calling for R&D funds to support national defense basic research projects to be carried out by military and civilian research institutions in a coordinated manner.[294] This list includes mention of "advanced pressurized water nuclear reactors and high-temperature gas-cooled reactors."[295]

In 2017, China began construction of a sodium-cooled pool-type fast neutron nuclear reactor in Xiapu County, Fujian province.[296] Russia's TVEL Fuel Company (a subsidiary of Rosatom) is supplying the fuel for the reactor as well as the fuel assembly and reactor-control and protection components according to a 2018 Sino-Russian agreement for comprehensive cooperation in nuclear energy.[297] In December 2020, the China National Nuclear Corporation announced that construction work had begun on a second unit at the plant. According to US nuclear experts, the spent fuel used in these civil reactors could be reprocessed into weapons-grade plutonium.[298] Although there is no evidence that China is currently doing so, the 2022

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292 Sokolski, *China's Civil Nuclear Sector: Plowshares to Swords*, p. 14.

293 US Department of State, "Military-Civil Fusion and the People's Republic of China," accessed June 28, 2023, https://www.state.gov/wp-content/uploads/2020/05/What-is-MCF-One-Pager.pdf.

294 "State Council's Notice on the Release of the 13th Five Year National Science and Technology Innovation Plan" (国务院关于印发"十三五"国家科技创新规划的通知), July 28, 2016, http://www.gov.cn/zhengce/content/2016-08/08/content_5098072.htm.

295 For an in-depth analysis of military-civil fusion, see Alex Stone and Peter Wood, *China's Military-Civil Fusion Strategy: A View from Chinese Strategists*, China Aerospace Studies Institute, June 15, 2020, https://www.airuniversity.af.edu/Portals/10/CASI/documents/Research/Other-Topics/2020-06-15%20CASI_China_Military_Civil_Fusion_Strategy.pdf.

296 IAEA, *CFR-600 (China Institute of Atomic Energy, China)*, accessed Dec. 3, 2022, https://aris.iaea.org/PDF/CFR-600.pdf.

297 "Russia Completes Fuel Deliveries for China's CFR-600 Fast Reactor," *Nuclear Engineering International*, Jan. 3, 2023, https://www.neimagazine.com/news/newsrussia-completes-fuel-deliveries-for-chinas-cfr-600-fast-reactor-10486493.

298 Sokolski, *China's Civil Nuclear Sector: Plowshares to Swords*,.

DOD assessment indicates that China will likely use this civilian reprocessing infrastructure in the near term to produce nuclear warhead material in support of its nuclear force expansion.[299] After the March 2023 Xi-Putin summit, however, Russian and Chinese nuclear energy officials agreed to collaborate in producing HEU fuel and in handling spent fuel.[300]

China also can mine uranium from within its borders. According to recent discoveries, China's uranium deposits are believed to be about as substantial as those of Australia, the world's third-largest producer of uranium and the location of one-third of the world's uranium resources. Nevertheless, Chinese uranium is of relatively poor quality and difficult as well as costly to access. Consequently, China produces only one-third of the uranium it requires.[301] It must obtain the remainder on the open market and through its equity investments despite its aspiration to become self-sufficient in the production of nuclear fuel.[302]

To ensure long-term supply, since the mid-2000s, the Chinese government has followed a policy of "facing two markets and using two kinds of resources" involving domestic production and overseas sourcing through investment and trade. The PRC nuclear industry has followed the "three one-thirds" rule, with one-third of China's uranium coming from domestic reserves, one-third from foreign investments, and one-third from trade, although Chinese officials aim to increase the domestic component to as much as 40 to 50 percent.[303] China primarily imports natural uranium (rather than enriched uranium), and Kazakhstan accounts for 47 percent of

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299 Office of the Secretary of Defense, US Department of Defense, *Military and Security Developments Involving the People's Republic of China*, 2021, p. 96.

300 "China and Russia Sign Fast-Neutron Reactors Cooperation Agreement: Nuclear Policies," World Nuclear News, Mar. 22, 2023, https://www.world-nuclear-news.org/Articles/China-and-Russia-to-cooperate-on-fast-neutron-reac; Echo Xie, "Russia Confirms Enriched Uranium Supplies to China," *South China Morning Pos*t, May 5, 2023, https://www.scmp.com/news/china/science/article/3219424/russia-confirms-enriched-uranium-supplies-china.

301 Australian Safeguards and Non-Proliferation Office, *Annual Report 2018-2019*, https://www.dfat.gov.au/publications/corporate/asno-annual-report-2018-19/site/section-2/australias-uranium-production-and-exports.html.

302 Stephen Chen, "China Finds Uranium at Impossible Depths," *South China Morning Post*, May 30, 2022, https://www.scmp.com/news/china/science/article/3179441/china-finds-uranium-impossible-depth-scientists.

303 Hui Zhang and Yunsheng Bai, *China's Access to Uranium Resources*, Harvard University Kennedy School, Belfer Center for Science and International Affairs, May 2015, p. 29, https://www.belfercenter.org/sites/default/files/files/publication/chinasaccesstoruraniumresources.pdf.

China's imports and 45 percent of the global supply.[304] China has invested in mines and nuclear fuel production in Kazakhstan as well as Uzbekistan, Namibia, Niger, Australia, and Canada.[305]

Nuclear weapons work

China's nuclear weapons work is shrouded in secrecy. China does not publish information on the size of its nuclear arsenal or the numbers of its delivery systems. What is known of China's arsenal is based on estimates from Western scientists and nuclear experts, the US government, (notably DOD), and unclassified intelligence community reporting. One US expert who participated in a series of 10 lab-lab exchanges with the PRC and toured key PRC nuclear weapons–related facilities between 1990 and 2001 judged that at the time, "Chinese nuclear weapons technology is on par with that of the United States."[306]

In tandem with the widespread reform and modernization of its military, China is seeking to achieve a survivable nuclear triad by developing and upgrading air-, sea-, and land-based nuclear delivery systems. According to DOD, China is developing new ICBMs that will improve its nuclear-capable missile forces. These new missiles will require China to increase its nuclear warhead production, partly because of the incorporation of multiple independently targetable reentry vehicle (MIRV) capabilities into the missile platform.[307]

Although the PRC publishes little information on the specifics of its nuclear forces, some Chinese and Western sources provide clues for understanding China's nuclear weapons work.

Nuclear weapons delivery system development

PLA Air Force

Part of China's work to achieve a nuclear triad involves upgrading its strategic bomber wing to include nuclear delivery. In October 2019, during the PRC's 70th anniversary military parade,

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[304] "China Uranium Resource Import 2022: Import Analysis 2018-2022 and Outlook 2023-2032," Globe Newswire, Dec. 23, 2022, https://www.globenewswire.com/news-release/2022/12/23/2579035/28124/en/China-Uranium-Resource-Import-2022-Import-Analysis-2018-2022-and-Outlook-2032-2032.html.

[305] Genevieve Donnellon-May, "Powering China's Nuclear Ambitions," *The Diplomat*, Sept. 20, 2022, https://thediplomat.com/2022/09/powering-chinas-nuclear-ambitions/.

[306] Danny B. Stillman, "Notes on D.B. Stillman's Ten Visits to the Chinese Nuclear Weapon Complex, 1990-2001," In *The Nuclear Express: A Political History of the Bomb and its Proliferation*, ed. Thomas Reed and Danny Stillman (Zenith Press, 2009).

[307] Office of the Secretary of Defense, US Department of Defense, *Military and Security Developments Involving the People's Republic of China*, 2021.

the PLA Air Force (PLAAF) displayed the newest version of its H-6 bomber: the H-6N strategic bomber.[308] According to DOD assessments in 2020, the H-6N has been associated with an air-launched ballistic missile (ALBM) platform with the US designation CH-AS-X-13.[309] In addition, the PLAAF is developing a new H-20 stealth strategic bomber capable of carrying both nuclear and conventional payloads, which would greatly expand China's power projection capabilities.[310]

PLA Navy

The sea leg of China's nuclear triad could extend the range of its nuclear deterrent and allow the PLA Navy (PLAN) to reach the United States from its littoral waters. The PLAN currently operates six operational Jin-class nuclear-powered ballistic missile submarines (SSBNs), each capable of carrying 12 JL-2 or JL-3 submarine-launched ballistic missiles (SLBMs).[311] In 2019, China displayed 12 of the JL-2 nuclear-capable missiles during its 70th anniversary military parade, indicating that the PLA can outfit at least one SSBN with a full nuclear complement.[312]

The 2020 *Science of Military Strategy*, one of China's core textbooks on military strategy, states that sea-based nuclear forces have distinct advantages over the other two legs of the nuclear triad. The text explains, "Compared with land-based and space-based nuclear forces, sea-based nuclear forces have the advantages of strong survivability, a wide range of maneuverability, and large strike power, and they have the capability of a second nuclear strike."[313] However, submarine survivability largely hinges on how quiet the submarines are. Unclassified assessments of China's Jin-class SSBNs suggest that they are comparable to 1970s Soviet SSBNs and considerably noisier than the contemporary SSBNs of both Russia and the United States.[314]

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[308] "70th Anniversary Military Parade: Bomber Echelon H-6N" (70 周年大阅兵：轰炸机梯队轰-6N), China Central Television, Oct. 1, 2019, http://v.cctv.com/2019/10/01/VIDEu0VAz5zMMNT5faPGRZoS191001.shtml.

[309] Office of the Secretary of Defense, US Department of Defense, *Military and Security Developments Involving the People's Republic of China*, 2022.

[310] Office of the Secretary of Defense, US Department of Defense, *Military and Security Developments Involving the People's Republic of China*, 2021, p. 60.

[311] Office of the Secretary of Defense, US Department of Defense, *Military and Security Developments Involving the People's Republic of China*, 2021, p. 60.

[312] "70th Anniversary Military Parade: Bomber Echelon H-6N."

[313] National Defense University, *Science of Military Strategy*, p. 156.

[314] Tong Zhao, *Tides of Change: China's Nuclear Ballistic Missile Submarines and Strategic Stability*, Carnegie Endowment for International Peace, 2018, https://carnegieendowment.org/2018/10/24/tides-of-change-china-s-nuclear-ballistic-missile-submarines-and-strategic-stability-pub-77490.

PLA Rocket Force

Since at least 2012, China has been upgrading, diversifying, and improving its ground-based strategic missile arsenal.[315] These improvements include the standup of the PLA Rocket Force (PLARF, formerly the PLA second artillery) as a new service in late 2015. Today, the PLARF is tasked with manning, training, and equipping the force that controls China's ground-based strategic nuclear arsenal and conventional ballistic missile force. In addition to this major organizational change, the PRC has unveiled several new missile systems, including the following:[316]

- ICBMs with MIRV capabilities
- Intermediate-range ballistic missiles (IRBMs)
- Ground-based cruise missiles
- HGVs capable of carrying an ICBM into space for a fractional orbital launch

In addition, China has been rapidly constructing up to 300 ICBM silos in sites in the western and central-northern part of the country, significantly improving the PLARF's nuclear-capable missile force (see Figure 25).[317] For decades, China has operated only around 20 ICBM silos housing DF-5 liquid-fueled ICBMs. The rapid construction of new silo fields greatly expands the PLARF's ability to house DF-5 ICBMs—once completed, the number of ICBM silos will be well over ten times those in operation today. Whether these 300 silos will all be loaded with ICBMs or whether a portion will be used as empty decoys to improve the overall survivability of the PRC's ICBM force is currently unclear.[318]

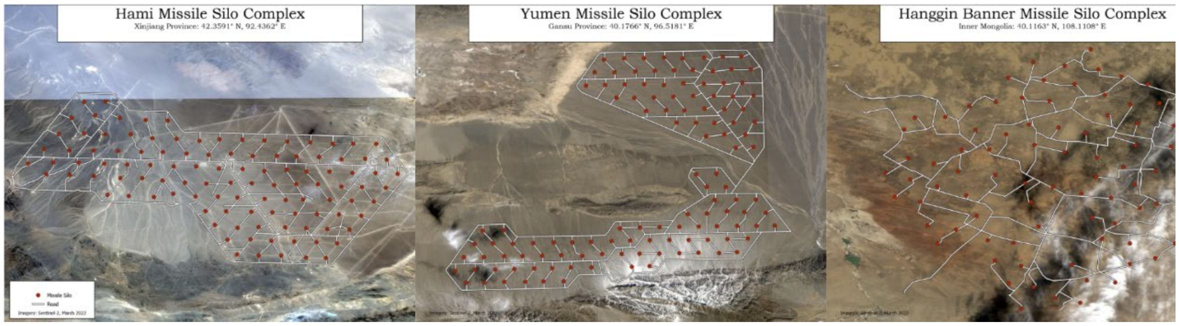
[315] "The PLA Rocket Force Focuses on Preparing for and Fighting Wars, Accelerates the Promotion of Strategic Capabilities: The New Type Missile Phalanx Forms the Long Sword of a Great Power" (火箭军聚焦备战打仗加速推动战略能力提升 新型导弹方阵铸就大国长剑), *PLA Daily*, Aug. 8, 2022, http://military.cnr.cn/jq/20220808/t20220808_525954319.shtml.

[316] Office of the Secretary of Defense, US Department of Defense, *Military and Security Developments Involving the People's Republic of China*, 2022.

[317] Office of the Secretary of Defense, US Department of Defense, *Military and Security Developments Involving the People's Republic of China*, 2022, p. 64.

[318] Matt Korda and Hans Kristensen, "China Is Building a Second Nuclear Missile Silo Field," Federation of American Scientists, July 26, 2021, https://fas.org/blogs/security/2021/07/china-is-building-a-second-nuclear-missile-silo-field/.

Figure 25. PLARF ICBM fields at Hami, Yumen, and Hanggin Banner



Source: Sentinel-2 satellite image via Tearline.mil.

Nuclear weapons and delivery system testing

China conducted 47 nuclear tests from 1964 through 1996, 23 of these in the Earth's atmosphere.[319] The tests were conducted at the Lop Nur testing site in the Xinjiang Autonomous Region in Western China.[320] In 1996, China stated that it ceased nuclear testing when it signed the Comprehensive Nuclear-Test-Ban Treaty (CTBT) banning nuclear weapons tests. China, along with the US, Egypt, Iran, and Israel, has signed but not yet ratified the treaty.[321] In July 2021, satellite imagery showed the construction of new facilities at the Lop Nur nuclear test site, including the digging of a new tunnel and construction of roads around the site, although the purpose of the new construction was unclear.[322]

In addition, the PLARF regularly conducts live-fire testing of its conventional and nuclear-capable missiles. In a widely publicized test in June 2021, the PLARF conducted a nighttime launch of its DF-26 IRBM, which is capable of nuclear or conventional strikes against naval

[319] Center for Nonproliferation Studies, Monterey Institute of International Studies, *China's Nuclear Tests: Dates, Yields, Types, Methods, and Comments*, June 1998, http://cns.miis.edu/archive/country_china/coxrep/testlist.htm.

[320] "China's Nuclear Tests," Atomic Archive, https://www.atomicarchive.com/almanac/test-sites/prc-testing.html.

[321] "Comprehensive Test Ban Treaty (1996)," Atomic Archive, accessed Dec. 3, 2022, https://www.atomicarchive.com/resources/treaties/ctbt.html.

[322] Geof Brumfiel, "A New Tunnel Is Spotted at a Chinese Nuclear Test Site," NPR, July 30, 2021, https://www.npr.org/2021/07/30/1022209337/a-new-tunnel-is-spotted-at-a-chinese-nuclear-test-site.

targets.[323] The test was significant for the PLARF because night launches are generally regarded as more challenging than daytime launches. The DF-26 used in the exercise has a range of 3,000 to 4,000 kilometers, capable of striking US Navy carriers in the South China Sea as well as US military assets on the US territory of Guam.[324]

How does China command and control its nuclear forces?

Little is found in open sources about China's evolving nuclear command and control practices. What sparse information exists may be unreliable or outdated. The available information suggests that the PRC is continuing its long-standing practice of keeping nuclear decision-making authority highly centralized—specifically in the hands of President Xi Jinping. In addition, the PRC appears to be improving its early warning systems, which are currently quite limited. Although there are several plausible explanations for these early warning upgrades, some Western analysts speculate that this step could be part of a decision to move PRC nuclear forces to a higher state of alert that would allow them to be launched promptly upon warning of an incoming nuclear attack.[325]

Decision-making

The Central Military Commission (CMC) is the highest authority in the PLA.[326] The CMC's membership changes every five years as new members are chosen during the CCP National

[323] Liu Xuanzun, "PLA Rocket Force Practices Night DF-26 Missile Launch," *Global Times*, June 9, 2021, https://www.globaltimes.cn/page/202106/1225886.shtml.

[324] "DF-26 'Guam Express' IRBM," Global Security, accessed Dec. 14, 2022, https://www.globalsecurity.org/wmd/world/china/df-26.htm.

[325] See, for example, Austin Long, "Myths or Moving Targets? Continuity and Change in China's Nuclear Forces," War on the Rocks, Dec. 2020, https://warontherocks.com/2020/12/myths-or-moving-targets-continuity-and-change-in-chinas-nuclear-forces/; Patty-Jane Geller, "China's Nuclear Expansion and Its Implications for U.S. Strategy and Security," The Heritage Foundation, Sept. 14, 2022, https://www.heritage.org/missile-defense/commentary/chinas-nuclear-expansion-and-its-implications-us-strategy-and-security; Office of the Secretary of Defense, US Department of Defense, *Military and Security Developments Involving the People's Republic of China*, 2022, p. 93-94; Charles A. Richard, "Statement of Charles A. Richard Commander United States Strategic Command Before the Senate Committee on Armed Services 20 April 2021," *Senate Committee on Armed Services*, April 20, 2021, p.7, https://www.armed-services.senate.gov/imo/media/doc/Richard04.20.2021.pdf.

[326] "CMC," Ministry of Defense of the People's Republic of China, accessed Dec. 3, 2022, http://eng.mod.gov.cn/cmc/index.htm.

Congress, but it typically consists of seven members—a civilian chief and uniformed generals and flag officers.[327] The CMC's chairman and only civilian member is Xi Jinping, who orders and oversees PLA military operations, including nuclear operations. [328] There is scant publicly available information detailing the decision-making process for nuclear use. A 2017 report by a US think tank argues that for the purpose of nuclear retaliation, or even nuclear signaling, "the CMC would make all the key decisions, including scale, timing, and targets."[329] A 2019 report by another US NGO further states that because Xi Jinping is the only civilian member of the CMC, the decision will probably, in effect, be his alone.[330] A 2022 analysis of the PLARF by a Western defense think tank states that while "nuclear forces are subordinate to their individual bases, [… they] are placed under direct operational control of the CMC."[331]

In addition, the process for nuclear decision-making in the event that Xi Jinping is killed or incapacitated is unknown.[332] One think tank report notes that possible successors include the prime minister (as of March 2023 Li Qiang, the second-in-command who is not a member of the CMC) and the military officers who are the vice chairmen of the CMC but not members of the Politburo Standing Committee (as of March 2023 He Weidong and Zhang Youxia, who are military officers). However, the report concludes that "unexpected incapacitation [of Xi] would likely set off a succession crisis." [333] One report alleges the existence of a PLA Central Emergency Command Center under the Yuquanshan Mountain outside of Beijing that is

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327 Brian Waidelich, "China's New Military Leadership Possible Strengths and Weaknesses," *InDepth (CNA blog),* accessed Dec. 3, 2022, https://www.cna.org/our-media/indepth/2022/11/chinas-new-miliatry-leadership-possible-strengths-and-weaknesses.

328 Lewis and Tertrais, *The Finger on the Button: The Authority to Use Nuclear Weapons in Nuclear Armed States*; Logan, "Making Sense of China's Missile Forces."

329 Heginbotham et al., *China's Evolving Nuclear Deterrent: Major Drivers and Issues for the United States*, p. 22..

330 Lewis and Tertrais, *The Finger on the Button: The Authority to Use Nuclear Weapons in Nuclear Armed States*; Tellis, *Striking Asymmetries: Nuclear Transitions in Southern Asia*, p. 35.

331 Ma Xiu, "PLA Rocket Force Organization: Executive Summary," *China Aerospace Studies Institute*, January 5, 2022, p. 2, https://www.airuniversity.af.edu/Portals/10/CASI/documents/Research/PLARF/2022-01-05%20PLARF%20Organization%20ExecSum.pdf.

332 Lewis and Tertrais, *The Finger on the Button: The Authority to Use Nuclear Weapons in Nuclear Armed States*.

333 Lewis and Tertrais, *The Finger on the Button: The Authority to Use Nuclear Weapons in Nuclear Armed States*, p. 21.

intended to provide continuity of government.[334] However, it is unclear whether and how this facility would be used in a crisis or war, whether PRC leaders might relocate there, and what roles they might play in nuclear decision-making.

Early warning and command, control, and communications

The PRC's early warning system consists of ground-based large phased-array radars (LPARs) and at least one ballistic missile early warning satellite,[335] although US-based nongovernment nuclear experts assessed in 2019 that the satellite is likely not advanced enough to provide PRC leadership much notice of attack.[336] As a result, China's command and control system as a whole may encounter additional time-latency challenges flowing from a possible lag in early warning information.

A LOW posture would enable a country to launch some or all of its nuclear weapons following a warning of an incoming adversarial strike. In some cases, there may be a perceived benefit to launching these weapons before they are destroyed—called the "use it or lose it" phenomenon. Such a posture would require quick and reliable early warning as well as nuclear command, control, and communications capabilities.

Many experts predict that China will endeavor to advance the capabilities of its early warning system in coming years.[337] Within the PRC's 2015 Defense White Paper, China pledged to "improve strategic early warning" and its other command and control capabilities.[338] Such

[334] Peter Hayes, *Nuclear Command, Control, and Communications (NC3) in Asia Pacific*, Asia-Pacific Leadership Network, 2021, https://www.whytrident.uk/__data/assets/pdf_file/0018/17415/Peter-Hayes_NC3_AsiaPacific.pdf; "Yuquan Shan Mountain," FAS Weapons of Mass Destruction, https://nuke.fas.org/guide/china/facility/yuquan_shan.htm.

[335] Office of the Secretary of Defense, US Department of Defense, *Military and Security Developments Involving the People's Republic of China,* 2021, p. 94.

[336] Cunningham, *Nuclear Command and Control and Communications Systems of the People's Republic of China*. For a more comprehensive overview of China's early warning (more broadly defined) and nuclear command, control, and communications systems, see Elsa Kania, "China's Strategic Situational Awareness Capabilities," *On the Radar (CSIS blog)*, July 29, 2019, https://ontheradar.csis.org/issue-briefs/china-situational-awareness/.

[337] Cunningham, *Nuclear Command and Control and Communications Systems of the People's Republic of China*; Defense Intelligence Agency, *China Military Power: Modernizing a Force to Fight and Win*, p. 37; Kania, "China's Strategic Situational Awareness Capabilities."

[338] Kania, "China's Strategic Situational Awareness Capabilities."

improvement includes installing additional radars[339] and developing a more advanced space-based early warning capability, which would better support a LOW posture by providing more warning time to characterize the attack, consider and select from response options, and prepare the forces; however, this capability may not be ready for several more years.[340] In October 2019, Russian President Vladimir Putin revealed that Russia was assisting China to develop an early warning system that he predicted would "drastically increase China's defense capability."[341] Because of Russia's location in the flight path that ICBMs would follow if launched from the US against China, the PRC's ability to detect and react to ICBM launches would be increased substantially if it accepted this offer of assistance. Satellite imagery shows a new LPAR array was built sometime after November 2019 onto to an existing mountaintop site in Yiyuan County, Shandong province, although it is unknown whether this is the result of Russian assistance. This new array is pointed northeast, potentially giving China early warning of ballistic missile launches from North and South Korea, most of Japan, and even parts of Russia's Far East.[342]

339 Mike Yeo, "New Chinese Radar Looks Toward Japan, Satellite Image Shows," Defense News, Apr. 18, 2022, https://www.defensenews.com/global/asia-pacific/2022/04/18/new-chinese-radar-looks-towards-japan-satellite-image-shows/.

340 Cunningham, *Nuclear Command and Control and Communications Systems of the People's Republic of China*.

341 "Valdai Discussion Club Session," President of Russia, Oct. 3, 2019, http://en.kremlin.ru/events/president/news/61719. Also see Office of the Secretary of Defense, US Department of Defense, *Military and Security Developments Involving the People's Republic of China*, 2021, p. 94.

342 Yeo, "New Chinese Radar Looks Toward Japan, Satellite Image Shows."

Nuclear-armed states have two basic options for granting nuclear use authority. **Centralization** is the tight central control—typically by an individual—over nuclear weapons to prevent instances of theft or unauthorized use. In contrast, **pre-delegation** pushes nuclear launch authority down to one or more subordinate leaders. This authority may be conditional on certain criteria having been met—for example, enemy nuclear attack. Pre-delegation may mitigate the risk that a country would be unable to retaliate if its leader is killed or incapacitated. However, pre-delegation also increases the risk of mistaken or unauthorized nuclear use.

The PRC's modern nuclear command, control, and communications infrastructure is generally not discussed in the public domain. However, analysts believe that the PLARF has military communication satellites and fiber-optic networks that were laid during the 1990s and early 2000s.[343] These systems may support both conventional and nuclear operations.[344]

These early warning systems are linked to manned command and control stations that can transmit attack assessment information to the CMC for deliberation.[345] If Xi or the CMC decided to place nuclear weapons on alert or their launch, the CMC would likely transmit the orders to the Joint Operations Command Center and then to the PLARF Headquarters, the subordinate missile bases, and ultimately to the respective launch brigades.[346] However, some reports note that some of these bodies may be bypassed in the chain of command when required, using an automated system to skip echelons when passing orders down the chain of command.[347]

343 Cunningham, *Nuclear Command, Control, and Communications Systems of the People's Republic of China*,.

344 Hayes, *Nuclear Command, Control, and Communications (NC3) in Asia Pacific*; "Yuquan Shan Mountain"; Cunningham, *Nuclear Command and Control and Communications Systems of the People's Republic of China*.

345 Office of the Secretary of Defense, US Department of Defense, *Military and Security Developments Involving the People's Republic of China*, 2022, p. 94.

346 Cunningham, *Nuclear Command and Control and Communications Systems of the People's Republic of China*; Bates Gill, "Organization of China's Strategic Forces," in *China's Strategic Arsenal: Worldview, Doctrine, and Systems*, ed. James M. Smith and Paul J. Bolt (Washington, DC: Georgetown University Press, 2021), 159–194 (as cited in Tellis, *Striking Asymmetries: Nuclear Transitions in Southern Asia*, p. 57).

347 Cunningham adds: "To ensure the survivability of command over nuclear missile units, command of those units is organized into basic (*jiben*), reserve (*yubei*), and rear (*houfang*) command posts. As appropriate, the missile

China is known to prioritize negative control of its nuclear weapons, meaning that strict centralization and extensive barriers are in place to prevent unauthorized access.[348]A 2022 DOD assessment indicates that China may be adjusting at least some of these nuclear weapons to a higher alert level.[349] Some analysts report that the PRC also employs a "two-man rule" to enable nuclear launch to make an unauthorized launch less likely.[350] One report also notes that "there is no evidence that Chinese leaders have pre-delegated authority to use nuclear weapons down the chain of command if [China's] leadership is decapitated."[351]

While the PRC continues to prioritize negative control of its nuclear weapons, it is also moving toward the goal of being able to retaliate faster following an adversary nuclear attack, which has led to some recent changes in PLARF training.[352] For example, the aforementioned 2022 DOD report states that nuclear PLARF brigades conduct drills of "combat readiness duty" and "high alert duty." According to the report, China views such a posture as "conceptually comparable" to the level of alert kept by portions of US and Russian nuclear forces.[353]

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force may also establish forward (*qianjin*) and directional; (*fangxiang*) command posts. Reserve and rear command posts are only staffed at the second and third tiers of China's alert levels, when missile units are preparing and actually ready to carry out launch orders." Cunningham, *Nuclear Command and Control and Communications Systems of the People's Republic of China*; also noted in Gill, "Organization of China's Strategic Forces" (as cited in Tellis, *Striking Asymmetries: Nuclear Transitions in Southern Asia*, p. 57).

[348] Fiona Cunningham even adds: "Where Chinese leaders have faced trade-offs between the requirements of strict control and survivability of the missile force in the past, they have prioritized strict control." Cunningham, *Nuclear Command and Control and Communications Systems of the People's Republic of China*; Heginbotham et al., *China's Evolving Nuclear Deterrent: Major Drivers and Issues for the United States*, p. 21.

[349] Office of the Secretary of Defense, US Department of Defense, *Military and Security Developments Involving the People's Republic of China*, 2022, p. 99.

[350] "Command and Control."

[351] Cunningham, *Nuclear Command and Control and Communications Systems of the People's Republic of China*; Office of the Secretary of Defense, US Department of Defense, *Military and Security Developments Involving the People's Republic of China*, 2021, p. 91; Kristensen and Korda, "Chinese Nuclear Weapons"; Congressional Research Service, *China's Military: The People's Liberation Army (PLA)*, p. 19.

[352] Tellis, *Striking Asymmetries: Nuclear Transitions in Southern Asia*, p. 61.

[353] Office of the Secretary of Defense, US Department of Defense, *Military and Security Developments Involving the People's Republic of China*, 2022, p. 99.

What nuclear weapons–related R&D has China undertaken?

The PRC prioritizes maintaining a second-strike capability for its nuclear weapons program. Although perceived Soviet and US threats during the Cold War era provided the initial impetus, today China is modernizing, diversifying, and increasing its nuclear arsenal to ensure its deterrent capability in response to rapidly advancing global military technologies and perceived pressure from the US and its Indo-Pacific allies, who are expanding their own military capabilities and deepening security cooperation, as well as the potential for conflict over Taiwan and in the South China Sea.

China's nuclear weapons activities, including its R&D efforts, have evolved rapidly in the past two to three years following decades of slow, relatively predictable evolution. This section draws on open-source reporting and analysis from Chinese media, US and Chinese academic work, open-source satellite imagery, and other open sources.

China is a maturing nuclear state. It has fielded advanced nuclear weapons including thermonuclear and miniaturized warheads, and, according to the above noted 2022 US DOD report, could be considering fielding lower yield nuclear weapons in the future.[354] These warheads have been mated with a variety of delivery systems including ground-based, mobile medium-range ballistic missiles (MRBMs) and IRBMs, silo-based ICBMs, SLBMs, and ALBMs.

Much like China's nuclear weapons program in general, PRC nuclear weapons research and design labs, institutions, and academies are opaque about the work they do. However, by examining the few PRC public domain writings available combined with Western analysis of China's nuclear R&D facilities, we can form a somewhat more complete picture of China's nuclear program and the type of nuclear weapons R&D it conducts.

Throughout the 1960s and 1970s, China's nuclear weapons R&D focused on producing and testing a wide variety of missile technologies and warhead designs. After the 1980s, much of the initial R&D was complete and China's institutions, labs, and research organizations began focusing on improving successfully tested missile designs.[355] According to the Federation of

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[354] Office of the Secretary of Defense, US Department of Defense, *Military and Security Developments Involving the People's Republic of China,* 2022, p. 98.

[355] "1960-1980: China Independently Develops and Tests Nuclear Weapons and Missile Technology," Nuclear Weapons Education Project, Massachusetts Institute of Technology, accessed Feb. 23, 2023, https://nuclearweaponsedproj.mit.edu/Node/131.

American Scientists (FAS), China's nuclear weapons R&D apparatus has designed at least six different types of nuclear payload assemblies (the payload assembly contains the warhead, guidance system, decoys, electronic jammers, and other penetration aids), including the following:[356]

- A 15-40 kiloton (kt) fission bomb
- A 20 kt missile warhead
- A 3 megaton (MT) thermonuclear missile warhead
- A 3 MT thermonuclear gravity bomb
- A 4-5 MT missile warhead
- A 200-300 kt missile warhead

By this account, China has developed three high-yield MT-range payload assemblies, two payload assemblies with lower yields in the double-digit kt range, and one middle-yield payload assembly with a yield in the hundreds of kt. China continues to focus nuclear weapons R&D on modernizing, expanding, and diversifying its nuclear force through the development of land-, sea-, and air-based delivery platforms and constructing the infrastructure to support such an expansion.[357]

Fissile material production

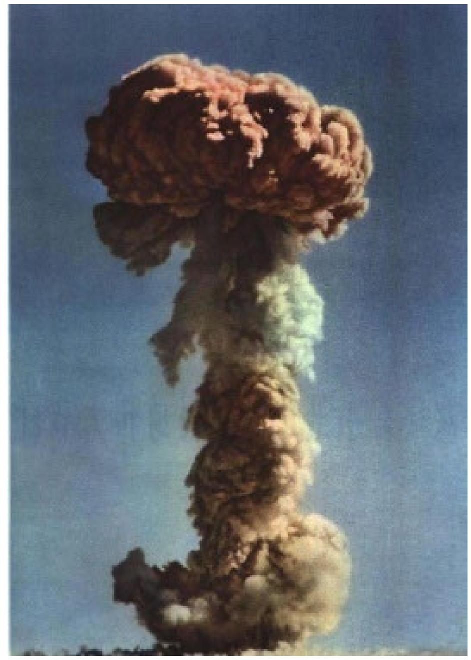
China began construction of its fissile material production facilities in the late 1950s with technical assistance from the Soviet Union. In August 1960, when Moscow ended its assistance to China, China was forced to continue work on its own and by January 1964 began producing 90 percent HEU, paving the way for its first nuclear test in October (see Figure 26).[358]

[356] "Nuclear Weapons - China Nuclear Forces," Federation of American Scientists.

[357] Office of the Secretary of Defense, US Department of Defense, *Military and Security Developments Involving the People's Republic of China*, 2022.

[358] Zhang, *China's Fissile Material Production and Stockpile*.

Figure 26. China's first nuclear test, "Miss Qiu"



Source: Wikimedia Commons.

After 1964, China constructed facilities for producing HEU and plutonium in the interior of the country, which were designed to be concealed near mountains or in caves to protect them from potential attacks by the Soviet Union or the United States.[359] Construction of these fissile material production plants continued throughout the 1960s and into the late 1970s, when the Chinese government began to shift its focus away from military production and wartime preparation and onto economic development and reform.[360]

In 1982, the PRC Ministry of Nuclear Industry and the Commission for Science, Technology and Industry for National Defense established a set of guiding principles for China's nuclear industry. These principles were rooted in the PRC government's assessment that the existing military stockpile of fissile material was sufficient. Therefore, going forward the main line of effort was to be improving the technical quality of production techniques and weapons. This policy decision shifted China from a focus on production of quantities of military fissile materials that could be used to field a larger arsenal and toward further improvements in technology, increased quality of nuclear products, and improved weapons performance.[361]

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[359] These concerns were not entirely unfounded. See William Burr and Jeffrey T. Richelson, "Whether to 'Strangle the Baby in the Cradle': The United States and the Chinese Nuclear Program, 1960–64," *International Security* 25 no. 3 (2001): 54–99, doi: https://doi.org/10.1162/016228800560525.

[360] Li Jue et al., eds., *China Today: Nuclear Industry* (Beijing: China Social Science Press, 1987) (in Chinese). Selections were translated and published by the US Foreign Broadcast Information Service, JPRS-CST-88-002, Jan. 15 1988; and JPRS-CST-88-008, Apr. 26, 1988; Zhang, *China's Fissile Material Production and Stockpile*.

[361] Zhang, *China's Fissile Material Production and Stockpile*.

According to the International Panel of Fissile Materials, a group of independent nuclear experts from 17 countries, China's stockpile of fissile materials is estimated to include 14 ± 3 metric tons of HEU and 2.9 ± 0.6 metric tons of weapons-grade plutonium.[362] Western nuclear experts assess that China's current stocks of military plutonium limit how much it could expand its arsenal without restarting plutonium production.[363] For example, China's current stockpile of plutonium, HEU, and tritium can easily support a doubling of the stockpile, but to triple or quadruple the numbers of nuclear weapons in its arsenal would likely require production of additional material.[364]

Nuclear weapons design

After China tested its first uranium-based atomic bomb in October 1964, Chinese scientists then tested a thermonuclear device in June 1967. According to Western nuclear experts, the interval between this second test of a thermonuclear device (also called a hydrogen bomb) and the initial nuclear test was considerably shorter than it was for any other nuclear weapons state. This rapid progress was likely enabled by prior assistance from the Soviet Union during the 1950s.[365]

In 1955 the Soviet Union and China began cooperating in peaceful nuclear energy, which included the delivery of China's first experimental nuclear reactor and a cyclotron, a type of particle accelerator that repeatedly propels a beam of charged particles (protons) in a circular path. Beginning in 1956, Chinese scientists, along with their counterparts from other socialist countries, trained at the cutting-edge facilities at the Joint Institute for Nuclear Research near Moscow.[366]

[362] Zhang, *China's Fissile Material Production and Stockpile*.

[363] Gregory Kulacki, *China's Nuclear Arsenal: Status and Evolution*, Union of Concerned Scientists, Oct. 2011, https://www.ucsusa.org/sites/default/files/2019-09/UCS-Chinese-nuclear-modernization.pdf.

[364] Kristensen and Korda, "Chinese Nuclear Weapons, 2021."

[365] "1960-1980: China Independently Develops and Tests Nuclear Weapons and Missile Technology."

[366] Sergei Goncharenko, "Sino-Soviet Military Cooperation," in *Brothers in Arms: The Rise and Fall of the Sino-Soviet Alliance, 1945-1963,* Odd Arne Westad, ed. (Washington, DC: The Woodrow Wilson International Center for Scholars, 1998), p. 157.

Types of nuclear warheads

Types of nuclear warhead designs are listed below from the least complex and efficient to the most complex and efficient.

I. Devices that rely on only fission—the original type of nuclear weapons—are often called ***atomic bombs*** or ***A-bombs***. There are two types:

- **Gun assembly** – Explosives propel one half of a subcritical fissile mass to the other half, resulting in supercriticality, or an explosive nuclear chain rection.
- **Implosion** – Explosives compress a subcritical sphere of fissile material inward, which creates a supercriticality.

II. **Boosted fission warheads** – A small amount of deuterium or tritium is placed in the core of an implosion-type weapon to produce fusion, which "boosts" the fission reaction, producing greater explosive yield. This method can also reduce the amount of plutonium or uranium needed.

III. **Staged warheads** – A primary boosted fission device explodes first, which triggers the explosion of a secondary component. The explosion of the secondary component causes nuclear fusion, which creates a much larger explosive yield. These types of weapons are called ***hydrogen bombs***, ***H-bombs***, or ***thermonuclear weapons***.[367]

By 1957, the Soviet Union had agreed to assist China in developing nuclear weapons and missile technology, providing documentation, equipment, and training by Soviet specialists. Although the Sino-Soviet alliance would begin to unravel by 1958 and a promised sample

[367] Office of the Deputy Assistant Secretary of Defense for Nuclear Matters, "Basic Nuclear Physics and Weapons Effects," in *Nuclear Matters Handbook 2020 [Revised]*, https://www.acq.osd.mil/ncbdp/nm/NMHB2020rev/chapters/chapter13.html; Michael V. Hynes, "Nuclear Weapon Development," MIT Nuclear Weapons Education Project, 2018, https://nuclearweaponsedproj.mit.edu/Node/158.

atomic bomb would never be delivered, Soviet aid accelerated China's progress toward a bomb.[368]

From 1964 to 1996, China conducted 47nuclear tests at its Lop Nur nuclear test site in Western China. According to Western experts, this relatively small number of tests—compared to the 1,054 tests by the US and the 715 by the Soviet Union/Russia—suggests that China may have "a limited number of tested warhead designs certified for deployment."[369] FAS estimates that China has developed at least 6 types of nuclear payloads,[370] compared to the 92 warhead types fielded by the US throughout its history.[371] On one hand, China's relatively small number of nuclear tests could limit the PRC's ability to field advanced new weapons designs. On the other hand, the PRC may be able to overcome these challenges by drawing on information about US nuclear weapons designs that it allegedly gathered through espionage.[372]

Before the PRC signed on to the CTBT in 1996,[373] China accelerated the pace of its nuclear testing beginning in 1993 to complete a series of tests to design a miniaturized warhead.[374] As a result, the PRC was able to reduce the weight of a warhead from approximately 2,200 kilograms to around 700 kilograms.[375]

Shrinking the size and weight of a nuclear warhead provides a country with more flexibility in how it postures its nuclear forces. Miniaturized warheads may increase the range of the missile onto which they are loaded and may provide additional space for decoys and chaff used to

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[368] Zhihua Chen and Yafeng Xia, "Between Aid and Restriction: The Soviet Union's Changing Policies on China's Nuclear Weapons Program, 1954-1960," *Asian Perspective* 36, no. 1 (January-March 2012), p. 104.

[369] Kulacki, *China's Nuclear Arsenal: Status and Evolution*.

[370] "Nuclear Weapons - China Nuclear Forces."

[371] Office of the Deputy Assistant Secretary of Defense for Nuclear Matters, *Nuclear Matters Handbook 2020 [Revised]*, https://www.acq.osd.mil/ncbdp/nm/NMHB2020rev/index.html.

[372] US Congress, House, Select Committee of The United States House of Representatives, *Chapter 2: PRC Theft of US Thermonuclear Warhead Design Information*, 105th Cong., 2d sess., H. Rep. 105-851, https://www.govinfo.gov/content/pkg/GPO-CRPT-105hrpt851/html/ch2bod.html#anchor4311396.

[373] Although the PRC stopped nuclear testing after becoming a signatory to the CTBT, it has not ratified the Treaty, along with the DPRK, Egypt, India, Indonesia, Israel, Iran, Pakistan, and the United States. See "Comprehensive Test Ban Treaty, Chapter XXVI," United Nations Treaty Collection, accessed Feb. 6, 2023, https://treaties.un.org/pages/ViewDetails.aspx?src=TREATY&mtdsg_no=XXVI-4&chapter=26.

[374] Kulacki, *China's Nuclear Arsenal: Status and Evolution*.

[375] "Nuclear Weapons," FAS Weapons of Mass Destruction, accessed Feb. 6, 2023, https://nuke.fas.org/guide/china/nuke/.

penetrate missile defenses. Miniaturization could also enable the development of smaller, more mobile missiles that are more difficult to track. Finally, miniaturization can enable "MIRVing"—placing MIRVs atop a single missile. Thus, warhead miniaturization provides the PRC with more options for developing its nuclear forces in the future.

Nuclear weapons delivery systems

In addition to nuclear warheads, China's R&D centers have designed, tested, and produced a wide variety of nuclear delivery systems for these warheads—the key to China's credible nuclear deterrent.

According to Western assessments, throughout the 1980s, China's missile research was primarily focused on modernizing and improving old designs as opposed to developing new clean-sheet systems.[376] China's early efforts in nuclear delivery systems were focused on the production of liquid-fuel, silo-based, and truck- or rail car–based rollout ballistic missiles that could be positioned in protected caverns and rolled out for launch. Although liquid-fuel missiles have the advantage of high energy (thrust) per unit of fuel mass, they are slow to fuel, have a limited readiness window once fueled because of corrosion issues, and are difficult to maintain.[377]

China's first generation of ballistic missiles was the DF series (abbreviated from Dong Feng, or "East Wind" in the Chinese weapon nomenclature system—a reference to an early Mao speech in which he declared the "East wind will prevail over the West," i.e., socialism will prevail against imperialism)[379]—the DF-2, DF-3, DF-4, and DF-5 (see Figure 27). The DF-2, having a range of approximately 1,000

> Fractional orbital bombardment systems launch a missile into low earth orbit, and it can transit the earth before reentering the atmosphere at hypersonic speeds toward its intended target.[378]

[376] "1960-1980: China Independently Develops and Tests Nuclear Weapons and Missile Technology."

[377] "Ballistic Missile Basics," Federation of American Scientists, accessed Feb. 6, 2023, https://nuke.fas.org/intro/missile/basics.htm.

[378] Mark Zastrow, "How Does China's Hypersonic Glide Vehicle Work?" Astronomy, Nov. 4, 2021, https://astronomy.com/news/2021/11/how-does-chinas-hypersonic-glide-vehicle-work.

[379] "Revealed: The Development History of China's Dongfeng Series of Missiles" (揭秘：中国东风系列导弹的发展历程), *Sohu*, Mar. 8, 2017, https://m.sohu.com/n/482687604/.

kilometers, provided only a basic regional deterrent capability and was phased out of the PLA in the 1980s.[380]

Figure 27. Chinese DF-5 missile

Source: Wikimedia Commons, https://commons.wikimedia.org/wiki/File:DF-5B_intercontinental_ballistic_missiles_during_2015_China_Victory_Day_parade.jpg.

Following the DF-2 test of 1966, China continued to develop its land-based nuclear-capable missile force through the design and testing of new MRBMs, IRBMs, and ICBMs. China's present R&D for nuclear weapons delivery systems continues to focus on developing and refining its arsenal of MRBMs and IRBMs, silo-based ICBMs, SLBMs, and ALBMs. The goal appears to be to field a complete and credible nuclear triad—like the triads of the United States and Russia—consisting of land-, sea-, and air-launched nuclear weapons.

China's July 2021 test of a fractional orbital launch of a land-based ICBM with an HGV indicates that China may also be exploring fractional orbital bombardment systems (FOBS). FOBS differ from traditional ICBMs in that they can loft their warheads into a partial orbit, allowing them to approach their targets from unexpected directions—for example, from the south as opposed

380 Logan, "Making Sense of China's Missile Forces," p. 396.

to over the North Pole. FOBS, as well as maneuvering HGVs, are a potential means of bypassing US missile defense systems and attaining qualitative parity with the US as global military technologies continue to advance.[381]

In addition, China's nuclear R&D facilities are reportedly using computer modeling to examine the potential effects and performance of nuclear blasts in near space for anti-satellite weapons. Researchers from the PLA research institute Northwest Institute of Nuclear Technology (NINT) have developed a computer model to conduct simulations on the performance of nuclear anti-satellite weapons at varying altitudes and yields. According to the researchers, the model suggested that a 10 MT warhead could significantly threaten satellites when detonated at an altitude of 80 kilometers.[382] This finding suggests a PRC interest in the ability to threaten militarily usable satellite constellations during conflict.

What sites or facilities does China use for nuclear weapons–related R&D?

China has three primary R&D centers for military-related nuclear research: the China Institute of Atomic Energy (CIAE), NINT, and the Chinese Academy of Engineering Physics (CAEP).

In addition, China has a network of state-owned enterprise (SOE) defense contractors that design, develop, and manufacture its missile systems. The two most prominent are China Aerospace Science and Technology Corporation Limited (CASC) and China Aerospace Science and Industry Corporation (CASIC). These companies are owned by the State-Owned Assets and Administration Commission of the State Council but are under the charge of the State Administration for Science, Technology, and Industry for National Defense (SASTIND), which in turn is under the control of the Ministry of Industry and Information Technology (MIIT). These SOEs maintain military procurement relationships with the CMC Equipment

[381] Office of the Secretary of Defense, US Department of Defense, *Military and Security Developments Involving the People's Republic of China*, 2022.

[382] Stephen Chen, "Researchers Simulate Nuclear Blast to Bring Down Satellites," *South China Morning Post*, Oct. 21, 2022, https://www.scmp.com/news/china/science/article/3196629/chinese-physicists-simulate-nuclear-blast-against-satellites.

Development Department and service equipment procurement bureaus, who ultimately direct the R&D program.[383]

Fissile material production facilities

Until the 1980s, production of HEU took place at the following plants:

- The Lanzhou gaseous diffusion plant produced HEU throughout the 1960s and ended production in 1980. Lanzhou then began producing low enriched uranium (LEU) for civilian power plants until it was shuttered in 2000.[384]
- The Heping gaseous diffusion plant began production of HEU in 1970 and is reported to have ended HEU production for nuclear weapons in 1987. The Heping plant is still in operation and produces enriched uranium for naval reactors, research reactors, and civilian power reactors.[385]

Production of weapons-grade plutonium took place at two nuclear complexes:

- The Jiuquan plutonium production reactor began operation in 1960, reaching design power in 1975. The Jiuquan facility (Plant 404) was decommissioned after 1990.[386]
- The Guangyuan plutonium production facility (Plant 821) achieved criticality in 1973 and was reported to have been shut down in 1984 and decommissioned after 1990.[387]

China currently operates three civilian centrifuge enrichment plants producing LEU for civilian use: [388]

- Hanzhong in Shaanxi province (Plant 405)
- Lanzhou in Gansu province (Plant 504)
- Emeishan in Sichuan province (Plant 814)

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383 Peter Wood and Alex Stone, *China's Ballistic Missile Industry*, China Aerospace Studies Institute, May 2021, https://www.airuniversity.af.edu/Portals/10/CASI/documents/Research/PLARF/2021-05-11%20Ballistic%20Missile%20Industry.pdf?ver=Y3oJa8Z9eK2rpAO9tQGCcQ%3d%3d.

384 Zhang, *China's Fissile Material Production and Stockpile*.

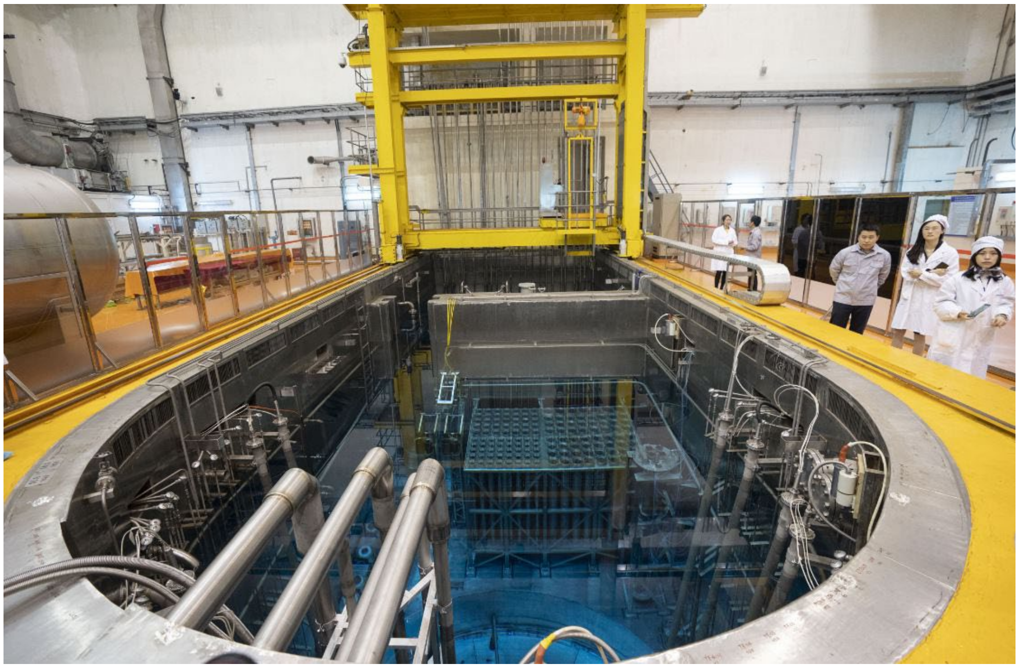
385 Zhang, *China's Fissile Material Production and Stockpile*.

386 Zhang, *China's Fissile Material Production and Stockpile*.

387 Zhang, *China's Fissile Material Production and Stockpile*.

388 Zhang, *China's Fissile Material Production and Stockpile*; "Country Profile: China."

Figure 28. Nuclear reactor at the China Institute of Atomic Energy



Source: *China Daily*, https://global.chinadaily.com.cn/a/201905/07/WS5cd0f146a3104842260ba3e9.html.

Nuclear weapons design facilities

The CIAE, a branch of the Institute of Modern Physics of the Chinese Academy of Sciences, was China's first institution for comprehensive R&D in the nuclear field. Founded in 1950, CIAE is located in Tuoli, 40 kilometers southwest of Beijing. CIAE benefited from early Sino-Soviet nuclear cooperation, and Moscow supplied its first heavy water research reactor and cyclotron in 1958, with the proviso that the equipment would be for peaceful use only. In 1957 Marshal Nie Rongzhen, the vice premier in charge of PRC nuclear industries, had traveled to Moscow to request Soviet assistance with the development of an atomic bomb, but Soviet officials refused to commit to specifics.[389]

[389] "Tuoli/China Institute of Atomic Energy (CIAE)," FAS Weapons of Mass Destruction, https://nuke.fas.org/guide/china/facility/tuoli.htm; Shu Guang Zhang, "Sino-Soviet Economic Cooperation," in *Brothers in Arms: The Rise and Fall of the Sino-Soviet Alliance, 1945-1963*, ed. Odd Arne Westad (Washington, DC: Woodrow Wilson International Center for Scholars Press, 1998), pp. 206–207.

The Haiyan (Kokonor) site in Qinghai province (also known as NINT or the Northwest Nuclear Weapons and Design Academy (Base/State Factory 221, and the Ninth Academy) produced explosive and fissile components and assembled and tested nuclear weapons, including China's first atomic bomb (in 1964) and hydrogen bomb.[390] The Northwest Nuclear Weapons and Design Academy continues to carry out nuclear weapons research. For example, in response to research by Chinese military experts about the potential effect of the Starlink commercial satellite constellation on the PRC's national security, in October 2022 scientists from NINT published the results of a simulation examining the consequences of using nuclear weapons with various yields and at different altitudes as anti-satellite weapons.[391]

CAEP is the main design laboratory for the PRC's nuclear weapons program. Founded in 1958, CAEP is the only nuclear weapon development and production unit that is listed separately in the national scientific plan, which underscores its importance.[392] CAEP engages in both comprehensive nuclear weapons research and production through a workshop system in which scientists advise in the production process. Moreover, CAEP claims to be the only nuclear weapons research and production unit in China.[393] Its primary location is in Mianyang in Sichuan province, although CAEP has other facilities in Beijing (Institute of Applied Physics

[390] "Northwest Nuclear Weapons Research and Design Academy Ninth Academy/Factory 211/State Plant 221/Haiyan," FAS Weapons of Mass Destruction, https://nuke.fas.org/guide/china/facility/haiyan.htm; "Basic Situation of "China's First Nuclear Industry Base in Qinghai" (中国第一个核工业基地" 在青海的基本情况), June 7, 2021, https://new.qq.com/rain/a/20210706A05VTG00. Haiyan was closed in 1987.

[391] "China Academy of Engineering Physics: My Country's Only Nuclear Weapon Development and Production Unit!" (中国工程物理研究院：我国唯一核武器研制生产单位!), Apr. 16, 2015, http://guba.eastmoney.com/news,gssz,158568489.html?jumph5=1; "Recruitment by the Chinese Academy of Sciences in 2019 | Join the Glorious Cause and Achieve the Glorious Dream!" (中物院2019年招聘|加盟光荣事业，成就光辉梦想!), Sept. 17, 2018, https://web.archive.org/web/20190926035758/https://www.yingjiesheng.com/job-003-915-443.html; Cong Cao, Richard P. Suttmeier, and Denis Fred Simon, "China's 15-Year Science and Technology Plan," *Physics Today* 59, no. 12 (2006), p. 36, https://physicstoday.scitation.org/doi/10.1063/1.2435680.

[392] "China Academy of Engineering Physics: My Country's Only Nuclear Weapon Development and Production Unit!"; "Recruitment by the Chinese Academy of Sciences In 2019 | Join the Glorious Cause and Achieve the Glorious Dream!"

[393] "Visit China's Only Nuclear Production Unit" (鉴军堂, 探访中国唯一核武生产单位：中国工程物理研究院), Feb. 2, 2015, https://mp.weixin.qq.com/s?src=3&timestamp=1675178444&ver=1&signature=hV8gxqgfboTRtIZZIVcWzsFRpUgmlWqbLrKrgKWOwhA6QpvgNq9eXOLwVYCwD4up4c*1NrKDk701f4MWo0Hxe1D7O4jwEKXa0d5cpUUdM3K821Z8eXeuoQgmRlYcilxLhK6zIelaOUlzGhyaSPlCMQ==.

and Computational Mathematics) and Chengdu (Southwest Institute of Chemical Materials).[394] CAEP's four main tasks are as follows:[395]

1. Research, design, experimentation, and production of nuclear weapons
2. Research and development of new technologies, such as laser nuclear fusion, high-power laser technology, and high-energy weapons
3. Design of conventional weapons
4. Civil-military integration

Nuclear weapons delivery system facilities

China uses its system of SOEs to produce missiles for its nuclear force. CASC and CASIC are the primary state-owned R&D enterprises for China's missile systems. R&D is primarily conducted at the following subunits:[396]

- CASC 1st Academy (responsible for DF-4, DF-5, DF-15, DF-31/JL-2, DF-26, and DF-41 missiles)
- CASC 4th Academy, CASC 6th Academy
- CASIC 4th Academy (responsible for DF-11, DF-16, and DF-21/JL-1 missiles)
- CASIC 6th Academy

CASC was officially established in July 1999 having previously been one part of the former China Aerospace Corporation. CASC is headquartered in Haidian District, Beijing, and is China's sole supplier of ICBMs; it also develops, produces, and tests some tactical missiles and other weapons systems.[397]

[394] "China Leadership: Politburo Member and Vice Premier Liu Visits Chinese Academy of Engineering Physics," Centre for Chinese Analysis and Strategy, https://www.ccasindia.org/newsdetails.php?nid=5141; "Chinese Academy of Engineering Physics," China Defence Universities Tracker, https://unitracker.aspi.org.au/universities/chinese-academy-of-engineering-physics.

[395] "Casting the Cornerstone of National Defense and Being the Backbone of the Nation—Record of the 2015 Recruitment Fair of China Academy of Engineering Physics" (铸国防基石 做民族脊梁—记中国工程物理研究院2015 校招), Sept. 15, 2021, https://web.archive.org/web/20190926042240/http://www.job.sdu.edu.cn/info/1016/1239.htm.

[396] Wood and Stone, *China's Ballistic Missile Industry*.

[397] China Aerospace Science and Technology Corporation, http://english.spacechina.com/n16421/index.html; Wood and Stone, *China's Ballistic Missile Industry*.

CASIC was similarly formed in 1999 from the former China Aerospace Corporation as part of a defense organization reform effort. CASIC is headquartered in Haidian District, Beijing, and primarily focuses on tactical missiles; it also has comprehensive R&D and production systems for surface-to-air missiles, cruise missiles, tactical ballistic missiles, and solid-fuel launch vehicles.[398]

How knowledgeable, educated, and skilled are the scientific and technical personnel who make up China's nuclear weapons program?

According to our analysis, China is emerging as a global leader in science, technology, engineering, and mathematics (STEM), in terms of numbers of postgraduates in STEM fields, global rankings of China's top-level universities with STEM programs, numbers of postdoctoral students in nuclear engineering, and numbers of papers and citations for PRC authors published in international scientific journals. In addition, the PRC is investing heavily in its STEM education system, has a national mandate to become self-reliant in its technology sector, and has more than 200 state-sanctioned talent recruitment programs incentivizing high-level PRC-born scientists to return to China. Despite the paucity of PRC-published information on the technical specifics of the PRC's nuclear weapons program, the above-listed factors indicate that the PRC has a relatively high-quality scientific talent pool that is capable of modernizing and advancing the PRC's nuclear weapons program. As the PRC continues its nuclear modernization, the numbers and quality of their scientists will likely not be limiting factors.

To understand the quality of the scientific and technical personnel employed in the PRC's nuclear force, we analyzed data on China's academic programs, number of universities, and global rankings for its universities focusing on STEM fields. We examined data from US academic and government institutions such as Georgetown University's Center for Security and Emerging Technology (CSET), the National Science Board, and the National Science Foundation. We also analyzed data from international scientific and policy analysis organizations such as Japan's National Institute of Science and Technology Policy (NISTEP) and Australia's Strategic Policy Institute, as well as academic ranking publications QS World University Rankings, Scimago Journal Rank, the Times Higher Education World University Rankings, and EduRank. In addition, we looked at PRC official government documents,

[398] Wood and Stone, *China's Ballistic Missile Industry*.

statements, and data from the PRC Ministry of Education. However, we found only limited information on the size, scale, and details of the PRC's nuclear program workforce.

University rankings in nuclear-relevant fields

We compared the quality of the nuclear technology–relevant academic departments, such as physics, engineering, and technology, at each country's top universities. To make these comparisons, we used two global university ranking databases: QS World University Rankings and the Times Higher Education World University Rankings. Each database divides its categorizations of academic departments and disciplines differently and uses a somewhat different methodology. Neither is a perfect measure of quality. For example, both weight reputation—assessed via survey—heavily. The university department rankings that they provide are therefore driven by perceptions of quality as assessed by a cross section of academics in the field in question. In addition, both databases also use data on publications, meaning that the university department rankings presented here are not independent of publication-based comparisons. As a result of these shortcomings, these department rankings should be treated as imperfect measures of quality that nevertheless provide some insight into how the nuclear-relevant training available in China compares with that in other countries.

Table 9 represents the top five PRC universities' physics and astronomy departments, ranked among 611 global schools, and engineering and technology departments, ranked among 533 global schools, according to QS World University Rankings in 2022. The Times Higher Education World University Rankings ranks PRC universities with physics and astronomy departments among 1,227 global schools but does not list rankings for engineering and technology departments.

Table 9. Top five PRC universities' global rankings

PRC University	Subject	Ranking Globally	Year	Global Top Percent of Schools
Tsinghua University	Physics and astronomy	24,[a] 18[b]	2022	4%,[a] 1.4%[b]
	Engineering and technology	14[a]	2022	2.6%[a]
Peking University	Physics and astronomy	26,[a] 15[b]	2022	4.25%,[a] 1.2%[b]
	Engineering and technology	43[a]	2022	8%[a]

PRC University	Subject	Ranking Globally	Year	Global Top Percent of Schools
Shanghai Jiao Tong University	Physics and astronomy	73,[a] 81[b]	2022	12%,[a] 6.6%[b]
	Engineering and technology	39[a]	2022	7.3%[a]
University of Science and Technology of China	Physics and astronomy	77,[a] 39[b]	2022	12.6%,[a] 3.2%[b]
Fudan University	Physics and astronomy	89,[a] 30[b]	2022	14.6%, 2.4%
	Engineering and technology	92[a]	2022	17.2%[a]

Sources: [a] "QS World University Rankings by Subject 2022: Engineering & Technology: China," QS World University Rankings, accessed Mar. 31, 2023, https://www.topuniversities.com/university-rankings/university-subject-rankings/2022/engineering-technology?&countries=cn"; [b] "World University Rankings 2021 by Subject: Physical Sciences: China," Times Higher Education, accessed Mar, 31, 2023, https://www.timeshighereducation.com/world-university-rankings/2021/subject-ranking/physical-sciences#!/page/0/length/25/locations/CHN/subjects/3060/sort_by/rank/sort_order/asc/cols/stats.

According to the two databases, PRC institutions offering programs in physics/astronomy and engineering/technology overall do not qualitatively rank highest in the worldwide top listings. Massachusetts Institute of Technology, for example, ranks 1st globally for engineering and technology, whereas PRC institution Tsinghua University ranks 14th.[399] However, both database providers, using the methodology described above, place PRC universities within the top 10 percent of schools globally, according to a calculation of the percentages' average from Table 9. International Consultants for Education and Fairs Market, an international education market intelligence organization, assesses that "the quality of Chinese institutions that STEM students are graduating from are often excellent."[400]

China's elite STEM universities are known as "Double First Class" (DFC) institutions—those the PRC government believes have the potential to become world-class universities with world-class curricula. These 42 institutions receive the most funding, and the Chinese government is

399 "QS World University Rankings by Subject 2022: Engineering & Technology: China."

400 "US: More International STEM Students Will Be Granted Three-Year OPT," International Consultants for Education and Fairs Market, Feb. 1, 2022, https://monitor.icef.com/2022/02/us-more-international-stem-students-will-be-granted-three-year-opt/.

heavily invested in them.[401] For example, the PRC Ministry of Education roughly doubled its spending on higher education between 2012 and 2021, with PRC expenditures of 3.95 trillion RMB (roughly $575 billion) in 2022 on education overall in China.[402] According to PRC government figures for the same period, investment throughout all sectors of scientific R&D increased approximately 270 percent, from 1.03 trillion RMB ($150 billion) in 2012 to 2.79 trillion RMB ($406 billion) in 2021.[403]

Graduates from China's DFC STEM universities have gone on to hold high-level positions in prestigious international nuclear and scientific organizations, although reportedly other factors beyond their technical knowledge or skill led to these appointments. For example, the following Chinese scientists have held the position of IAEA deputy director general:

- Yang Dazhu obtained his doctorate in chemical engineering, master's degree in separation engineering, and bachelor's degree in applied chemistry from Tsinghua University. He held the position of IAEA deputy director general and head of the department of technical cooperation from 2015 to 2021.[404]
- Liu Hua graduated with a bachelor's degree in nuclear radiation physics from China's National University of Defense Technology and a master's degree in radiation protection and nuclear safety from CIAE. Since February 20, 2021, Liu has been the deputy director general and head of the department of technical cooperation.[405]

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401 "US: More International STEM Students Will Be Granted Three-Year OPT."

402 In comparison, the US Department of Education's budget for fiscal year 2022 was $102.8 billion. US Department of Education, *Fiscal Year 2022 Budget Summary*, accessed Apr. 18, 2023, https://www2.ed.gov/about/overview/budget/budget22/summary/22summary.pdf; Remco Zwetsloot et al., *China Is Fast Outpacing U.S. STEM PhD Growth*, Center for Security and Emerging Technology, Aug. 2021, resource://a8tmp/a8ss-download-0/China-is-Fast-Outpacing-U.S.-STEM-PhD-Growth.pdf.

403 "Economic Strength, Scientific and Technological Strength, and Comprehensive National Strength Have Leapt to a New Level" (经济实力科技实力综合国力跃上新台阶), *People's Daily* (人民日报), Aug. 23, 2022, http://politics.people.com.cn/n1/2022/0823/c1001-32508685.html.

404 "Do I Need Superpowers to Work in the IAEA?—Interview with Yang Dazhu, Former Deputy Director-General of the International Atomic Energy Agency" (进入IAEA工作，需要三头六臂吗?—专访国际原子能机构原副总干事杨大助)," Ministry of Human Resources and Social Security of the People's Republic of China (中华人民共和国人力资源和社会保障部), Oct. 14, 2022, http://io.mohrss.gov.cn/a/2022/10/14/11264.html.

405 "Head of the Department of Technical Cooperation," International Atomic Energy Agency, Feb. 20, 2021, https://www.iaea.org/about/organizational-structure/department-of-technical-cooperation/deputy-director-general-of-department-of-technical-cooperation.

In addition to the overall quality of China's universities for the above-listed STEM fields, China also has a large number of universities offering degree programs directly linked to the nuclear technology field. For example, according to data released by the PRC State Council, "As of June 2019, there were 72 universities in China running programs on nuclear engineering, of which 47 had separate schools on nuclear science, enrolling some 3,000 undergraduates in nuclear engineering each year."[406] Another data source, EduRank, an independent metric-based ranking site, lists 81 universities in China in 2023 with nuclear engineering programs.[407] In comparison, 34 institutions in the United States offer nuclear engineering programs, most of which are public four-year or above institutions, with 877 completions in 2020, according to DATA USA.[408] According to data collected by EduRank using 14,131 universities from 183 countries, the following are the top 10 universities in China for nuclear engineering:[409]

1. *Tsinghua University*: ranked number 1 in the world
2. *Xi'an Jiaotong University*: ranked number 2 in the world
3. *Shanghai Jiao Tong University*: ranked number 5 in the world
4. *University of Science and Technology of China:* ranked number 6 in the world
5. *Tianjin University*: ranked number 10 in the world
6. *Huazhong University of Science and Technology*: ranked number 22 in the world
7. North China Electric Power University: ranked number 28 in the world
8. Harbin Institute of Technology: ranked number 29 in the world
9. *Zhejiang University:* ranked number 31 in the world
10. *South China University of Technology:* ranked number 51 in the world

Of the above universities, eight (italicized) are directly managed by the PRC's defense industry agency, SASTIND. Harbin Institute of Technology (underlined) is listed as one of the "Seven Sons of National Defense," a group of leading universities with deep ties to the PRC's military and defense industry. Harbin Institute of Technology is subordinate to the PRC MIIT, which is

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406 "Full Text: Nuclear Safety in China."

407 "81 Best Universities for Nuclear Engineering in China," EduRank, accessed Mar. 29, 2023, https://edurank.org/engineering/nuclear/cn/.

408 "Nuclear Engineering."

409 According to EduRank, the best universities in China are ranked based on their research performance in nuclear engineering. A graph of 101,000 citations received by 9,330 academic papers made by 81 universities in China was used to calculate publications' ratings, which then were adjusted for release dates and added to final scores. "81 Best Universities for Nuclear Engineering in China."

responsible for overseeing the PRC national defense industry through its subordinate SASTIND.[410]

Figure 29. Tsinghua University

Source: Li Shaoji Science and Technology Building, Tsinghua University, Wikimedia Commons, Sept. 4, 2020.

As discussed above, the PRC produces a large number of STEM graduates and nuclear physicists from increasingly globally competitive, high-quality universities yearly. Although not all these graduates go on to work in and contribute to the PRC's nuclear weapons program, a significant number of China's top university graduates do move into the PRC defense sector.

[410] Alex Joske, *The China Defence Universities Tracker: Exploring the Military and Security Links of China's Universities*, Australian Strategic Policy Institute, 2019, https://www.aspi.org.au/report/china-defence-universities-tracker.

For example, a 2020 CSET report states that in 2019, "Chinese defense state-owned enterprises (SOEs) directly hired a combined 6,000 graduates from 29 leading Chinese universities."[411] According to data from the CSET report, in 2019 at least 92 graduates from China's top universities took positions at China's leading nuclear weapons lab, CAEP.[412] CAEP is believed to employ 24,000 workers and, according to its website, reports that each year 170 master's students and 171 doctoral students (including 30 joint doctoral students) are recruited from universities across China.[413] Table 10 shows the top-ranked PRC universities and the number of hires into CAEP in 2019.

Table 10. 2019 hiring data for graduates from PRC top universities working at CAEP

University	Number of 2019 Graduates	Portion of all Employed Graduates Working at CAEP
Xi'an Jiaotong University	24	1%
University of Science and Technology of China	20	1%
Harbin Institute of Technology	19	<1%
Zhejiang University	16	<1%
Beihang University	8	<1%
Tianjin University	5	<1%

Source: CNA. Adapted from Fedasiuk and Weinstein, *Universities and the Chinese Defense Technology Workforce*.

China's scholars studying abroad in nuclear-relevant fields

China, like many other nations, has scholars studying in foreign universities, especially in STEM fields. In the 1950s, PRC students studied in Soviet scientific and engineering institutions, and some graduates of these schools, such as Premier Li Peng, went on to top positions in the Chinese leadership. More than 800 PRC and Soviet scientific institutions cooperated throughout the 1950s, a period when Soviet technology replaced Western technology in

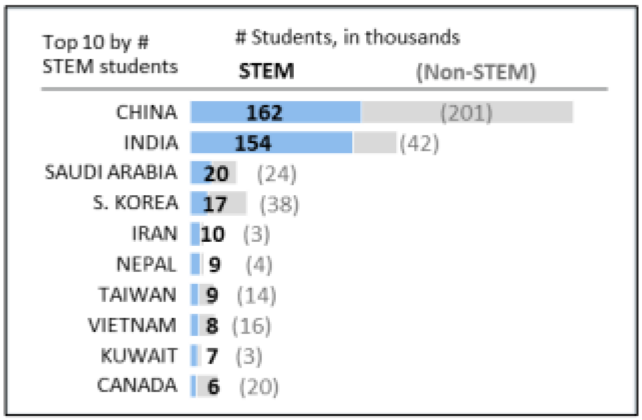
[411] Ryan Fedasiuk and Emily Weinstein, *Universities and the Chinese Defense Technology Workforce*, CSET, Dec. 2020, https://cset.georgetown.edu/wp-content/uploads/CSET-Universities-and-the-Chinese-Defense-Technology-Workforce.pdf.

[412] Fedasiuk and Weinstein, *Universities and the Chinese Defense Technology Workforce*.

[413] "Cast the Cornerstone of National Defense as the Backbone of the Nation" (铸国防基石 做民族脊梁), China Academy of Engineering Physics (中国工程物理研究院人才招聘网), accessed Apr. 20, 2023, https://zpxx.caep.cn/#/yuanDesc/index.

China.[414] After the normalization of US-China relations in 1979 and as the Chinese economy began opening to the global economy, PRC students began to study in the United States. Their numbers began growing rapidly in the 2000s: from 60,000 students in 2005 to about 370,000 studying in all fields in 2018.[415] According to a report by the US Congressional Research Service, in the 2017–2018 school year there were 162,000 Chinese citizens studying in STEM fields in the US. Figure 30 shows the numbers of foreign STEM students in the US.

Figure 30. Top 10 countries of origin for foreign STEM students in the US, 2017–2018 school year



Source: Congressional Research Service, *Foreign STEM Students in the United States*, Nov. 1, 2019, https://crsreports.congress.gov/product/pdf/IF/IF11347.

In 2020, about 130,000 of the total 370,000 Chinese students studying in the United States were in STEM fields at the master's or doctoral levels.[416] These numbers declined 15 percent during the 2021–2022 school year in part because of the COVID-19 pandemic but also because of policies introduced by the Trump Administration in May 2020 that prevented students

414 Baichun Zhang, Jiuchun Zhang, and Fang Yao, "Technology Transfer from the Soviet Union to the People's Republic of China, 1949-1966, *Comparative Technology Transfer and Society* 4, no. 2 (August 2006), p. 133.

415 Jacob Feldgoise and Remco Zwetsloot, *Estimating the Number of Chinese STEM Students in the United States,* CSET, Oct. 2020, https://cset.georgetown.edu/publication/estimating-the-number-of-chinese-stem-students-in-the-united-states.

416 Anastasya Lloyd-Damnjanovic and Alexander Bowe, *Overseas Chinese Students and Scholars in China's Drive for Innovation*, US-China Economic and Security Review Commission, Oct. 7, 2020, https://www.uscc.gov/sites/default/files/2020-10/Overseas_Chinese_Students_and_Scholars_in_Chinas_Drive_for_Innovation.pdf.

affiliated with several Chinese universities from studying in STEM fields by blocking their US visas.[417] Now the Chinese government is encouraging students specializing in subjects such as aviation, space, and engineering to study in Russia instead.[418]

Many PRC students studying in STEM fields in the US elect to remain in the US, contributing to US scientific advancements. Data show that most Chinese PhD graduates from US institutions choose to stay and work in the US after receiving their diplomas. For example, according to the National Science Foundation and the National Science Board, the rate of Chinese science and engineering doctorates remaining in the US from 2006 to 2008 was 90 percent; the rate of Chinese doctorates remaining from 2011 to 2013 was 83 percent.[419] However, there are national security concerns associated with those PRC citizens who do return to China and apply their advanced degrees and scientific knowledge acquired in the US to the PRC's defense sector.

[417] Yifan Yu, "Chinese Students in U.S. Plummet as COVID, Tensions Create Barriers," *Nikkei*, Nov. 14, 2022, https://asia.nikkei.com/Business/Education/Chinese-students-in-U.S.-plummet-as-COVID-tensions-create-barriers.

[418] Laura Zhou, "China Gives Russian Studies High Grades," *South China Morning Post*, Feb. 3, 2023, https://www.scmp.com/news/china/diplomacy/article/3208887/china-gives-russian-studies-high-grades-new-overseas-scholarship-drive. A Russian engineering institute is now building a campus in China. See Iris Deng, "China's Resort Island Hainan to Host New Campus of Top Russian Technical University," *South China Morning Post*, Oct. 17, 2022, https://www.scmp.com/tech/big-tech/article/3196275/chinas-resort-island-hainan-host-new-campus-top-russian-technical.

[419] "Science and Engineering Labor Force," National Science Board Science and Engineering Indicators, accessed Mar. 29, 2023, https://ncses.nsf.gov/pubs/nsb20198/immigration-and-the-s-e-workforce.

Figure 31. The University of Science and Technology of China

Source: "The University of Science and Technology of China," Wikimedia Commons, https://web.archive.org/web/20161023110617/http://www.panoramio.com/photo/66358552.

In response to the large numbers of PRC STEM graduates remaining in foreign countries after graduation, the PRC has created national-level mandates to recruit scientists to return to China and work in its high-tech sector, including in national defense. There are 200 such recruitment programs, and the Thousand Talents Program (TTP) is one of the more significant of these initiatives.[420] Launched in 2008 by the PRC government, TTP's purpose is to recruit experts in science and technology from abroad, principally but not exclusively from overseas Chinese

[420] See, for example, "Questions and Answers from the Organization Department of the Central Committee on the 'Thousand Talents Program'; and Dongbo, Weichen, and Yanbo, "Has China's Young Thousand Talents Program Been Successful?"

communities.[421] In 2020, FBI Director Christopher Wray described TTP as the "Chinese government [trying] to entice scientists to secretly bring [US] knowledge and innovation back to China—even if that means stealing proprietary information or violating [US] export controls and conflict-of-interest rules."[422] The PRC's recruitment policies for STEM fields are part of a larger "military-civilian fusion" effort to build China's economic and military strength. This fusing of the military and civilian domains, especially for scientific research, significantly increases the porosity between the PRC's university system and the state defense sector.

Some PRC citizens trained in STEM fields in the US who have remained in the US for decades do return to work for the PRC. For example, a 2022 private sector intelligence report states that at least 154 Chinese scientists, out of a total 14,150 employees,[423] who worked on government-sponsored research at Los Alamos National Laboratory—the preeminent national security laboratory where the US first developed nuclear weapons—for more than two decades were recruited to do scientific work in China.[424] According to the report, these scientists were lured by PRC government recruitment policies and paid as much as $1 million to return to China to make advances in technologies such as deep-earth-penetrating warheads, hypersonic missiles, quiet submarines, and drones.[425]

Another US national security concern is PLA research collaboration with universities outside of China. Since 2007, the PLA has sponsored more than 2,500 military scientists and engineers to study abroad and has developed relationships with researchers and institutions across the globe.[426] According to a 2018 report by the Australian Strategic Policy Institute, PLA scientists and researchers from PLA institutes such as the Northwestern Institute of Nuclear Technology, Rocket Force Engineering University, China Aerodynamics Research and Development Center, and many others related to the PRC's national defense and nuclear weapons program have

[421] "Questions and Answers from the Organization Department on the 'Thousand Talents Program.'"

[422] Christopher Wray, "The Threat Posed by the Chinese Government and the Chinese Communist Party to the Economic and National Security of the United States," (Remarks at the Hudson Institute Video Event: China's Attempt to Influence U.S. Institutions, July 7, 2020), https://www.fbi.gov/news/speeches/the-threat-posed-by-the-chinese-government-and-the-chinese-communist-party-to-the-economic-and-national-security-of-the-united-states.

[423] "About the Lab," Los Alamos National Laboratory, accessed June 29, 2023, https://about.lanl.gov.

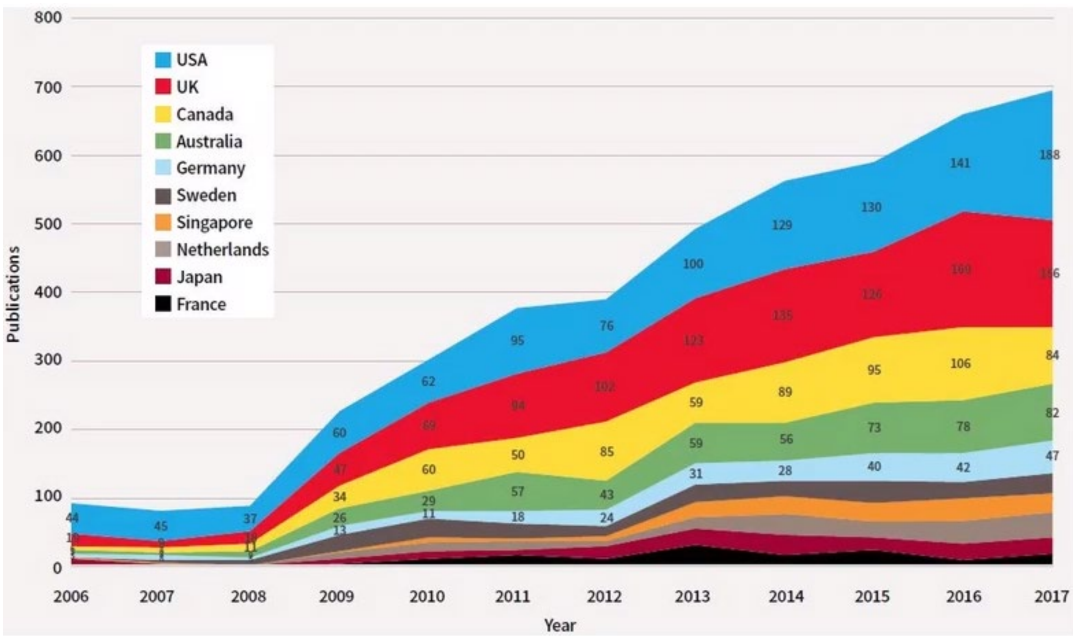
[424] Strider Technologies, *The Los Alamos Club*, 2022, accessed Mar. 24, 2023, https://www.striderintel.com/resources/the-los-alamos-club/.

[425] Strider Technologies, *The Los Alamos Club.*

[426] Alex Joske, *Picking Flowers, Making Honey: The Chinese Military's Collaboration with Foreign Universities*, Australian Strategic Policy Institute, 2018, https://www.aspi.org.au/report/picking-flowers-making-honey.

collaborated with US and other countries' universities, often unknowingly on the part of the university.[427] Figure 32 shows the top 10 countries for PLA collaboration. In May 2020, the Trump Administration put forth new rules limiting the issuance of visas to Chinese nationals with ties to the CCP or PLA for graduate and postgraduate study in the United States. The policy explicitly targets PRC nationals that are linked with entities "in the PRC that implement or support the PRC's 'military-civil fusion strategy.'"[428]

Figure 32. Top 10 countries for PLA collaboration with international universities



Source: Joske, *Picking Flowers, Making Honey: The Chinese Military's Collaboration with Foreign Universities*.

[427] Alex Joske, *Picking Flowers, Making Honey: The Chinese Military's Collaboration with Foreign Universities*.

[428] "Proclamation on the Suspension of Entry as Nonimmigrants of Certain Students and Researchers from the People's Republic of China," National Archives, May 29, 2020, https://trumpwhitehouse.archives.gov/presidential-actions/proclamation-suspension-entry-nonimmigrants-certain-students-researchers-peoples-republic-china/.

Publication volume and quality in nuclear-relevant fields

PRC scholars are increasingly cited in academic and scientific papers, with some metrics indicating that China is becoming a world leader in both numbers of published papers and citations in journals. According to a report by NISTEP, in 2022 PRC scholars became the group most cited in scientific journals globally, edging out the US for number of most cited papers. NISTEP used a methodology called "fractional counting" to calculate the top 1 percent of papers in terms of citations. If a paper had authors from multiple countries, the credit for the citation was divided among authors. For example, if one American and three Swedish institutions contributed to a paper, America received 25 percent of the credit and Sweden 75 percent. Using the fractional counting method, NISTEP calculated that China accounted for 27.2 percent of the most cited papers published in 2018, 2019, and 2020 and the United States for 24.9 percent.

Insights from visits to China's nuclear weapons R&D-related facilities

One of the highest profile instances of US nuclear scientists visiting PRC nuclear weapons facilities occurred in the 1990s and early 2000s. From 1990 through 2001, former Los Alamos National Laboratory nuclear weapons scientist and intelligence analyst Danny B. Stillman made 10 trips to China, visiting the PRC's secret nuclear weapons facilities. During these authorized visits, Stillman and other US nuclear scientists inspected nuclear weapons labs and testing sites, interviewed Chinese weapons designers, and photographed PRC nuclear facilities.[429]

According to Stillman, on one of these visits to the PRC's NINT in 1990, he saw Chinese scientists using advanced technologies and diagnostic equipment for monitoring and evaluating nuclear reactions that surprised him. Stillman assessed that, given the level of sophistication in diagnostic tools used by PRC nuclear scientists, "even in 1990, the Chinese nuclear weapons program was pulling ahead of the United States in many areas."[430] Summarizing his 10 trips to PRC nuclear labs and weapons facilities over the course of a decade, Stillman stated, "I am convinced that Chinese nuclear weapons technology is on par with the United States."[431]

[429] Thomas C. Reed and Danny B. Stillman, *The Nuclear Express* (Minneapolis: Zenith Press, 2009).

[430] Reed and Stillman, *The Nuclear Express,* p. 228.

[431] Reed and Stillman, *The Nuclear Express,* p. 356.

What nuclear weapons and delivery systems does China possess, where are they deployed, and how capable are they?

Land-based strategic forces

Since at least 2012, China has been upgrading, diversifying, and improving its ground-based strategic ICBM arsenal.[432] The 2022 DOD National Defense Strategy assesses that the PRC continues to make dramatic advances in its conventional and nuclear-armed ballistic and hypersonic missile capabilities, in many areas continuing to "close the gap with the United States, and…to develop and expand its missile capabilities."[434] See Table 11 for a list of China's strategic nuclear systems.

> HGVs differ from ballistic reentry vehicles in that they can maneuver as well as potentially adopt a flatter trajectory after they separate from the missile.[433] These elements could make HGVs more difficult to detect and destroy using missile defense systems.

The PRC has unveiled several new missile systems, including the following:[435]

- ICBMs with MIRV capabilities
- IRBMs
- Ground-based cruise missiles
- HGVs capable of carrying an ICBM into space for a fractional orbital launch

In addition, China has been rapidly constructing up to 300 ICBM silos in sites in the western and central-northern part of the country, significantly improving

[432] "The PLA Rocket Force Focuses on Preparing for and Fighting Wars, Accelerates the Promotion of Strategic Capabilities: The New Type Missile Phalanx Forms the Long Sword of a Great Power" (火箭军聚焦备战打仗加速推动战略能力提升 新型导弹方阵铸就大国长剑), *PLA Daily*, Aug. 8, 2022, http://military.cnr.cn/jq/20220808/t20220808_525954319.shtml.

[433] "Defense Primer: Hypersonic Boost-Glide Weapons," Congressional Research Service, updated Nov. 14, 2022, sgo.fas.org/crs/natsec/IF11459.pdf.

[434] US Department of Defense, *2022 National Defense Strategy of the United States of America*.

[435] Office of the Secretary of Defense, US Department of Defense, *Military and Security Developments Involving the People's Republic of China*, 2022.

the PLARF's nuclear-capable missile force.[436] Whether these 300 silos will all be loaded with ICBMs or whether a portion will be used as empty decoys to improve the overall survivability of the PRC's ICBM force is currently unclear.[437]

Table 11. Strategic nuclear systems

Name/Type	NATO Designator	Launcher	Year Deployed	Characteristics (MIRV, Yield, etc.)	Warhead Totals	Locations
DF17 MRBM	CSS-22	54	2021	1 X HGV		Possible locations: 614th Brigade, Yongan; 615th Brigade, Meizhou[438]
DF-21 A/E MRBM	CSS-5 Mods 2, 6	24	2000, 2016	1 X 200-300 (kilotons)	24	612th Brigade, Leping; 651st Brigade, Dengshahe[439]
DF-26 IRBM	CSS-18	162	2016	1 X 200-300 (kilotons)	54	647th Brigade, Xining; 654th Brigade, Dalian; 656th Brigade, Laiwu-Xiqincun; 666th Brigade, Xinyang[440]
DF-4 ICBM	CSS-3	6	1980	1 X 3,300 (kilotons)	0	

436 Office of the Secretary of Defense, US Department of Defense, *Military and Security Developments Involving the People's Republic of China*, 2022, p. 64.

437 Korda and Kristensen, "China Is Building a Second Nuclear Missile Silo Field."

438 Janes notes these as possible locations according to satellite imagery, but they are not confirmed, "Strategic Weapon Systems: PLA Rocket Force," Janes, Feb. 1, 2023.

439 "Strategic Weapon Systems: PLA Rocket Force."

440 "Strategic Weapon Systems: PLA Rocket Force."

Name/Type	NATO Designator	Launcher	Year Deployed	Characteristics (MIRV, Yield, etc.)	Warhead Totals	Locations
DF-5A ICBM	CSS-4 Mod 2	6	1981	1 X 4,000-5,000 (kilotons)	6	633rd Brigade, Huitong[441]
DF-5B ICBM	CSS-4 Mod 3	12	2015	(up to) 5 X 200-300 (kilotons) (MIRV)	60	661st Brigade, Lushi[442]
DF-5C ICBM	CSS-4 Mod 4	In development	(2024)	(MIRV)		
DF-27 ICBM		In development	(2026)			
DF-31 ICBM	CSS-10 Mod 1	6	2006	1 X 200-300 (kilotons)	6	662nd Brigade, Luanchuan[443]
DF-31A ICBM	CSS-10 Mod 2	24	2007	1 X 200-300 (kilotons)	24	621st Brigade, Yibin; 622nd Brigade, Yuxi[444]
DF-31B ICBM	CSS-10 Mod 3 (?)	In development				
DF-31AG ICBM	CSS-10 Mod 2	60	2018	1 X 200-300 (kilotons)	60	632nd Brigade, Shaoyang; 642nd Brigade, Datong; 643rd Brigade, Tianshui[445]
DF-41 (mobile) ICBM	CSS-20	28	2020	(up to) 3 X 200-300 (kilotons)	84	644th Brigade, Hanzhong
DF-41 (silo) ICBM	CSS-20	In development	(2025)	3 X 200-300 (kilotons)		

Source: Unless otherwise noted, data in this table are from Hans M. Kristensen, Matt Korda, and Eliana Reynolds, "Nuclear Notebook: Chinese Nuclear Weapons, 2023," *Bulletin of the Atomic Scientists*, Mar. 13, 2023, https://thebulletin.org/premium/2023-03/nuclear-notebook-chinese-nuclear-weapons-2023/.

441 "Strategic Weapon Systems: PLA Rocket Force."

442 "Strategic Weapon Systems: PLA Rocket Force."

443 "Strategic Weapon Systems: PLA Rocket Force."

444 "Strategic Weapon Systems: PLA Rocket Force,"

445 "Strategic Weapon Systems: PLA Rocket Force."

Sea-based strategic forces

China developing sea-based nuclear forces could extend the range of its nuclear deterrent and allow the PLAN to reach the United States from its littoral waters. See Table 12 for a list of China's sea-based strategic systems.

Since 2007, the PLAN has built 12 nuclear submarines (SSNs):[446]

- 2 Shang-class SSNs (Type 093)
- 4 Shang II-class SSNs (Type 093A)
- 6 Jin-class SSBNs (Type 094)

According to the 2022 DOD annual report, "The PRC is conducting continuous at-sea deterrence patrols with its six Jin-class SSBNs."[447] US defense analysts point out that this is a significant development showing crucial improvements in PLAN capabilities as China joins other countries with top navies such as the United States, Russia, Britain, and France, all of whom have conducted continuous deterrence patrols for decades.[448]

The current range limitations of the JL-2 (around 7,000 kilometers) would require the PLAN's SSBN fleet to operate north and east of Hawaii if the PRC sought to hit targets on the East Coast of the continental US (CONUS). However, with the introduction of the JL-3 SLBM and its longer range of around 9,000 to 10,000 kilometers, the PLAN could strike targets within CONUS from PRC littoral waters.[449] This expanded range greatly enhances the survivability of the PRC's sea-based deterrent, allowing the PRC to threaten a nuclear counterattack even if its land-based missiles and systems were to be destroyed.

Despite the PLAN's recent advancements, PLAN submarines are considered relatively noisy when compared with US or Russian submarines. In submarine technology, the ability to be quiet equates directly with the ability to remain undetected. For example, one Chinese

[446] Office of the Secretary of Defense, US Department of Defense, *Military and Security Developments Involving the People's Republic of China*, 2022, p. 53.

[447] Office of the Secretary of Defense, US Department of Defense, *Military and Security Developments Involving the People's Republic of China*, 2022, p. 94.

[448] Greg Torode and Eduardo Baptista, "Analysis: China's Intensifying Nuclear-Armed Submarine Patrols Add Complexity for U.S., Allies," Reuters, Apr. 3, 2023, https://www.reuters.com/world/chinas-intensifying-nuclear-armed-submarine-patrols-add-complexity-us-allies-2023-04-04/?utm_campaign=dfn-ebb&utm_medium=email&utm_source=sailthru&SToverlay=2002c2d9-c344-4bbb-8610-e5794efcfa7d.

[449] Office of the Secretary of Defense, US Department of Defense, *Military and Security Developments Involving the People's Republic of China*, 2022, p. 96.

researcher stated that "the Type-093 is not as quiet as the USN Seawolf class[450] or Virginia class but is on a par with the improved Los Angeles class."[451] In 2009, the US Office of Naval Intelligence released a chart displaying the quieting trends of submarines for world navies, which shows that the PLAN's submarines are on the more detectable end of the spectrum (Figure 33).

More recently, in October 2022 Chinese scientists from China's State Key Laboratory of Mechanical System and Vibration at Shanghai Jiao Tong University claimed to have developed a new pump-jet propulsion system capable of giving PLAN submarines higher thrust while reducing noise from vibrations by "more than 90 per cent."[452] Although this is research is still theoretical and under development, if implemented, this technology could allow the PLAN to produce substantially quieter future generations of submarines.

Table 12. Sea-based strategic systems

Name/Type	NATO Designator	Year Deployed	Characteristics (MIRV, Yield, Range)	Warhead Totals	Locations
JL-2 SLBM	CSS-N-14	2016	1 X 200-300 (kilotons), 7,000+ km range	0	Likely Longposan naval base on Hainan Island[453]
JL-3 SLBM	CSS-N-20	2022	Single or MIRV, 9,000+ km range	72	Likely Longposan naval base on Hainan Island[454]

Source: CNA.

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[450] The USN Seawolf is a nuclear-powered fast attack submarine (SSN) designed in 1983.

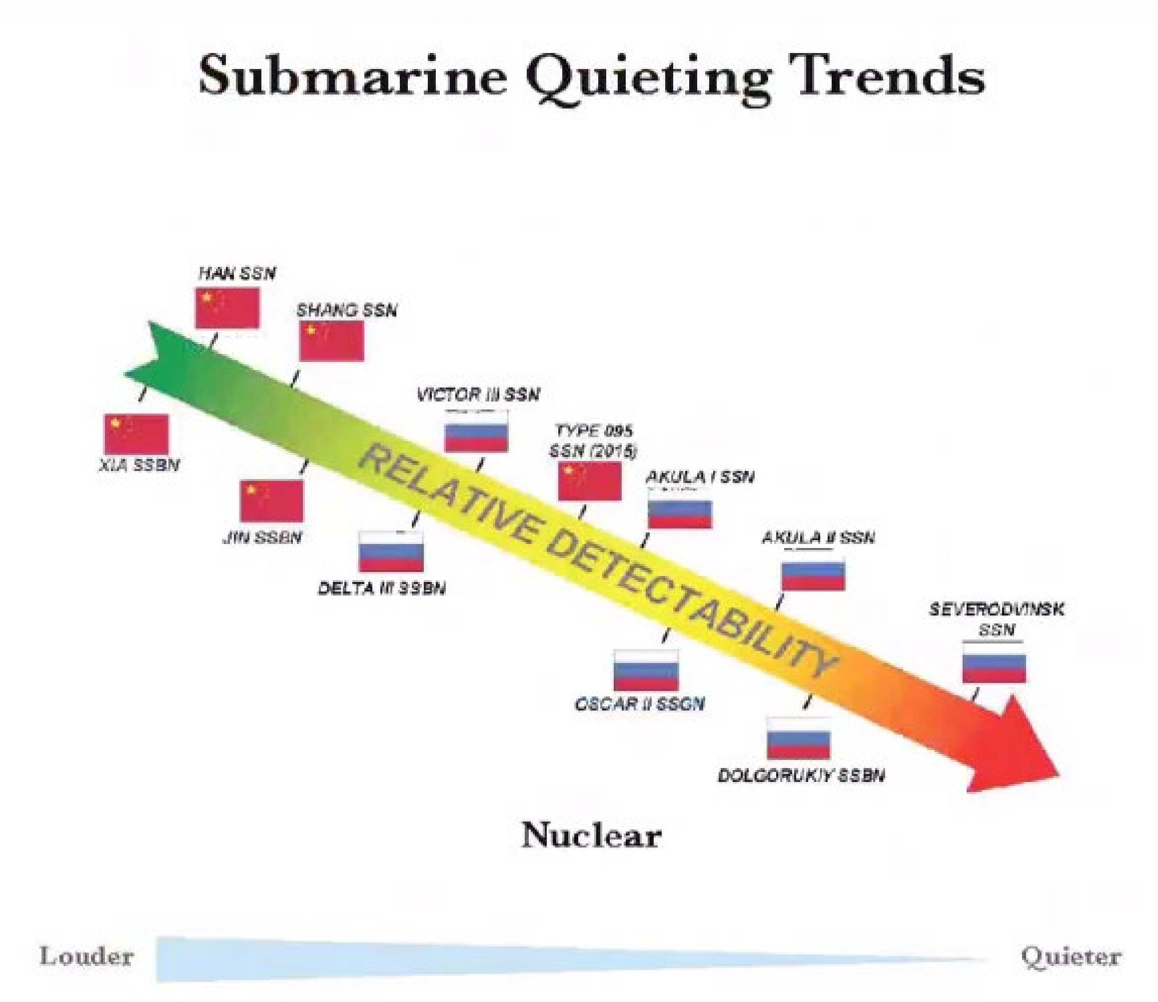
[451] As quoted in Andrew S. Erickson and Lyle J. Goldstein. "China's Future Nuclear Submarine Force," *Naval War College Review* 60, no. 1 (2007), https://digital-commons.usnwc.edu/nwc-review/vol60/iss1/6.

[452] Stephen Chen, "China's Submarines Can Be Quieter, More Powerful with New Pump-Jet: Scientists," *South China Morning Post*, Oct. 14, 2022, https://www.scmp.com/news/china/science/article/3195922/chinas-submarines-can-be-quieter-more-powerful-new-pump-jet.

[453] Kristensen, Korda, and Reynolds, "Nuclear Notebook: Chinese Nuclear Weapons, 2023."

[454] Kristensen, Korda, and Reynolds, "Nuclear Notebook: Chinese Nuclear Weapons, 2023."

Figure 33. Graphic showing detectability of submarines



Source: *The People's Liberation Navy: A Modern Navy with Chinese Characteristics*, ONI, Aug. 2009, https://irp.fas.org/agency/oni/pla-navy.pdf.

Air-launched strategic forces

China continues to develop its strategic bomber wing, expanding the PRC's nuclear deterrent and increasing the range of its air-launched nuclear delivery. The H-20 stealth strategic bomber will likely have a range of more than 10,000 kilometers, allowing coverage into the

Western Pacific, and with the addition of aerial refueling, the PLAAF's strategic deterrent reach could be extended globally.[455] See Table 13 below for a list of China's air-launched strategic nuclear systems.

Table 13. Air-launched strategic nuclear systems

Launcher	Number of Launchers	Year Deployed	Characteristics	Totals	Locations
H-6K bombers	10	1965 with 2009 upgrades	1 X bomb	10[a]	Anqing, Anhui province[b]
H-6N bombers	10	2020	1 X ALBM	10[a]	Neixiang, Henan province[c]
H-20 (in development)		(2028)	(bomb/ALCM)		

[a] Likely a conventional ALBM that could be armed with a nuclear warhead.
[b] Fielded at the PLAAF 10th Air Division's 28th Air Regiment (AR), Kenneth W. Allen, *PLA Air Force: Bomber Force Organization*, China Aerospace Studies Institute, May 2, 2022, https://www.airuniversity.af.edu/Portals/10/CASI/documents/Research/CASI%20Articles/2022-05-02%20PLAAF%20Bomber%20Organization.pdf.
[c] Fielded at the PLAAF Headquarters, 106th Air Brigade, Allen, *PLA Air Force: Bomber Force Organization*.

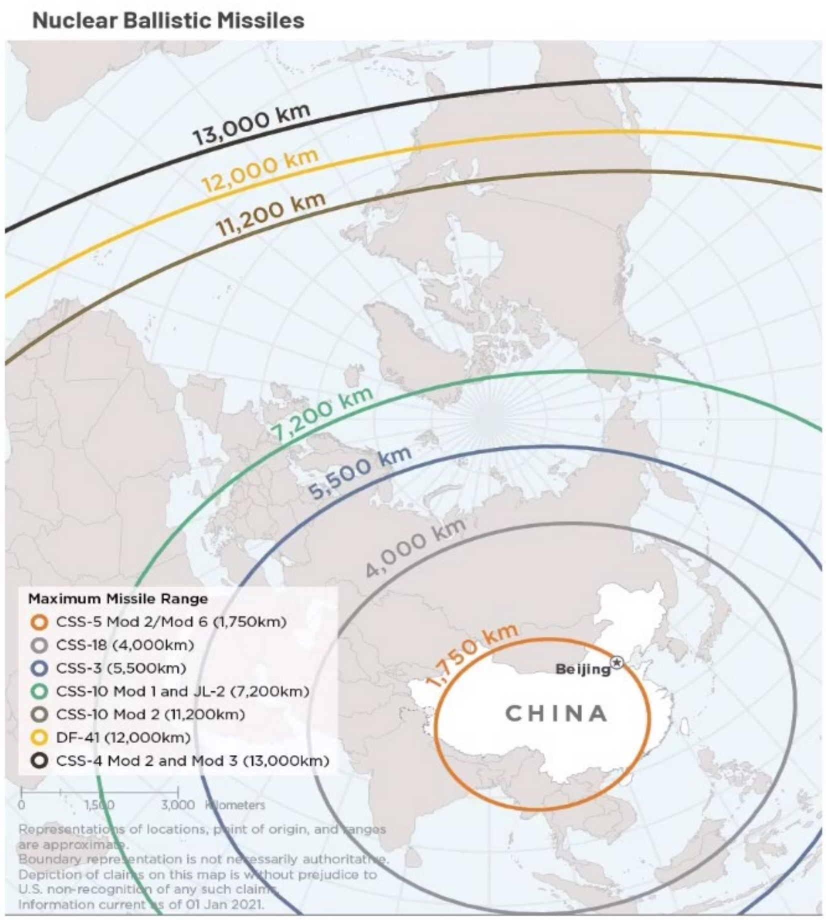
China's nuclear capabilities

China is actively modernizing its nuclear arsenal, making robust qualitative and quantitative improvements to its capabilities. The US DOD National Defense Strategy (2022) identifies the PRC as the "overall pacing challenge for US defense planning and a growing factor in evaluating our nuclear deterrent."[456] China likewise perceives the United States as its main threat and key competitor in this regard. As China modernizes its nuclear force, its capability to reach CONUS with nuclear weapons increases—because of longer range delivery systems and an emerging nuclear triad capable of patrolling farther from China's shores. Figure 34 illustrates the ranges of China's ICBMs, with at least three types able to reach CONUS.

[455] Office of the Secretary of Defense, US Department of Defense, *Military and Security Developments Involving the People's Republic of China*, 2022, p. 83.

[456] US Department of Defense, *2022 National Defense Strategy of the United States of America*.

Figure 34. PRC nuclear ballistic missile ranges



Source: Office of the Secretary of Defense, US Department of Defense, *Military and Security Developments Involving the People's Republic of China,* 2022, p. 66.

Conclusion

China is a rapidly maturing nuclear weapons state that declares an NFU employment policy but assures a retaliatory strike in defense if attacked with nuclear weapons. Historically, China maintained a relatively low number of warheads compared to the US and Russia—enough to assure a survivable second strike. China's nuclear posture has also been believed to be at a low alert level, with its warheads stored separately from delivery systems. However, China's perceptions of evolving strategic deterrence, which could erode the mutual vulnerability at the core of US-China relations, coupled with a changing international security environment and China's rising prominence as a global economic and military power appear to be pushing the PRC to modernize and expand its nuclear arsenal as well as extend its suite of strategic options. China is rapidly developing a resilient nuclear triad of sea-, air-, and ground-based delivery systems (as well as testing space-based delivery systems) and may be considering changing its nuclear posture to a LOW alert level, in alignment with the US and Russian postures. Although China declares that it stopped producing fissile material in the 1980s, it still maintains a stockpile capable of doubling its arsenal and could theoretically turn to its civilian reactors to increase its fissile stockpile. In addition, China's research facilities, human talent in the STEM field, state-sanctioned scientific recruitment policies, and investments in STEM education likely give it the capabilities necessary to modernize and advance its nuclear arsenal in accordance with strategic demands.

North Korea's Nuclear Program

North Korea's aspiration to become a nuclear power dates back to the Korean War, when it faced the threat of nuclear attack by the United States.[457] Over the decades, it slowly assembled the foundations of a nuclear program, and progress accelerated after the end of the Cold War, when the regime shifted its military doctrine away from reunification of the Korean Peninsula by force to regime survival. As the regime's conventional force atrophied and fell further behind that of its primary enemies on the Korean Peninsula, the Republic of Korea (ROK—also called South Korea) and the United States, Pyongyang shifted to an asymmetric strategy based on a nuclear force to ensure a viable deterrent. In 2003, North Korea withdrew from the Non-Proliferation Treaty (NPT) in the face of what it described as an increasingly aggressive US posture around the world that included the use of regime change.[458] This move was accompanied by a rapid increase in missile and nuclear tests despite international condemnation and sanctions.[459]

North Korea admitted to having nuclear weapons in 2005 and then conducted its first nuclear test in 2006. Since then, it has conducted five additional nuclear tests as well as hundreds of short-, medium-, and long-range missile tests through 2022. The development of two intercontinental ballistic missiles (ICBMs), the Hwasong-15 and Hwasong-17, and the Pukkuksong submarine-launched ballistic missile (SLBM) signals North Korea's determination to achieve the ability to range the continental United States with nuclear weapons. In addition, North Korea also aspires to field tactical or theater nuclear weapons that could be used on the Korean Peninsula. In 2012, the Supreme People's Assembly (SPA) amended the constitution to refer to North Korea as a nuclear weapons state. The country's policy on the use of nuclear weapons was left ambiguous. Ten years later, in September 2022, the SPA passed a new law reinforcing the status of North Korea's nuclear program, which North Korean Supreme Leader

[457] Joseph S. Bermudez Jr., *North Korea's Development of a Nuclear Weapons Strategy*, US-Korea Institute at SAIS, 2015, https://www.38north.org/wp-content/uploads/2015/08/NKNF_Nuclear-Weapons-Strategy_Bermudez.pdf.

[458] Kelsey Davenport, "Chronology of U.S.-North Korean Nuclear and Missile Diplomacy," Arms Control Association, updated Apr. 2022, accessed Nov. 14, 2022, https://www.armscontrol.org/factsheets/dprkchron.

[459] US-led diplomatic initiatives intended to curtail North Korea's nuclear program, including the Agreed Framework (1994–2002), Six Party Talks (2003–2009), 2018–2019 Nuclear Diplomacy, and sanctions-based economic pressure, have failed to halt Pyongyang's nuclear development.

Kim Jong Un said is "irreversible." The new law also enshrined Pyongyang's right to use preemptive nuclear strikes to protect itself—updating a previous stance under which it had said that it would keep its weapons only until other countries denuclearized and would not use them preemptively against nonnuclear states.

What factors drive North Korea's nuclear program?

Strategic decision-making by North Korea's rulers has primarily been driven by two key objectives: regime survival and perpetuation of the Kim family's rule. North Korea, as an economically and diplomatically isolated state, views nuclear weapons as the ultimate guarantor of its security and a deterrent to any attempt at regime change.[460] This section provides a brief overview of the ideological and historical factors that have driven North Korea's determination to develop nuclear weapons and the role that these weapons play in the regime's strategic calculus.

Ideological underpinnings: the *Juche* doctrine of self-reliance

The ideological foundation of the North Korean regime rests on the philosophy of *Juche*, which means "agency" but is often translated as "self-reliance." Dating back to the late 1940s and the creation of the regime, *Juche* legitimizes the narrative of victimization at the hands of a belligerent international order that forced the country to go its own way. It shapes the country's view of the world as being inherently hostile and preaches independence along three axes: politics, defense, and the economy.[461] It provides the justification for the nuclear program as a deterrent against threats posed by the great powers, namely the United States.

[460] This includes deterring both the ROK (using shorter range nuclear weapons) and the United States (using ICBMs). Note that North Korea's interest in using different range weapons to threaten the US homeland and its allies has a different logic than Cold War era "decoupling." A perennial concern during the Cold War was that the Soviet Union could invade US North Atlantic Treaty Organization allies while deterring US intervention using its strategic-range forces that could threaten the US homeland. Using the threat of attack on the homeland could "decouple" US interests from those of its allies. The North Koreans almost certainly do not envision using their ICBMs in this way because they likely understand that they lack the ability to invade South Korea without risking regime survival. Thus, using the logic of decoupling to enable aggression against the ROK while keeping the US out of the conflict is likely not a motivator for North Korea's pursuit of ICBMs.

[461] Edward Howell, "The Juche H-Bomb? North Korea, Nuclear Weapons and Regime-State Survival," *International Affairs* 96, no. 4 (2020): 1051–1068.

The nuclear program and national ideology are inextricably linked in that they feed off each other in how the regime portrays itself to the people and how the people view the legitimacy of the regime. Military self-reliance (자위; *jawi*) is crucial for the country to maintain its political independence. Self-reliance is done through the development of a domestic defense industry that can handle threats along the spectrum from the conventional to the nuclear. North Korea's propaganda since the Korean War has contrasted its military autonomy with the presence of US forces in South Korea.[462] Although North Korea relied on foreign support to develop its military power, including its nuclear program, Kim Jong Il justified this apparent contradiction by arguing that it was acceptable because such aid would be effective only if the state was militarily strong in its own right.[463]

Possibly more important to the Supreme Leader and the wider leadership, the nuclear program undergirds the ideology by providing the means by which *Juche* can be executed. Without the deterrent that the nuclear program provides, the independence that *Juche* espouses would be vulnerable to external interference up and to the point of regime survival. By providing the "treasured sword" to protect the North Korean people, the nuclear program conveys legitimacy on the regime as the provider of that sword, as well as the Supreme Leader. In the absence of progress on the economy, Kim Jong Un has had to rely on the nuclear program as his sole source of legitimacy. By developing the program, he can argue that he has allowed North Korea to survive despite the challenges it faces, thus realizing the basic precepts of *Juche*.

Historical underpinnings of the nuclear program

North Korea's first ruler, Kim Il Sung, recognized the destructive power of nuclear weapons and their effect on the geopolitical strategic environment upon hearing reports of how atomic weapons used against Hiroshima and Nagasaki had forced Japan to surrender, ending World War II.[464] Kim Il Sung's opinion of nuclear weapons was further hardened after learning that the US had strongly considered using such weapons during the Korean War against North Korea.[465]

Economic and security factors and Cold War competition shaped North Korea's pursuit of nuclear weapons in the 1950s, 1960s, and 1970s. After fighting in the Korean War ended with

[462] Michael E. Robinson, *Korea's Twentieth-Century Odyssey* (Honolulu: University of Hawaii Press, 2007).

[463] Kim, Jong Il, *On the Juche Idea* (Pyongyang: Foreign Languages Publishing House, 1982).

[464] Bermudez Jr., *North Korea's Development of a Nuclear Weapons Strategy*, p. 8.

[465] Bermudez Jr., *North Korea's Development of a Nuclear Weapons Strategy.*

an armistice in 1953, reunification of the Korean Peninsula was a closely held goal by both North and South Korea. Pyongyang and Seoul were determined that neither country gain the economic, political, or military advantage that would enable either state to break the armistice and reunify the peninsula under its own rule by force or by economic or political absorption. This competition manifested in the nuclear space as South and North Korea began to pursue nuclear energy programs, receiving support from the United States and the Soviet Union, respectively. In February 1956, through the "Atoms for Peace" program, US President Dwight D. Eisenhower formalized a preliminary agreement with South Korea on the peaceful use of nuclear energy.[466] Shortly thereafter, Moscow signed a separate agreement with North Korea on the organization of joint nuclear research. In 1958, the United States deployed nuclear weapons in South Korea, keeping as many as 950 warheads in the south until withdrawing the arsenal in 1991.[467] In 1959, North Korea and the Soviet Union signed a treaty providing Soviet technical assistance for the establishment of a North Korean nuclear research center at Yongbyon, which created the basis for Soviet assistance in the construction of an experimental reactor in North Korea.[468]

Throughout the 1960s and 1970s, North Korea continued to attempt to leverage its relations with the Soviet Union and to an extent the People's Republic of China (PRC) in its competition with South Korea. However, by the 1980s, South Korea began to dramatically outperform North Korea in both the economic and security domains. South Korea's economy and conventional military force capabilities surpassed those of North Korea. With the collapse of the Soviet Union around the end of the decade, North Korea lost its primary patron and major source of economic and military aid. North Korea's leadership—Kim Il Sung and his son and successor Kim Jong Il—understood that as long as this economic and security status quo

[466] Balázs Szalontai and Sergey Radchenko, *North Korea's Efforts to Acquire Nuclear Technology and Nuclear Weapons: Evidence from Russian and Hungarian Archives*, Woodrow Wilson Center, Cold War International History Project, Working Paper #53, Aug. 2006, https://www.wilsoncenter.org/sites/default/files/media/documents/publication/WP53_web_final1.pdf, p. 3.

[467] The decision to withdraw US nuclear weapons from South Korea was part of US President George H.W. Bush's initiative to withdraw the United States' "entire worldwide inventory of ground-launched, short-range…theater nuclear weapons." As of 1991, approximately 100 US warheads remained in South Korea. George H.W. Bush, "Address to the Nation on Reducing United States and Soviet Nuclear Weapons," Sept. 27, 1991, https://bush41library.tamu.edu/archives/public-papers/3438, cited in Hans M. Kristensen and Robert Norris, "A History of US Nuclear Weapons in South Korea," *Bulletin of Atomic Scientists*, Nov. 2, 2017, https://thebulletin.org/2017/11/a-history-of-us-nuclear-weapons-in-south-korea/#:~:text=During%20the%20Cold%20War%2C%20the%20United%20States%20deployed,umbrella%E2%80%9D%20using%20nuclear%20bombers%20and%20submarines%20based%20elsewhere.

[468] Szalontai and Radchenko, *North Korea's Efforts to Acquire Nuclear Technology and Nuclear Weapons*.

persisted, the regime would be vulnerable. In response, each Kim leader prioritized the country's nuclear program, reasoning that having a nuclear capability would allow North Korea to defend itself and would raise adversaries' (namely the United States and South Korea) cost of threatening North Korea's security.

North Korea's interpretation of US actions taken against other states from the 1980s onward also played a role in hardening North Korea's calculus by reinforcing the leadership's belief that Washington, if given the opportunity, would attempt to impose regime change in North Korea. North Korean officials have cited US military action against regimes in Grenada (Operation Urgent Fury, 1983), Iraq (and Operation Iraqi Freedom, 2003), and Libya (Operation Odyssey Dawn, 2011), as key informative events for their leadership's thinking on US intentions.[469] In three of the four cases, the US took military action that eventually led to regime change.[470] Although it was not US forces that ultimately overthrew Libyan leader Muammar Qaddafi, North Koreans also cite the case of Libya as a lesson learned.[471] North Koreans pointed out that Qaddafi made a fatal error in trusting "the West" by giving up his country's nuclear program in the early 2000s in exchange for improving relations with the international community and receiving economic aid.[472] According to the North Korean narrative, the West's bargain with Libya was "an invasion tactic to disarm the country," which made Qaddafi vulnerable to eventual invasion.[473]

[469] "Foreign Ministry Statement," KCNA, Oct. 25, 2002; Bermudez Jr., *North Korea's Development of a Nuclear Weapons Strategy*; "The Full Text of Kim Jong Un's Remarks at the Plenary Session of the Party Central Committee," Korean Central News Agency, Apr. 1, 2013.

[470] Following the end of major combat operations in Iraq, North Korea issued the following statement: "The bloody lesson of the war in Iraq for the world is that only when a country has physical deterrent forces and massive military deterrent forces that are capable of overwhelmingly defeating any attack by state of the art weapons, can it prevent war and defend its independence and national security." Quoted in Joseph S. Bermudez, "KPA Lessons Learned from Foreign Conflicts 1960-Present, Part II," *KPA Journal* 1 (2010), cited in Jerry Meyerle, *Nuclear Weapons and Coercive Escalation in Regional Conflicts: Lessons from North Korea and Pakistan*, CNA, Nov. 2014, DRM-2014-U-008209-Final2.

[471] "The present Libyan crisis teaches the international community a serious lesson…. that peace can be preserved only when one builds up one's own strength…The DPRK was quite just when it took the path of Songun (military first policy) and the military capacity for self-defense built up…" North Korean Foreign Ministry Spokesperson via KCNA, http://www.kcna.co.jp/item/2011/201103/news22/20110322-34ee.html.

[472] Mark McDonald, "North Korea Suggests Libya Should Have Kept Nuclear Program," *New York Times*, Mar. 24, 2011, http://www.nytimes.com/2011/03/25/world/asia/25korea.html.

[473] McDonald, "North Korea Suggests"; "N. Korea Condemns U.S. over Air Strikes on Libya," KCNA in Yonhap News, Mar. 22, 2011, via http://english.yonhapnews.co.kr/northkorea/2011/03 /22/87/0401000000AEN20110322009900315F.HTML.

Nuclear weapons have also played a significant role in North Korea's internal political situation. Current leader Kim Jong Un inherited North Korean leadership after the sudden death of his father, Kim Jong Il, in 2011. The younger Kim—in only his late 20s when he assumed power—lacked any real political experience before his accession.[474] Moreover, the complexities of power transition in North Korea posed threats to stability from within. To establish his leadership and consolidate his power over the regime, Kim Jong Un had to produce a signature vision for the country's future. In 2013 he announced his strategic policy, *byungjin*, which calls for the parallel development of the country's national defense programs and modernization of the economy. In practice, "national defense programs" has translated to improving the country's nuclear weapons capabilities. By linking his name to *byungjin*, a term that dates to the Kim Il Sung era,[475] Kim Jong Un was able to expand his own legitimacy among the wider leadership and domestic audience. Since establishing the *byungjin* policy line, North Korea has achieved significant progress on its nuclear program, even as meaningful improvement of the country's economic conditions has remained elusive. This lack of economic improvement is in part due to international sanctions imposed on the regime in response to North Korea's nuclear weapons activities. North Korean propaganda highlights that North Korea's nuclear weapons advancement and the security assurance that nuclear weapons provide are a direct result of Kim's guidance and vision. Through this messaging, the regime can attempt to downplay the Kim regime's deficiencies in improving the country's economic prospects. North Korea's nuclear program, therefore, provides Kim, and by extension the Kim family regime, with a key source of legitimacy.

> *Byungjin* is Kim Jong Un's strategic policy guideline promoting both the advancement of economic development and the strengthening of national defense programs. It is a significant shift away from the previous policy, *songun,* "security for the country by military first," that his father, Kim Jong Il, promoted.

[474] Kim Jong Un's exact age is a source of debate. Estimates of his birth year range between 1982 and 1985.

[475] Kim Il Sung proclaimed his *byungjin* policy of "economic and national defense capability" during the 5th plenary session of the 4th Central Committee in December 1962, with the accompanying revolutionary slogan, "A gun in one hand, a hammer and sickle in the other!" Cheon Seong Whun, *The Kim Jong Un Regime's "Byungjin" (Parallel Development) Policy of Economy and Nuclear Weapons and the "April 1st Nuclearization Law*," Korea Institute for National Unification (KINU), Online Series CO 13-11, Apr. 23, 2013, https://repo.kinu.or.kr/bitstream/2015.oak/2227/1/0001458456.pdf.

What are North Korea's nuclear weapons policies?

Although North Korea does not release formal military strategy documents, such as defense white papers or nuclear posture review reports, it is still possible to discern components of the country's emergent nuclear policy through public statements, legislative activities, and careful interpretation of political rhetoric.

As North Korea's nuclear program has developed, Pyongyang has incrementally clarified its emergent nuclear policy. Before 2003, North Korea claimed that it had "no intention of developing nuclear weapons" and that its nuclear activities would be limited to civil energy generation.[476] However, in the same year, after being presented with evidence by the US of its clandestine program, Pyongyang acknowledged its intent to build a "nuclear deterrent force." Subsequent regime statements consistently referred to the country's sovereign right to nuclear weapons for self-defense against nuclear or conventional attack from "hostile forces."[477]

North Korea amended its constitution in 2012 to refer to itself as a nuclear weapons state. Two laws on nuclear policy passed in 2013 and 2022 provide the most clarity on North Korea's emergent nuclear policy. During the Kim Jong Un era, North Korea has consistently emphasized the defensive nature of its nuclear weapons program while simultaneously alluding to its potential for preemptive and offensive employment were North Korea to be attacked. North Korea's messaging generally reinforces four principles of North Korea's emergent nuclear policy:

1. North Korea is a responsible nuclear state.
2. North Korea's nuclear program is necessary to deter outside aggression from hostile forces.
3. North Korea reserves the right to use nuclear weapons if attacked.
4. North Korea will not unilaterally denuclearize.

[476] Dong-Ki Sung, "North Korea Announces It Has No Intention of Developing Nuke Weapons," Dong-A Ilbo, Jan. 22, 2003. However, the Yongbyon nuclear reactor reportedly was not attached to the electrical grid, at least before 2005. Nicholas Eberstadt, "A Skeptical View," *Wall Street Journal*, Sept. 21, 2005, p. 26.

[477] Leonie Allard, Mathieu Duchatel, and Francois Godement, *Pre-Empting Defeat: In Search of North Korea's Nuclear Doctrine, European Council on Foreign Relations*, Nov. 22, 2017, https://ecfr.eu/publication/pre_empting_defeat_in_search_of_north_koreas_nuclear_doctrine/.

Although these general principles have remained consistent, in recent years, a shift in North Korea's rhetoric has more explicitly emphasized the possible preemptive use of nuclear weapons and potential employment of tactical nuclear weapons and provided more insight on conditions that would affect North Korean nuclear decision-making.

In 2022, North Korea passed its law on State Policy on the Nuclear Forces. The 2022 law supersedes the 2013 law, and it reiterates and reinforces many of the central tenets of the country's nuclear policy and provides additional insights into the missions, command and control (C2) structure,[478] and principles and conditions for use of nuclear weapons.[479] Of note, the 2022 law makes the clearest distinction to date on North Korea's thinking on preemption and tactical use of nuclear weapons in a conflict but is still quite ambiguous in terms of North Korea's employment policy.

Missions of the nuclear force

The 2022 law briefly describes the primary missions of the country's nuclear forces: to deter attack and counter or repel an attack should deterrence fail.

"The nuclear forces of the DPRK [Democratic People's Republic of Korea] shall be a main force of national defense which safeguards the sovereignty and territorial integrity of the country and the lives and safety of the people from outside military threat, aggression and attack."[480] The law states the following:[481]

1. "The nuclear forces of the DPRK shall regard it as their main mission to deter a war by making hostile forces have a clear understanding of the fact that the military confrontation with the DPRK brings about ruin and give up their attempts at aggression and attack."
2. "The nuclear forces of the DPRK shall carry out an operational mission for repulsing hostile forces' aggression and attack and achieving decisive victory of war in case war deterrence fails."

[478] Implications of the 2022 law for North Korean nuclear C2 will be discussed in a later section of this paper.

[479] Bruce Klingner, *The Troubling New Changes to North Korea's Nuclear Doctrine*, Heritage Foundation, Oct. 17, 2022, https://www.heritage.org/asia/report/the-troubling-new-changes-north-koreas-nuclear-doctrine.

[480] "DPRK's Law on Policy of Nuclear Forces Promulgated," accessible through KCNA Watch, Sept. 2022, https://kcnawatch.org/newstream/1662721725-307939464/dprk%E2%80%99s-law-on-policy-of-nuclear-forces-promulgated/.

[481] "DPRK's Law on Policy of Nuclear Forces Promulgated."

Principles of nuclear use

The law reiterates that North Korea would use nuclear weapons only in an extreme scenario in which the regime is threatened and that North Korea would not threaten use of nuclear weapons against a nonnuclear state unless they "join aggression or attack [North Korea] in collusion with other nuclear states." The law states the following:[482]

1. "The DPRK shall regard it as its main principle to use nuclear weapons as the last means in order to cope with outside aggression and attack seriously threatening the security of the country and the people."
2. "The DPRK shall neither threaten nonnuclear states with its nuclear weapons nor use nuclear weapons against them unless they join aggression or attack against the DPRK in collusion with other nuclear states."

Conditions for nuclear use

The law also lists five conditions in which North Korea would employ nuclear weapons. [483]

1. "In case an attack by nuclear weapons or other weapons of mass destruction (WMDs) has been launched or the like **is judged to be on the horizon**."
2. "In case **a nuclear or non-nuclear attack** by hostile forces **on the state leadership and the command of the state's nuclear forces** has been launched or is judged to be on the horizon."
3. "In case a fatal military attack **against important strategic objects of the state** has launched or the like is judged to be on the horizon."
4. "In case the operation for preventing the expansion and protraction of a war and **taking the initiative in the war is inevitably needed**."
5. "In other case [sic] an **inevitable situation** in which it is compelled to respond by nuclear weapons alone to the catastrophic crisis over the existence of the state and safety of the people is created." (All emphases added by CNA)

These conditions provide a framework for better understanding North Korean decision-making regarding nuclear use; however, several questions and ambiguities remain. For instance, it is unclear how or when North Korea would judge that a strategic strike is "on the

[482] "DPRK's Law on Policy of Nuclear Forces Promulgated."

[483] "DPRK's Law on Policy of Nuclear Forces Promulgated."

horizon" or what North Korea considers "important strategic objects of the state." Collectively, the conditions highlight that North Korea's nuclear policy explicitly permits the use of nuclear weapons preemptively. Although North Korea's declaration of intent to initiate preemptive nuclear attacks against threats has been previously expressed in policy and in leadership statements over the past decade,[484] this new law codifies specific circumstances in which preemptive nuclear use might be initiated—including countering perceived preparations for a nuclear or nonnuclear attack on regime leadership, nuclear command structure, or important strategic targets. Whereas earlier statements have mentioned specific aggression from the enemy, this law highlights the significance of a *perceived* attack.

Other nuclear-armed states—including the United States—have adopted similar policies or left their policies ambiguous. Although this approach may strengthen deterrence by introducing caution-inducing uncertainty into adversary decision-making, it may also increase the risk that a misunderstanding could lead to nuclear use. Many of the conditions rely on North Korea's perspective or judgment of a situation, but how such judgments would be informed is unclear. For example, it is not clear that North Korea has developed a robust early warning system or the ability to detect an incoming attack.[485] How North Korea would judge that a WMD attack is imminent is unclear.

At the time of the 2022 law's promulgation, inter-Korean tensions were building amid North Korea's aggressive missile testing, the election of President Yoon Suk Yeol in South Korea, and the overall stall in inter-Korean dialogue pursued by the previous South Korean president, Moon Jae-in. The conditions for nuclear use described within the 2022 law appear to establish key counterpoints to the escalating "war of words" on the Korean Peninsula under the Yoon Administration. The second condition is particularly instructive because it clarifies that an attack on the state leadership or the C2 of the state's nuclear forces could trigger a nuclear response from North Korea. This condition is likely directed, in part, to counter South Korea's

[484] After United Nations Sanctions Resolution 2270 was unanimously passed by the United Nations Security Council (sanctions primarily targeting North Korean state entities specifically involved in weapons development, such as the Ministry of Atomic Energy Industry and the Munitions Industry Department), Kim Jong Un as Commander-in-Chief of the Korean People's Army (KPA, North Korea's military) reportedly ordered the KPA to have deployed nuclear warheads on standby so that they can be "fired at any moment" and also said that "now is the time for us to convert our mode of military counteraction toward the enemies into a pre-emptive attack one in every aspect." Choi Kang and Kim Gibum, "A Thought on North Korea's Nuclear Doctrine," *The Korean Journal of Defense Analysis* 29, no. 4 (2017): 495–511; Jack Kim, "N. Korea Leader Tells Military to Be Ready to Use Nuclear Weapons," Reuters, Mar. 4, 2016, accessed Feb. 22, 2017, http://www.reuters.com/article/northkorea-nuclear-kim/n-korea-leader-tells-military-to-beready-to-use-nuclear-weapons-idUSKCN0W52PN.

[485] Details of North Korea's aging early warning system will be covered in the section on North Korea's nuclear C2.

increased references to its "decapitation strategy," which comprises "Kill Chain" and "Korean Massive Punishment and Retaliation" strategies.[486]

Figure 35. Kim Jong Un in front of Hwasong-17 intercontinental ballistic missile

Source: "Respected Comrade Kim Jong Un Has Photo Session with Contributors to Successful Test-Fire of New-Type ICBM Hwasongpho-17," KCNA, Nov. 27, 2022, http://www.youth.rep.kp/index.php/article/2022/11/27/1.

[486] South Korea's "decapitation strategy" refers to its military planning for preemptive and retaliatory strikes against the North Korean leadership under its Kill Chain and Korean Massive Punishment and Retaliation (KMPR) strategies, respectively. Kill Chain, first introduced in 2013 following North Korea's third nuclear test, refers to a preemptive strike against North Korea's ballistic missiles or WMDs. As described by Doyeong Jung, "If there are signs of an imminent attack by North Korea to launch a ballistic or nuclear-loaded missile targeting South Korea, Kill Chain aims to preemptively eliminate the threat by initiating a precision strike against North Korea's military assets, such as missile silos, before the missile is launched." KMPR, first introduced under the Park Geun Hye Administration in 2016 following North Korea's fifth nuclear test, is specifically intended to target Kim Jong Un and other key nodes of the North Korean leadership. The Moon Administration did not emphasize the concept as he pursued diplomacy with North Korea. President Yoon, however, has vowed to reinvigorate military planning in support of the strategy and has presented a three-axis plan of which Kill Chain and KMPR are two parts; the third axis refers to South Korea's Air and Missile Defense. Doyeong Jung, "South Korea's Revitalized 3-Axis System," *Asia Unbound (CFR blog)*, Jan. 4, 2023, https://www.cfr.org/blog/south-koreas-revitalized-three-axis-system; Ankit Panda, "South Korea's 'Decapitation' Strategy Against North Korea Has More Risks Than Benefits," Carnegie Endowment for International Peace, Aug. 15, 2022, https://carnegieendowment.org/2022/08/15/south-korea-s-decapitation-strategy-against-north-korea-has-more-risks-than-benefits-pub-87672.

Leadership statements on nuclear policy and priorities

Kim Jong Un's statements on the nuclear program reinforce the nuclear policies expressed in North Korea's constitution and laws. In a speech given at the 2022 SPA—at which the 2022 State Policy on the Nuclear Forces law was passed—he underscored North Korea's commitment to nuclear weapons and specified that North Korea would not negotiate away its nuclear program, stating:

> There will never be any declaration of "giving up our nukes" or "denuclearization," nor any kind of negotiations or bargaining to meet the other side's conditions… Through stipulating our nuclear power policy in a law, our country's status as a nuclear weapons state has now become irreversible… As long as nuclear weapons exist on Earth and imperialism remains…our road towards strengthening nuclear power won't stop.[487]

Kim has also consistently participated in tests and demonstrations of the various components of North Korea's nuclear capabilities, signaling that he and the program are inextricably linked. At a November 2022 test of an ICBM, Kim underscored the key tenet of North Korea's nuclear policy, declaring, "if the enemies continue to pose threats to [North Korea], frequently introducing nuclear strike means, our Party and government will resolutely react to nukes [sic] with nuclear weapons and to total confrontation with all-out confrontation."[488]

Kim has also used speeches to reinforce North Korea's policy lines and intentions for his nuclear program. Examples include the following:

- In his 2021 New Year's Address, Kim Jong Un declared a goal of attaining an "advanced capability for making a pre-emptive and retaliatory nuclear strike by further raising the rate of precision good enough to strike and annihilate any strategic targets within

487 Kim Jong Un, quoted in *Rodong Simun*, "조선민주주의인민공화국 최고인민회의 제１４기 제７차회의에서 하신 경애하는 김정은동지의 시정연설 주체１１１(２０２２)년 ９월 ８일," Sept. 9, 2022, available via KCNA Watch, cited in Colin Zwirko and Jeongmin Kim, "Kim Jong Un Says He Will 'Never Give Up' Nuclear Weapons, Rejects Future Talks," NKNews, Sept. 9, 2022, https://www.nknews.org/2022/09/kim-jong-un-says-he-will-never-give-up-nuclear-weapons-rejects-future-talks/.

488 "Respected Comrade Kim Jong Un Guides Test-Fire of New-Type ICBM of DPRK's Strategic Forces," KCNA, Nov. 19, 2022, via KCNA Watch, https://kcnawatch.org/newstream/1669013191-228361935/respected-comrade-kim-jong-un-guides-test-fire-of-new-type-icbm-of-dprks-strategic-forces/.

a range of 15,000 kilometers with pinpoint accuracy."[489] In addition to reinforcing the concept of preemption, his statement alludes to improving North Korea's ICBMs, which can be used to range the entirety of the United States, and precision-guided technology, which was highlighted as an area of focus in North Korea's five-year plan announced at the 8th Party Congress. In 2021, North Korea returned to a more aggressive ballistic missile testing schedule and in 2022 returned to testing ICBMs.

- In his January 2021 address to the 8th Party Congress, Kim Jong Un emphasized the goal of developing "ultra-modern tactical nuclear weapons," "hypersonic gliding flight warheads," "multi-warhead" missiles, military reconnaissance satellites, a nuclear-powered submarine, and ground- and submarine-launched ICBMs that use solid fuel to raise [the missiles'] long-range nuclear striking capability.[490]As of late 2022, North Korea's testing schedule has touched on all these priorities.

How is North Korea's nuclear program funded?

The secretive nature of the North Korean regime makes any information on its defense budget highly speculative, as evidenced by the wide range of foreign estimates on how much Pyongyang spends on its defense programs. Although the North Korean government has said that about 15 percent of the country's budget is spent on defense,[491] some experts have

[489] "Great Program for Struggle Leading Korean-Style Socialist Construction to Fresh Victory on Report Made by Supreme Leader Kim Jong Un at Eighth Congress of WPK," KCNA, Jan. 9, 2021, via KCNA Watch, https://kcnawatch.org/newstream/1610272851-580631610/great-programme-for-struggle-leading-korean-style-socialist-construction-to-fresh-victoryon-report-made-by-supreme-leader-kim-jong-un-at-eighth-congress-of-wpk/?t=1610568921077.

[490] A copy of Kim Jong Un's speech at North Korea's 8th Party Congress delivered in January 2021 can be found here: https://www.ncnk.org/resources/publications/kju_8th_party_congress_speech_summary.pdf/file_view. Published and translated by the Korean Central News Agency (North Korea's state media).

[491] Although Kim Jong Un announced in 2021 that military spending held "overriding importance" over all other sectors, the SPA (North Korea's parliament) in 2022 reportedly decided to maintain the military's 15.9 percent share of the national budget, in keeping with defense spending of between 15.8 and 16 percent each year since 2012. According to Peter Ward, an expert on the North Korean economy, the Cabinet's military budget likely covers only "wages for soldiers and officers, and some capital expenditures and maintenance for conventional forces," whereas other departments not under the Cabinet's control are in charge of missile programs and other modern developments. See Colin Zwirko, "Cryptic Figures and Stagnant Projects: North Korea Announces 2022 Budget Plans," NKNews, Feb. 8, 2022.

estimated that the true figure could be up to 40 percent. Most estimates fall within the 20 to 30 percent range (approximately $7 to $11 billion per year),[492] although this figure might fallen since 2018 given the effect of sanctions and COVID-19. Regardless, these estimates would place North Korea at the top of the list of nations in terms of spending on defense as a percentage of gross domestic product (GDP).

Information on how much of North Korea's defense budget is allocated to the nuclear program on a yearly basis is even more opaque. It is not mentioned in any North Korean official reporting. That said, there are some rough estimates based on assumptions and extrapolation. In its report on global nuclear weapons spending, the Geneva-based International Campaign to Abolish Nuclear Weapons organization assessed that North Korea spends 6 percent of its military budget on nuclear weapons.[493] In 2021, this was estimated to be around $642 million.[494] In addition to the nuclear program itself, North Korea reportedly spends several hundred million more dollars a year on its delivery systems. According to the South Korean think tank Korea Institute for Defense Analysis (KIDA), North Korea spent between $400 and $650 million on 33 missile launches, or about 2 percent of its GDP from January to June of

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[492] Defense Intelligence Agency, *North Korea Military Power: A Growing Regional and Global Threat, 2021*, Sept. 2021. These numbers can vary depending on how the budget is calculated. According to Haena Jo, a defense analyst with the Military Balance Blog:

> The *2019 World Military Expenditures and Arms Transfers*, published by the US State Department, estimates that North Korea spent between 21.9% and 24.4% of GDP (between US$3.7 billion and US$4.2bn in 2017 dollars) annually on the military between 2007 and 2017. Converting the figures released by North Korean state media using the same market exchange rates over the same period results in far lower numbers, between US$0.64bn and US$1.2bn, which accounted for 3.9–6.9% of GDP. The 2020 budget would convert to approximately US$1.5bn (2017 dollars) at market exchange rates, still well below the US State Department's estimates. Adopting a purchasing power parity (PPP) rate to account for the lower cost of production inputs in North Korea would place actual military spending much higher – closer to US$8bn–US$10bn annually since 2007. Although official spending figures exist, the lack of transparency makes any kind of regional comparison tentative at best.

See Haena Jo, "North Korea: Sidelining Economic Development to Prioritize Strategic Weapons?" *Military Balance Blog*, July 10, 2020.

[493] In 2011, Global Zero estimated that North Korea spent about 6 percent of its military budget on its nuclear program. International Campaign to Abolish Nuclear Weapons assumes that North Korea has not deviated too much from this percentage of the defense budget dedicated to the nuclear program. Bruce G. Blair and Matthew A. Brown, *Nuclear Weapons Cost Study*, Global Zero, June 2011.

[494] Assuming that North Korea still spends 6 percent of its annual military spending on nuclear weapons, it would have spent approximately 734 billion North Korean won on its nuclear program in 2020. This is $642 million USD. International Campaign to Abolish Nuclear Weapons used this number for its 2021 figure. International Campaign to Abolish Nuclear Weapons, *Squandered: 2021 Global Nuclear Weapons Spending*. June 2022.

2022.[495] Combined, the total yearly cost of North Korea's nuclear program is more than $1 billion; however, some South Korean estimates put it as high as $3 billion.[496] That said, North Korea is probably able to stretch its limited defense budget through the use of cheap labor and possible external support.[497]

Nuclear and defense funding process

Authoritative insight on North Korea's defense budget process is similarly elusive. Most likely, it begins within Kim Jong Un's personal secretariat, where the broad guidance for the defense budget is worked out between Kim and his senior military and defense industry advisors. From there, Kim Jong Un, acting in his capacity as chairman of North Korea's communist party, passes guidance down to the Central Military Commission (CMC) of the Central Committee of the Workers' Party of Korea.[498] The CMC is responsible for coordinating the party organizations within the Korean People's Army (KPA) and defense industry. It authorizes defense/munitions spending and determines how natural resources and products from military-controlled production units are earmarked and distributed domestically and for sale abroad. The CMC in turn passes the guidance to the Central Committee's Machine-Building Department (also called the Defense Industry Department), which allocates funds and resources to the Academy of National Defense Science (ANDS) for research and development (R&D) and the Second Economic Committee (SEC) for manufacturing and production of weapons systems.[499] Together the ANDS and SEC oversee weapons tests, including for the nuclear and missile programs, which are often attended by Kim Jong Un as part of his guidance inspections.

Communication of the defense budget takes place in two venues. The broad parameters and trends related to the budget are articulated, normally by the Supreme Leader, at party

[495] Chaerim Ha, "Korea Institute for Defense Analyses: North Korea Spent 5,000-8,000 Billion Won on Missile Launches This Year," Yonhap News, June 9, 2022.

[496] Byun Duk-kun, "N. Korea Spends US$642 Million in 2021 to Develop Nuclear Weapons," Yonhap News, June 15, 2022, https://en.yna.co.kr/view/AEN20220615000200325.

[497] "How Does North Korea Pay for Its Many Missile Tests?" Voice of America, Nov. 12, 2022, https://learningenglish.voanews.com/a/how-does-north-korea-pay-for-its-many-missile-tests-/6827213.html.

[498] Kim Jong Un in his capacity as general secretary of the Korean Worker's Party and Supreme Commander is also chairman of the CMC. He uses this venue to convey policy and plans to the high command and the wider defense establishment. As of the 8th Party Congress in January 2021, the CMC consists of the chairman, vice chairman, and 11 members.

[499] Attached to ANDS and SEC are trade companies in charge of securing funds for priority programs.

congresses. These meetings are followed by meetings of the SPA (North Korea's rubber stamp parliament) in which the budget allocation as part of the country's overall GDP is publicized.

Prioritizing the nuclear program within defense funding

At the 8th Party Congress in January 2021, Kim Jong Un vowed to advance the country's nuclear capabilities by making a two-pronged advance toward smaller tactical nuclear weapons and higher yield warheads. He stated, "We must develop tactical nuclear weapons that can be applied in different means in the modern war depending on the purpose of operational missions and targets and continue to push ahead with the production of super-large nuclear warheads."[500]

This proclamation suggests that for the near term at least, nuclear weapons development will be a priority for defense expenditure. In his speech, Kim also talked about specific priorities of developing nuclear-powered submarines and increasing the precision and reliability of an ICBM with a range of 15,000 kilometers. The miniaturization of nuclear weapons, creation of tactical nuclear weapons, and the production of super-large nuclear warheads were also included as goals.[501]

In his September 2022 speech to the SPA, Kim Jong Un reemphasized strengthening the country's military capability and speeding up its development in accordance with the defense development strategy put forward by the Party Congress:

- Our defense industry should…speed up full steam the development of military hardware of a new generation for modern warfare.
- Most importantly, it is imperative to steadily expand the space for the operation of tactical nukes and diversification of operational applications.
- It is also necessary to steadily step up the deployment of cutting-edge strategic and tactical weapon systems for combat and direct all efforts to remarkably strengthening the war deterrent of the country.[502]

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[500] A copy of the Kim Jong Un's speech at North Korea's Eighth Party Congress delivered in January 2021 can be found here: https://www.ncnk.org/resources/publications/kju_8th_party_congress_speech_summary.pdf/file_view. Published and translated by the Korean Central News Agency.

[501] At an earlier meeting in May 2020, the CMC also outlined "new policies for further increasing" North Korea's nuclear capabilities, but state media did not provide details.

[502] Kim Jong Un, "Policy Speech at Seventh Session of the 14th SPA of DPRK," *Rodong Sinmun*, Sept. 9, 2022.

Exact allocations of funding toward military hardware, tactical nuclear weapons, combat systems, and operational applications are not clear; however, these priorities are in line with Kim Jong Un's decision at the December 2019 Party Central Committee meeting to skew the *byungjin* policy in the direction of defense and strategic weapons development, even at the cost of short-term economic gain.

Funding mechanism

The funding of the North Korean nuclear program has evolved over time as a result of North Korea's changing economic fortunes as well as efforts by the international community to counter proliferation.[503] Faced with increasing economic stagnation in the 1970s, Kim Il Sung removed the defense sector from the state economy and integrated it into the quasi-market party economy under the guidance of the Central Committee apparatus, namely the Machine Industry (Defense Industry) Department and the SEC.[504] Therefore, instead of the entire defense budget being funded from the national budget, much of the defense funding was generated by the party apparatus through market activities such as weapons sales and other activities of trade firms tied to both the defense apparatus and the Royal Economy, which serviced the needs of then heir apparent Kim Jong Il.

This apparatus remained in place until the early 2000s and was largely responsible for getting the nascent nuclear program off the ground. US military officials in South Korea asserted that missile sales played a vital role in propping up the Pyongyang regime and North Korea's economy. In 2001 alone, North Korean exports totaled $560 million, a substantial figure for a country with an estimated annual GDP of approximately $17 billion. North Korean defectors believe that such sales—including the sale of military hardware other than missiles—make up as much as 40 percent of North Korea's total exports.[505]

[503] For a detailed overview of North Korea's defense procurement apparatus, see Ken E. Gause, *North Korean House of Cards: Leadership Dynamics Under Kim Jong Un* (Washington, DC: Human Rights in North Korea, 2015).

[504] Facing increasing stagnation in the 1970s and additional costs tied to the designation of an heir apparent, Kim Il Sung concluded that if the Kim family control of the regime was to survive, the economic model nested in the command economy would have to change. Critical funds necessary for maintaining the defense industrial complex would have to be generated and controlled through separate channels, which was done by removing the munitions industry from Cabinet control and placing it under the newly created SEC. See Ken E. Gause, *North Korean House of Cards: Leadership Dynamics Under Kim Jong Un*.

[505] Bertil Lintner, "North Korea's Missile Trade Helps Fund Its Nuclear Program," Yale Global Online, May 5, 2003, https://archive-yaleglobal.yale.edu/content/north-koreas-missile-trade-helps-fund-its-nuclear-program.

As the international community began to clamp down on proliferation operations through enhanced sanctions and monitoring of smuggling routes, Kim Jong Il ordered the separation of the Royal Economy and the defense industrial complex. The Royal Economy could still feed into defense coffers, but its apparatus could no longer support weapons proliferation. By the late Kim Jong Il era and into the Kim Jong Un era, funding for defense programs, especially the nuclear and missile programs, was built around a dedicated set of front companies, banks, and cyber operations. This last capability was especially important in continuing to bring in funds for North Korea's nuclear program during COVID-19, when the country essentially shut itself down and closed many of its hard currency operations. A 2020 United Nations (UN) report on North Korea states that Pyongyang's cybercrime capabilities generated up to $2 billion in total revenue through August 2019 for its WMD programs using "widespread and increasingly sophisticated" cyberattacks.[506] Since the report was written, evidence indicates that the pace and ingenuity of North Korea's online threat have accelerated.[507] North Korean cyber organizations, such as the Lazarus Group, are operated by the Reconnaissance General Bureau,[508] North Korea's foreign intelligence agency, which was responsible for the sinking of the *Cheonan* in 2010.

What activities is North Korea's nuclear program engaged in?

As a nascent nuclear state, North Korea's nuclear activities are focused on R&D in pursuit of a nuclear weapons capability that can credibly threaten the United States and its allies. These activities include the full range of steps that a state must take to advance its military nuclear program, including the following:

1. Production of both weapons-usable uranium and plutonium fissile material
2. Design of nuclear weapons, including work toward development of a thermonuclear capability

[506] United Nations Security Council, *Report of the UN Panel of Experts Established Pursuant to Resolution 1874 (2009).* Aug. 30, 2019, https://www.securitycouncilreport.org/atf/cf/%7B65BFCF9B-6D27-4E9C-8CD3-CF6E4FF96FF9%7D/S_2019_691. pdf, p. 26.

[507] "The Incredible Rise of North Korea's Hacking Army," *The New Yorker*, Apr. 26, 2021.

[508] The Reconnaissance General Bureau houses its cyber capabilities within Bureau 121. See ROK Ministry of National Defense, *2014 Defense White Paper*, Dec. 31, 2014, p. 27.

3. Development of nuclear weapons delivery systems
4. Testing of nuclear weapons delivery systems
5. Public demonstrations of nuclear capabilities, including parades

Since North Korea announced its intention to withdraw from the NPT in 1994, international efforts have been made to negotiate with North Korea regarding the dismantlement of its nuclear program. These include the US–North Korea negotiated Agreed Framework, which held from 1994 to 2002; the Six Party Talks Forum from 2003 to 2009; and US–North Korea and Inter-Korean dialogues held between 2018 and 2019. Although these efforts defused periods of crisis or tension and led to temporary freezes of North Korea's overt nuclear development activities, all failed to deliver lasting diplomatic solutions or long-term commitments from North Korea.

Figure 36. Kim Jong Un oversees test of Hwasong-17 intercontinental ballistic missiles

Source: North Korean State Media, www.KCNA.kp, Nov. 19, 2022.

Significant diplomatic initiatives to address North Korea's nuclear program[509]

1994–2002: First North Korean Nuclear Crisis; United States and North Korea negotiate the Agreed Framework—North Korea agrees to freeze its nuclear weapons program in exchange for aid. The Agreement collapsed when US intelligence uncovered evidence of a covert uranium enrichment program; North Korea subsequently withdrew from the NPT in 2003.

2003–2009: Six Party Talks between North Korea, the United States, China, Russia, South Korea, and Japan to discuss the dismantling of North Korea's nuclear program. The forum dissolved following North Korea's 2006 nuclear test and 2009 missile and second nuclear tests.

2018–2019: A series of US–North Korea and Inter-Korean summits were held to address North Korea's nuclear program; the talks stabilized relations for a brief period, and North Korea mostly abstained from high-profile tests of its nuclear program. However, the talks did not result in any major breakthroughs on denuclearization or sanctions relief and eventually were abandoned.

North Korea has, at times, allowed international inspections of its nuclear facilities, but the extent of North Korea's nuclear weapons and missile capabilities remains subject to considerable uncertainty. Western analysts gain insight into North Korea's weapons development activities by analyzing commercial satellite imagery to track construction, modernization, and refurbishment efforts at key installations. When North Korea conducts nuclear and missile tests, they are analyzed by independent and government experts to gain insight into the potential explosive yields or potential ranges and assess North Korea's claims of progress. In addition, North Korea's media frequently publicize details of official leadership visits to important locations that analysts can mine for additional insights into North Korea's nuclear weapons–related activities.

[509] For a complete chronology of diplomatic initiatives to address North Korea's nuclear weapons program, see Davenport, "Chronology of U.S.-North Korean Nuclear and Missile Diplomacy."

Fissile material production

North Korea is actively engaged in the production of plutonium and enriched uranium for use in its weapons program. Pyongyang has gone to great lengths to hide much of its fissile material production and its enrichment route.[510] Most of what is known about North Korea's fissile production capabilities is based on the regime's declarations—verified when possible by international inspectors—and assumptions regarding facilities' production capacity. Estimates for North Korea's inventory of fissile material fall between 20 and 50 kilograms for plutonium, with a capacity to produce 6 kilograms per year at full operational capacity, and between 200 and 1,200 kilograms for enriched uranium.[511]

North Korea produces plutonium and enriched uranium at its Yongbyon Nuclear Scientific Research Center.[512] The Yongbyon complex was developed in coordination with the Soviet Union beginning in the 1960s. Planning for fissile material production is believed to have begun in the 1980s, with the reactor becoming operational in 1986.[513] Siegfried Hecker, a nuclear scientist and former head of Los Alamos National Laboratory, noted in 2021:

> Yongbyon is the heart of North Korea's fissile materials production complex. All of its plutonium and its tritium have been and will continue to be produced there. It houses most of the chemical facilities, such as those that convert yellowcake from the mining complex to uranium hexafluoride, for uranium enrichment and around half of its centrifuge capacity. Whereas HEU [highly enriched uranium] could still be produced [in North Korea] if Yongbyon is shut down, its production would be greatly curtailed.[514]

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[510] Olli Heinonen, "North Korea's Nuclear Enrichment: Capabilities and Consequences," Belfer Center, 2011, https://www.belfercenter.org/publication/north-koreas-nuclear-enrichment-capabilities-and-consequences.

[511] "Siegfried Hecker estimated in early 2021 that North Korea possibly had produced 600 to 950 kilograms of HEU as of the end of 2020. An assessment by the Stockholm International Peace Research Institute suggests a wider range of possibly 230 to 1,180 kilograms as of the beginning of 2021, whereas the International Panel on Fissile Materials estimated a slightly smaller range of 400 to 1,000 kilo- grams in 2022." Hans M. Kristensen and Matt Korda, "North Korean Nuclear Weapons, 2022," *Bulletin of the Atomic Scientists* 78, no. 5 (2022), https://doi.org/10.1080/00963402.2022.2109341.

[512] Kristensen and Korda, "North Korean Nuclear Weapons, 2022."

[513] Siegfried S. Hecker, Chaim Braun, and Chris Lawrence, "North Korea's Stockpiles of Fissile Material," *Korea Observer* 47, no. 4 (2016), http://www.iks.or.kr/rankup_module/rankup_board/attach/vol47no4/14833231665766.pdf.

[514] "Estimating North Korea's Nuclear Stockpiles: An Interview with Siegfried Hecker," 38North, Apr. 30, 2021, https://www.38north.org/2021/04/estimating-north-koreas-nuclear-stockpiles-an-interview-with-siegfried-hecker/.

Plutonium production

North Korea produces plutonium at its 5 megawatt-electric (MWe) graphite-moderated nuclear reactor at the Yongbyon Nuclear Scientific Research Center. The 5 MWe reactor is believed to have produced the entirety of North Korea's plutonium.[515] The reactor has been operational since 1986. By 1990, North Korea began operating a reprocessing plant to separate plutonium from spent fuel, producing up to 10 kilograms of plutonium by 1994—possibly enough for one or two crude nuclear weapons.[516] Operations at the reactor and the reprocessing facility were frozen between 1994 and 2002 under the Agreed Framework. Following the Framework's collapse, North Korea resumed operation of the 5 MWe reactor and began reprocessing spent fuel rods to produce plutonium. In 2008, as part of the Six Party Talks process, the 5 MWe reactor was shut down again and partially disabled, and the cooling tower was demolished.[517]

In April 2013, North Korea announced its intention to rebuild and restart the disabled reactor, and by September of that year, North Korea appeared to have restarted operations. By 2016, the US director of national intelligence indicated that North Korea was preparing to begin reprocessing fuel from the reactor to produce plutonium.[518] Experts estimate that the reactor can produce about 6 kilograms of plutonium per year, which is enough fissile material to produce about one nuclear weapon per year.[519] The reactor can operate for around two to three years before the core load must be replaced with new natural uranium fuel rods. Experts believe that the reactor could retain its ability to produce plutonium for several more years, assuming North Korea can continue to maintain its infrastructure and manage the reactor's

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515 Kristensen and Korda, "North Korean Nuclear Weapons, 2022."

516 Daniel Wertz, Matthew McGrath, and Scott LaFoy, *Issue Brief: North Korea's Nuclear Weapons Program*, NCNK, Apr. 2018, https://www.ncnk.org/resources/publications/DPRK-Nuclear-Weapons-Issue-Brief.pdf.

517 Wertz, McGrath, and LaFoy, *Issue Brief: North Korea's Nuclear Weapons Program.*

518 Wertz, McGrath, and LaFoy citing "North Korea Restarting its 5 MW Reactor," 38North, Sept. 11, 2013, http://38north.org/2013/09/yongbyon091113/; "More Evidence that North Korea Has Restarted Its 5MWe Reactor," 38North, Oct. 2, 2013, http://38north.org/2013/10/yongbyon100213/; David Albright and Robert Avagyan, *Steam Venting from Building Adjacent to 5 MWe Reactor: Likely Related to Reactor Restart*, Institute for Science and International Security, Sept. 11, 2013, http://isis-online.org/isis-reports/detail/steam-venting-from-building-a.; James Clapper, "Worldwide Threat Assessment of the U.S. Intelligence Community," Statement for the Record at a Hearing Before the Select Committee on Intelligence of the United States Senate, Current and Projected National Security Threats to the United States, 114th Congress, Second Session, Feb. 9, 2016.

519 Peter Makowsky et al., "Is North Korea Restarting Construction of the 50 MWe Reactor at Yongbyon? It's Unlikely," 38North, June 2022, https://www.38north.org/2022/06/is-north-korea-restarting-construction-of-the-50-mwe-reactor-at-yongbyon-its-unlikely/.

cooling system;[520] satellite imagery suggests that the reactor remained operational through 2022.[521]

Enriched uranium production

Estimates of North Korea's highly enriched uranium (HEU) quantities are uncertain because centrifuge enrichment facilities have a small physical footprint and are easy to conceal.[522] In 2009, North Korea declared its intent to develop HEU but did not declare associated production facilities.[523] Much of what is publicly known about North Korea's uranium enrichment capability is based on a 2010 visit by a US delegation led by Hecker, which was granted brief access to one then-newly-built North Korean uranium enrichment facility at Yongbyon (see Figure 37). The visit was short and highly controlled by North Korean interlocutors. However, based on what they were able to witness and derive from speaking with the plant's chief engineer, the delegation was able to confirm that the technical and physical infrastructure of the plant was consistent with the requirements for an HEU production capability.[524]

Figure 37. Hecker delegation inspecting Yongbyon facility

Source: Wikimedia Commons, via http://iis-db.stanford.edu/evnts/5220/gallery/images/IMG_2037.jpg.

As described by the delegation, the industrial-scale centrifuge facility contained 2,000 centrifuges, ancillary equipment, and a modern control room.[525] As one analyst noted in 2011,

[520] Hecker, Braun, and Lawrence, "North Korea's Stockpiles of Fissile Material."

[521] Kristensen and Korda, "North Korean Nuclear Weapons, 2022."

[522] Hecker, Braun, and Lawrence, "North Korea's Stockpiles of Fissile Material."

[523] In a September 4, 2009, letter to the president of the UN Security Council, the North Korean permanent representative to the UN stated that North Korea's "experimental uranium enrichment has successfully been conducted to enter into completion phase." "DPRK Permanent Representative Sends Letter to President of UNSC," KCNA, Sept. 4, 2009, cited in Hecker, Braun, and Lawrence, "North Korea's Stockpiles of Fissile Material," p. 736.

[524] Hecker, Braun, and Lawrence, "North Korea's Stockpiles of Fissile Material," p. 735.

[525] Hecker, Braun, and Lawrence, "North Korea's Stockpiles of Fissile Material," p. 733.

2,000 centrifuges, when operating at full capacity, could produce 1.8 tons of low enriched uranium (LEU) annually or at 3.5 percent U-235.[526] To make HEU, North Korea could reconfigure its 2,000-centrifuge installation or add 800 new centrifuges that could convert the annual 1.8 tons of LEU to 40 kilograms of HEU, an amount sufficient for the country to generate the necessary fissile material for one or two new nuclear bombs.[527] In 2013, satellite imagery of the facility showed evidence of building expansion, but it is not possible to determine whether the expansion was intended to increase the number of centrifuges operating at the facility or to fulfill another purpose.[528] Based on the parameters of the complex's expansion, experts posit that the plant could now house up to 4,000 centrifuges, which could theoretically allow North Korea to approximately double the amount of LEU for conversion to HEU produced at the site.

In August 2016, North Korean officials stated to Kyodo News that the country had been producing HEU necessary for nuclear arms and power but withheld information on quantities of enriched uranium or the locations of the production.[529] Although the complex at Yongbyon is the only known North Korean centrifuge facility,[530] it is widely believed that North Korea has at least one other uranium enrichment site.[531] In 2018, reports of an additional covert uranium enrichment site at Kangson, near Pyongyang, emerged. However, independent analysts question the role of the complex at Kangson because it appears to lack infrastructure typically found in North Korea and elsewhere to support uranium enrichment.[532] In its annual report

[526] Heinonen, "North Korea's Nuclear Enrichment: Capabilities and Consequences."

[527] Heinonen, "North Korea's Nuclear Enrichment: Capabilities and Consequences."

[528] Hecker, Braun, and Lawrence, "North Korea's Stockpiles of Fissile Material," pp. 736–737.

[529] Hecker, Braun, and Lawrence, "North Korea's Stockpiles of Fissile Material."

[530] Hecker, Braun, and Lawrence, "North Korea's Stockpiles of Fissile Material," p. 736; Kristensen and Korda, "North Korean Nuclear Weapons, 2022"; Heinonen. "North Korea's Nuclear Enrichment: Capabilities and Consequences."

[531] Kristensen and Korda, "North Korean Nuclear Weapons, 2022."

[532] Olli Heinonen, "New Evidence Suggests Kangson Is Not a Uranium Enrichment Plant," 38North, Dec. 2020, https://www.38north.org/2020/12/kangson201217/, cited in Kristensen and Korda, "North Korean Nuclear Weapons, 2022."

for 2021, the UN Panel of Experts listed Kangson as a "suspected clandestine uranium enrichment facility."[533]

Nuclear weapons design work and testing

Estimates of the number, type, and capability of the warheads in North Korea's arsenal vary considerably. In quantifying North Korea's warhead stock, analysts base their estimates on assumptions regarding North Korea's capacity to produce fissile material, the capacity of North Korea's nuclear infrastructure, North Korea's allocation of fissile material for weapons-usable fissile material, and spent plutonium and/or enriched uranium in previous tests.[534] Outside experts generally agree that North Korea has somewhere between 20 and 50 nuclear weapons, although at least one estimate puts the number over 100.[535]

There is little publicly available evidence regarding the characteristics of North Korea's nuclear warheads. North Korea has tested its nuclear weapons six times at its nuclear test site at Punggye-ri since 2006. As previously noted, with each nuclear test, North Korea has declared a new or more advanced nuclear capability. The timeline of nuclear testing is below:

- **October 2006:** North Korea's first underground nuclear test is a plutonium-fueled atomic bomb at Punggye-ri.[536] It produced a yield of between 0.5 and 2 kilotons (kt).[537]
- **May 2009:** The second underground nuclear test is conducted following the ejection of International Atomic Energy Agency (IAEA) and US monitoring personnel from the

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[533] United Nations Panel of Experts, *Final Report of the Panel of Experts Submitted Pursuant to Resolution 2569, 2021*, Mar. 2022, https://documents-dds-ny.un.org/doc/UNDOC/GEN/N22/252/09/PDF/N2225209.pdf?OpenElement, cited in Kristensen and Korda, "North Korean Nuclear Weapons, 2022."

[534] David Albright, *North Korea's Nuclear Capabilities: A Fresh Look*, Institute for Science and International Security, Apr. 22, 2017, https://isis-online.org/uploads/isis-reports/documents/North_Korea_Talk_April_28_2017_Final.pdf; 38North, "Estimating North Korea's Nuclear Stockpiles: An Interview with Siegfried Hecker"; Kristensen and Korda, "North Korean Nuclear Weapons, 2022."

[535] Kristensen and Korda, "North Korean Nuclear Weapons, 2022." The South Korea–based think tank Asan Institute and RAND produced a report in 2021, *Countering the Risks of North Korean Nuclear Weapons*, which estimates that North Korea had developed between 67 and 116 nuclear weapons by 2020, with a stockpile expected to grow by 12 to 18 weapons a year until 2027. Siegfried Hecker questioned this estimate based on his analysis of North Korea's stockpiles of and ability to produce fissile material. "Estimating North Korea's Nuclear Stockpiles: An Interview with Siegfried Hecker."

[536] Defense Intelligence Agency, *North Korea Military Power*.

[537] CSIS, "Missiles of North Korea." CSIS Missile Defense Project, updated Nov. 22, 2022, https://missilethreat.csis.org/country/dprk/.

Yongbyon nuclear complex a month before.[538] The test produced a yield between 2 and 4 kt.[539]

- **February 2013:** After warning that it would conduct a test the month before, North Korea conducted its third underground nuclear test, which had a yield of approximately 6 to 9 kt.[540] Following the test, the statement released by Korea Central News Agency (KCNA) stated that the country would continue testing and building its nuclear arsenal until its right to develop the program and launch satellites was recognized by the United States.[541]
- **January 2016:** North Korea announced that it had conducted its fourth underground nuclear test, claiming that it had detonated its first hydrogen bomb of about 7 to 10 kt.[542] However, such a low yield indicates that either the detonation was not a hydrogen bomb or it was a failed thermonuclear test. For comparison, past thermonuclear tests have typically produced yields between 1.6 and 10.4 megatons.[543]
- **September 2016:** North Korea conducted its fifth underground nuclear test, which had a yield of about 10 kt.[544] The Nuclear Weapons Institute of the Democratic People's Republic of Korea claimed that the test was of a newly manufactured nuclear warhead, the first test involving a warhead by the DPRK.[545]

[538] Davenport, "Chronology of U.S.-North Korean Nuclear and Missile Diplomacy."

[539] CSIS, "Missiles of North Korea."

[540] CSIS, "Missiles of North Korea"; Davenport, "Chronology of U.S.-North Korean Nuclear and Missile Diplomacy."

[541] Davenport, "Chronology of U.S.-North Korean Nuclear and Missile Diplomacy"; Defense Intelligence Agency, *North Korea Military Power*.

[542] Davenport, "Chronology of U.S.-North Korean Nuclear and Missile Diplomacy"; Sharon Squassoni, "The Latest North Korean Nuclear Test," Center for Strategic and International Studies, Sept. 2017, https://www.csis.org/analysis/latest-north-korean-nuclear-test.

[543] CSIS, "Missiles of North Korea."

[544] CSIS, "Missiles of North Korea."

[545] Jonathan D. Pollack, "What Makes This North Korean Test Different," Brookings, Sept. 2016, https://www.brookings.edu/blog/order-from-chaos/2016/09/09/what-makes-this-north-korean-nuclear-test-different/.

- **September 2017:** North Korea conducted its sixth underground nuclear test, which had a yield of more than 140 kt.[546] North Korea claimed that the test was of a hydrogen bomb and was a "perfect success."[547]

Figure 38. Kim Jong Un inspecting what North Korean official media called "an H-bomb to be loaded into a new intercontinental ballistic missile" at an undisclosed location

Source: North Korean State Media, www.KCNA.kp, released Sept. 3, 2017.

Although North Korea's six nuclear tests demonstrate a capability to produce high-yield explosive devices, several questions remain regarding North Korea's ability to operationalize its nuclear warhead inventory. North Korea has yet to demonstrate or prove that it can successfully mate a warhead with a ballistic missile, although some experts posit that it likely

546 CSIS, "Missiles of North Korea."

547 Davenport, "Chronology of U.S.-North Korean Nuclear and Missile Diplomacy."

has the capability to put a warhead on its short- and medium-range missiles.[548] Similarly, North Korea has published pictures of what it claims are actual warheads, and although these pictures appear to be of small lightweight devices that could be mated to a warhead, it is not possible to conclude whether these devices are actual warheads or models or to discern whether the devices shown match the devices detonated in the nuclear explosive tests.[549]

Kim Jong Un has indicated that North Korea will continue work on its nuclear warheads. At the 8th Congress of the Workers' Party of Korea held in January 2021, Kim Jong Un disclosed goals for North Korea's nuclear weapons program, including miniaturization of warheads and development of tactical weapons and a "super-large hydrogen bomb."[550]

Although North Korea has made many strides in its nuclear weapons program, it has not proven that it possesses critical elements of an operational nuclear capability, including the following:

- **Miniaturization.** Although developing a nuclear weapon is difficult on its own, miniaturizing the technology to fit on a deliverable missile is another challenge. Warhead miniaturization can help reduce the size of the missile required, expand the types of missiles to which nuclear warheads could be mated, and allow more warheads to fit onto a single missile (multiple independently targetable reentry vehicle).
- **Reentry vehicles.** Reentry vehicles are responsible for carrying the nuclear warhead through the atmosphere to its final target and thus must withstand extreme temperatures.

[548] David Albright, "North Korean Miniaturization," 38North, Feb. 13, 2013, https://www.38north.org/2013/02/albright021313/; Kristensen and Korda, "North Korean Nuclear Weapons, 2022."

[549] Kristensen and Korda, "North Korean Nuclear Weapons, 2022."

[550] Olli Heinonen, "Development of the Yongbyon Uranium Enrichment Plant Between 2009 and 2021," 38North, July 16, 2021, https://www.38north.org/2021/07/development-of-the-yongbyon-uranium-enrichment-plant-between-2009-and-2021/.

Nuclear weapons delivery system development and testing

North Korea has been developing ballistic missiles since the 1980s.[551] Early missiles were based on Soviet missile technology, but North Korea progressed to indigenously designed and constructed systems. Under Kim Jong Un, North Korea has focused on advancing its missile capabilities, with North Korea developing a full range of short-range, medium-range, intermediate-range, and intercontinental ballistic missiles.

During North Korea's 8th Party Congress (2021), North Korea noted several areas of focus for its missile programs. These priorities include precision guidance technology, multiple warhead reentry capability, and hypersonic technology.[552] Since 2021, North Korea has conducted an aggressive testing schedule for its ballistic missiles and in 2022 returned to testing its ICBM capability, which it had paused since 2017.

North Korea is moving toward solid-fuel systems, which require less launch preparation than the liquid-fuel systems that historically made up most of North Korea's ballistic missile inventory. In 2019, North Korea began testing new variants of its Scud short-range ballistic missiles (SRBMs) (KN23, KN 24, and KN25), which are solid fueled.

Under the purview of North Korea's Strategic Force, Pyongyang has conducted several tests of its ballistic missiles, which, similar to its nuclear tests, provide evidence of North Korea's progress in terms of both the sophistication of its missiles and their ability to reach targets anywhere across the globe.

In terms of launch capability, North Korea appears to be focusing on developing its ground- and submarine-launched missiles but not on an air-launched capability. North Korea appears to emphasize the development of delivery systems that are mobile, which are more difficult to track and detect than fixed-site launch facilities, thus increasing the survivability of its missile forces in a contingency.

North Korea is developing options for road- and rail-launch capabilities for its ballistic missiles. North Korea is believed to have purchased six mobile transporter erector launchers (TELs) from China in 2011, which it used to transport and launch variants of the Hwasong-class

[551] A more detailed overview of North Korea's ballistic missile capabilities will be included in a subsequent section.

[552] "On Report Made by Supreme Leader Kim Jong Un at 8th Congress of WPK," KCNA, Jan. 9, 2021, https://kcnawatch.org/newstream/1610155111-665078257/on-report-made-by-supreme-leader-kim-jong-un-at-8th-congress-of-wpk/?t=1610371630802.

ballistic missile.[553] In 2022 during a military parade, North Korea showed four potentially additional 11-axel TELs capable of transporting the Hwasong-17 ICBM. If these TELs are unique, North Korea could have up to 10—but experts note that North Korea could be deliberately obscuring the number of TELs it has and that only 4 North Korean TELs have been seen together at one time.[554]

In 2021, North Korea conducted tests of SRBMs launched from railcars. In coverage of the tests, North Korean media described the event as a "drill of the Railway Mobile Missile Regiment," which would be a new operational branch of North Korea's missile force.[555] A former State Department official noted in an analysis blog, "[North Korea's] statement suggests that going rail-mobile was intended to diversify and add to the mobility and flexibility of the missile force."[556]

In 2014, South Korea's Ministry of Defense announced that it had observed that North Korea is developing a "new weapons system capable of launching submarine-based ballistic missiles (SLBM)."[557] The Sinpo-class submarine, also called the Gorae ("whale") or Pongdae-class submarine, is currently North Korea's only ballistic missile submarine (SSB) platform. Homeported in Sinpo, the SSB is currently not operational. Experts believe that it is likely a test platform for an SLBM capability. In 2016, independent analysts observed evidence of a second Sinpo-class SSB, with ongoing construction being monitored. However, as of 2022, this second submarine has yet to be launched.[558]

553 Ethan Jewell, "North Korea May Have More Mobile Launchers for Its ICBMs Than Previously Known," NKNews, Apr. 27, 022, https://www.nknews.org/2022/04/north-korea-may-have-more-mobile-launchers-for-its-icbms-than-previously-known/.

554 Jewell, "North Korea May Have More Mobile Launchers."

555 Vann H. Van Diepen, "It's the Launcher, Not the Missile: Initial Evaluation of North Korea's Rail-Mobile Missile Launches," *38North (blog)*, Sept. 17, 2021, https://www.38north.org/2021/09/its-the-launcher-not-the-missile-initial-evaluation-of-north-koreas-rail-mobile-missile-launches/#:~:text=North%20Korea%E2%80%99s%20September%2015%20launches%20of%20short-range%20ballistic,North%20Korea%20has%20long%20deployed%20hundreds%20of%20SRBMs.

556 Van Diepen, "It's the Launcher, Not the Missile."

557 "Sinpo/GORAE-Class Ballistic Missile Sub," Global Security, updated 2016, accessed Dec. 10, 2022, https://www.globalsecurity.org/military/world/dprk/s-gorae.htm.

558 Jack Liu and Olli Heinonen, "Sinpo South Shipyard: Possible Preparations for New Submarine Launch," *38North (blog)*, Sept. 21, 2022, https://www.38north.org/2022/09/sinpho-south-shipyard-possible-preparations-for-new-submarine-launch/.

North Korea has developed the Pukkuksong-class SLBM, with initial testing of the Pukkukson-1 in 2015. In January 2021, North Korea tested the Pukkuksong-5 submarine-launched missile with a range of 1,864 miles.[559] Although North Korea has made progress toward a viable SLBM capability, it has yet to demonstrate key features, most notably an ability to launch an SLBM from a submerged submarine. Most tests of North Korea's nascent SLBM capability have been conducted from submerged barges.

Nuclear weapons exercises and demonstrations

North Korea's nuclear and missile tests serve two primary political purposes. First, they are a means for demonstrating progress on North Korea's nuclear weapons capability, which necessarily underscores North Korea's strategic goal of a nuclear deterrent. Second, they signal to both internal and external audiences that North Korea is continuing to advance its capability under the guidance of the Kim regime despite sanctions and international pressure to abandon or freeze its program. To this end, North Korean media regularly cover the country's nuclear and ballistic missile tests.

Since Kim Jong Un took power in 2012, North Korea has conducted 11 military parades. The purpose of modern military parades is to signal the advancements North Korea has made in the defense sector as a message of strength and deterrence as well as to express North Korea's intentions to continue to develop its programs.[560]

In addition to parades, North Korea frequently releases images and videos of weapons tests. These images often feature Kim Jong Un in the company of regime officials who oversee key components of North Korea's nuclear program, strategic forces, and party. These events are important parts of reinforcing Kim as Supreme Leader and premier authority within the North Korean system. In addition to contributing to Kim's image, these events also provide an opportunity to showcase the Kim family and may offer clues regarding Kim Jong Un's plans for the future of the regime. At the November 2022 launch of the Hwasong-17 ICBM, for example,

[559] Vann H. Van Diepen and Michael Elleman, "North Korea Unveils Two New Strategic Missiles in October 10 Parade," 38North, Oct. 2020, https://www.38north.org/2020/10/vdiepenmelleman101020/.

[560] Min Hong, "An Analysis of a Military Parade in Celebrating the 90th Anniversary of the Foundation of the Korean People's Revolutionary Army in North Korea," *Korea Institute for National Unification* 22, no. 11 (Apr. 2022), https://www.kinu.or.kr/2022/eng/0428/co22-11e.pdf., p. 4.

Kim was accompanied by his daughter, Kim Ju Ae.[561] Although any such analysis is highly speculative, Kim may have been using the opportunity to signal the centrality of North Korea's nuclear weapons to North Korea's future as well as to overtly link his family—and his potential line of succession for a fourth generation of Kim family rule—to the future of the country.

How does North Korea command and control its nuclear forces?

In the literature on North Korea's nuclear forces, the issue of C2 is often mentioned but rarely looked at in depth.[562] Who has authority over the nuclear force? Who makes the decision when to mate the warheads to delivery systems and launch the missile? What does the infrastructure look like from decision to employment? What positive and negative controls are in place to ensure that the nuclear force is employed as intended? This section will try to address these questions by looking at what little evidence is available on North Korean C2 and how it has evolved under Kim Jong Un. The section will examine the C2 of the nuclear program both in peacetime and in war—decisions to test the nuclear/missile programs and to operationally employ them.

[561] Kim Ju Ae is believed to be between 10 and 13 years old. In 2013 retired American basketball star Dennis Rodman said that Kim had a "baby" daughter named Ju Ae. Her appearance at the ICBM test was her first observed appearance at a public event. North Korea leadership experts noted the significant message her presence at the event represented. Josh Smith, "North Korea's Kim Reveals Daughter at Ballistic Missile Test," Reuters, Nov. 19, 2022, https://www.reuters.com/world/asia-pacific/north-koreas-kim-reveals-daughter-ballistic-missile-test-2022-11-18/.

[562] There are a few sources published on the topic, including Shane Smith and Paul Bernstein, *North Korean Nuclear Command and Control: Alternatives and Implications*, DTRA, Strategic Trends Research Initiative, HDTRA 1137878, Aug. 2022; Myeongguk Cheon, *DPRK'S NC3 System*, Nautilus Institute, June 6, 2019, https://nautilus.org/napsnet/napsnet-special-reports/dprks-nc3-system/?view=pdf; Vipin Narang and Ankit Panda, "Command and Control in North Korea: What a Nuclear Launch Might Look Like," War on the Rocks, Sept. 15, 2017; and Ildo Hwang, "North Korea's Nuclear Command and Control Estimate: Variables and Trends," *The Korean Journal of Defense Analysis* 33, no. 4 (2021), 617–638.

Figure 39. Kim Jung Un with daughter Kim Ju Ae before an intercontinental ballistic missile test

Source: North Korea State Media, www.KCNA.kp, Nov. 19, 2022.

Decision-making regarding the nuclear program

All power within North Korea originates with and is centered on the person of Kim Jong Un, who is simultaneously chairman of the State Affairs Commission (SAC), chairman of the Korean Workers' Party (KWP), chairman of the KWP CMC, and Supreme Commander of the Korean People's Armed Forces. He is the ultimate decision-making authority. Military policy and strategy are formulated and orders for operations are given, including for the testing and employment of the nuclear forces, through his offices.[563] The primary organs through which Kim exerts C2 sit atop the party and state apparatuses.

[563] Defense Intelligence Agency, *North Korea Military Power*, p. 18.

Under the recent September 2022 law on the DPRK's Nuclear Forces Policy, C2 was clarified to be under ultimate command of the chairman of the SAC (currently Kim Jong Un):

> Article 3. Command and Control of Nuclear Forces
>
> 1) The nuclear forces of the DPRK shall obey the monolithic command of the chairman of State Affairs of the DPRK.
>
> 2) The chairman of the State Affairs of the DPRK shall have all decisive powers concerning nuclear weapons. The state nuclear forces command organization composed of members appointed by the chairman of the State Affairs of the DPRK shall assist the chairman of the State Affairs of the DPRK in the entirety of the process from the decision concerning nuclear weapons to the execution.[564]

This is a change from the 2013 law, which stipulated that "nuclear weapons will only be used by final order of the Supreme Commander."[565] Although Kim Jong Un is still the Supreme Commander of North Korea's military forces, it is not clear that this position carries the same authorities it once did.[566] Although it is not unusual that North Korean leaders have held both the Head of State and Supreme Commander titles, among others, specifying the Head of State as the decision-maker on nuclear use reflects the state's jurisdiction over the military, a departure of the Kim Jong Un era from that of his father.[567] Another significant change is the added language on a "state nuclear forces command organization" (SNFCOM) that would assist the chairman of the SAC. Although what this organization looks like and its specific role and function remain to be seen, the constitutional creation of such a command is significant, and the statement in the law that the SNFCOM has responsibility for "the process…to the execution" could mean that it has administrative control authority over the nuclear forces and a portion of the Strategic Force (primarily delivery means).

564 "The Law of the Supreme People's Assembly of the DPRK on the State Policy on the Nuclear Force," Sept. 8, 2022. Translated by CNA.

565 In addition to amending the 2013 law, the 2022 law detracts from previous interpretations that focused on the "button on desk" theory, based primarily on Kim Jong Un's statement that "the nuclear button is on my office desk all the time." Kim Jong Un, "Kim Jong Un's 2018 New Year's Address," NCNK, https://www.ncnk.org/node/1427.

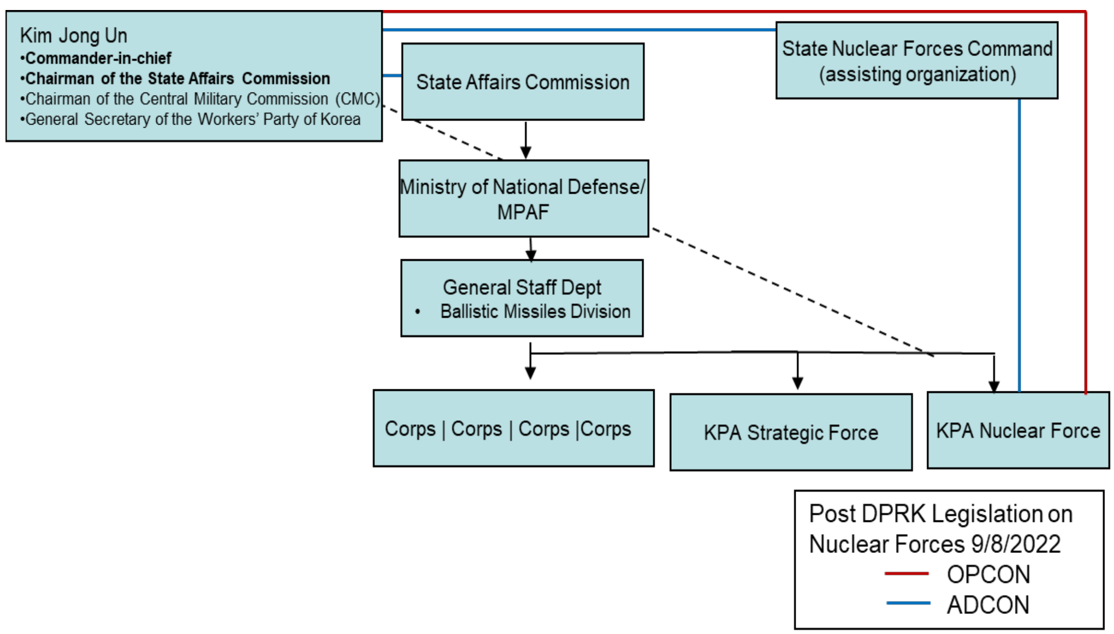
566 The apparent change in authorities tied to the title of Supreme Commander may be linked to changes in the role and function of the CMC since the 8th Party Congress. Instead of exercising a joint C2 function with the SAC, the CMC has now likely assumed a more operational and facilitation function, providing guidance and oversight of decisions made within the SAC.

567 Kim Jong Un's father, Kim Jong Il, governed with a *songun* (military-first) ideology. See Ildo Hwang, *DPRK's Law on the Nuclear Forces Policy: Mission and Command & Control*, Institute of Foreign Affairs and National Security, IFANS Focus 2022-22E, Sept. 14, 2022.

Evolving C2 structure for the nuclear forces

North Korea has a nascent nuclear capability supported by a C2 structure that is in its early phase of development. The linkages in terms of reporting mechanisms within this structure and how information is passed up and down the chain of command are at this point speculative. The community of North Korea analysts (collectively referred to as North Korea or Pyongyang watchers), however, have some theories about how the process might work given observations of how C2 generally works within the North Korean regime.

Figure 40. Plausible nuclear C2 structure reflecting recent law



Source: CNA.

The first assumption is that the North Korean C2 structure is not yet automated. According to defector reporting, North Korea has been working on an automated command, control, and communications system since the Kim Jong Il era to support C2 but has made only marginal progress.[568] At the General Staff and corps levels, some decision-making is supported by computers, but lower level commands still rely on telephony, radio, and couriers. Pyongyang

[568] Cheon, *DPRK's NC3 System*.

is connected to frontline commands, including missile and warhead storage bases as well as dispatch sites for TELs, primarily through fiber-optic cables.[569] According to one Korean analyst, North Korea's current C2 architecture has operational implications:

> If there is no prior delegation of fire authority, some delivery options such as surface and submarine vessels would be unlikely used for warhead delivery systems due to the restriction of communication. If one assumes that the Highest Commander specifies a target and an attack time in advance, those options could be considered for nuclear employment although it would be a great challenge to cancel the mission order.[570]

The second assumption is that the warheads and delivery systems are kept apart during peacetime and managed through two separate chains of command,[571] both of which report directly up to Kim Jong Un in his capacity as chairman of the SAC.[572] The mating of the warheads to the delivery systems would take place only once the order is given by the chairman.[573] It is conventional wisdom that all nuclear delivery systems are under the exclusive control of the KPA Strategic Force.[574] Based on North Korean state media reporting, the Strategic Force possesses fixed and mobile ballistic missiles with medium-, intermediate-,

[569] Cheon, *DPRK's NC3 System*.

[570] Cheon, *DPRK's NC3 System*.

[571] On March 7, 2017, the North Korean media reported that ballistic launch exercises were held to evaluate the warhead employment procedures of the Strategic Force Command's Hwaseong Artillery and their ability to conduct speedy operations. It is not clear from this reporting whether the Strategic Force Command maintained possession of nuclear warheads or was part of the mating process to the delivery system. See Cheon, *DPRK's NC3 System*.

[572] This assumption is based on the likely influence of the Soviet experience on North Korean thinking about nuclear weapons and nuclear C2. According to Western sources, the KGB had custody and transport responsibilities for nuclear charges, which were separated from missiles and aircraft, until the late 1960s. At that time, the KGB apparently relinquished its physical control over nuclear warheads but remained involved in the nuclear control process. Given the tight control the Supreme Leader has exerted over the nuclear force and its employment, it would make sense that two chains of command are required to launch a missile.

[573] This is likely true of land-based nuclear weapons, but submarine-based nuclear weapons would likely have to be preassembled and operational when put to sea. C2 would have to rely on a two-person system, with the submarine captain operating off procedural controls laid down by Kim Jong Un regarding launch authority. See Smith and Bernstein, *North Korean Nuclear Command and Control: Alternatives and Implications*; and Narang and Panda, "Command and Control in North Korea: What a Nuclear Launch Might Look Like."

[574] The KPA Strategic Force, which consists of 13 brigades, is predominantly under the direct command of the Supreme Commander without going through the General Staff, unlike its predecessors, the Missile Guidance Bureau, or the Strategic Rocket Force. See Ministry of National Defense of the Republic of Korea, *2020 Defense White Paper*, 2020, pp. 27–28.

and long-range capability. Once nuclear weapons move from the testing stage to deployment, multiple commands could possess delivery systems, including the Bodyguard and Artillery Commands.[575] As for control and security of the warheads, North Korean media have said nothing. Some sources have pointed to warheads being the purview of the party apparatus during peacetime and up to the point of employment.[576] Other speculation has pointed to the internal security apparatus, such as the Ministry of State Security, assuming that North Korea would pattern its C2 after the Soviet model.[577] More recent speculation has pointed to the Military Security Command (MSC) as having dedicated security units trained and tasked for the monitoring, maintenance, and logistics of nuclear warhead storage.[578] The fact that the MSC's political influence has risen in the Kim Jong Un era supports this assumption.[579]

The third assumption is that Kim Jong Un does not make decisions in a bubble regarding the nuclear program. Even though the recent law on nuclear doctrine discusses a support mechanism, the SNFCOM, there is reason to believe that Kim seeks advice and counsel in the lead up to making decisions on testing. From early on in Kim Jong Un's rule, the North Korean media have portrayed him as a deliberative decision-maker who seeks counsel on decisions of the highest importance to the state. In January 2013, for example, a photograph appeared of a so-called meeting between Kim and his National Security Council on the eve of the third nuclear

[575] According to one Korean source, C2 for tactical nuclear weapons (such as the KN-23 and KN-24) may differ from C2 for strategic nuclear weapons. To utilize tactical nuclear weapons as warfighting capabilities on the Korean Peninsula, they could be deployed under the C2 of conventional strike capabilities, consisting of the Supreme Commander, General Staff, and Artillery Command. On the other hand, in the case of mid- to long-range and strategic nuclear capabilities that can strike US territory, the Strategic Force, rather than the General Staff, will take charge. Hwang, "North Korea's Nuclear Command and Control Estimate: Variables and Trends."

[576] One source suggested that warheads would be the responsibility of a special institute under the direct control of the KWP CMC. Once Kim Jong Un authorizes the use of a nuclear weapon, a nuclear ordnance squadron would transport the warhead to the strategic rocket forces unit and mount it on a missile. Yun-Gul Lee, *The Status of DPRK's Nuclear/Missile Development and C2 System in Kim Jong Un's Era*, Sejong Policy Briefing No. 2017-04, Mar. 6, 2017.

[577] The Ministry of State Security reportedly has a Defense Industry Bureau, suggesting that it has a role in the security of weapon systems.

[578] It is possible that the MSC and Ministry of State Security might split responsibility for warhead and fissile material storage, security, and transportation. According to one source, the MSC oversees warhead security and storage for usable/deployable warheads, whereas the Ministry of State Security is responsible for the security of fissile material and experimental warheads being used by the KWP Munitions Industry Department (MID), including ANDS, the SEC, the Atomic Weapons Institute, and any other institutions subordinate to or affiliated with MID. Discussions with North Korea Leadership Watch.

[579] North Korean C2 conversations with Pyongyang watchers, including North Korea Leadership Watch.

test.[580] According to South Korean reporting, Kim Jong Un established an advisory body called the Military First Revolutionary Team in February 2013 to assist his decision-making regarding nuclear testing.[581] The unofficial body was subordinate to the Supreme Command and composed of representatives of the party, military, defense industry, internal security, and Kim family. It appeared to be based on a similar advisory body Kim Jong Il allegedly consulted before deciding to conduct missile or nuclear tests. The body reportedly provided input on the implications of a test in terms of technology, regional blowback, and internal security concerns. The team's advice was transmitted back to Kim either directly or through his personal secretariat where it would feed into the advice he received from his military advisors. The result was a signed order, which would be broadcast to the wider leadership via CMC channels. Whether the team still exists since Kim consolidated his power is unknown, although such a body would fit with his leadership style of seeking out expertise and advice as part of the national security decision-making process.[582]

Once a decision has been made and the orders are drawn up, a Management Team reportedly ensures execution of the mission. Although its makeup is not entirely clear, this team is composed of key military, security, and defense industry leaders. Depending on the nature of the mission, one or more of these entities will be involved in conveying the orders down the chain of command.

- If the mission involves a nuclear test, the KWP secretary for munitions would convey the orders through the KWP Munitions Industry Department to the ANDS and the SEC.
- If the mission involves a missile test, the head of the Strategic Force would likely take the order directly from Kim Jong Un and convey it to the operational forces.[583]

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580 *Rodong Sinmun Online*, Jan. 27, 2013.

581 "'Exclusive' Report on DPRK's Secret Nuclear Decision-Making Unit," *JoongAng Ilbo Online*, Jan. 8, 2016. The author identified other sources that believe that such a unit exists but with a broader range of responsibilities beyond the nuclear program.

582 Ken E. Gause, "Command and Control of the North Korean Armed Forces," (Paper in support of CNA-KIMS conference, 2017).

583 As North Korea's rockets are becoming more sophisticated, they are quickly becoming some of Kim Jong Un's most prized strategic assets, second only to nuclear weapons. Keeping the Strategic Force close to him and streamlining the C2 process makes sense for him from the risk management perspective. See below how Kim might streamline this C2 chain even further during a war given the country's outdated communications architecture.

North Korean nuclear C2 during a crisis or conflict

If North Korea entered a crisis or conflict, its C2 structure would likely transform to deal with an uncertain situation and the compression of time as things progressed up the escalatory ladder. The decision-making space around Kim Jong Un would be narrowed, and processes down the chain of command would be streamlined. An organizational realignment of the leadership institutions would also take place. Article 104 of the North Korea constitution states that in wartime, the chairman of the SAC has the duty and authority to organize and direct the National Defense Committee.[584]

Early warning and command, control, and communications

North Korea has many aging early warning and intercept radars that provide basic detection of large aircraft at long distances to support the defense of its airspace, especially around areas with key strategic infrastructure: Pyongyang, the demilitarized zone (DMZ), and both the west and east coasts.[585] These comprise aging P-14 Tall King radars—developed by the Soviet Union in the early 1960s—as well as more recently developed transportable strategic surface-to-air missile (SAM) sites, mobile tactical SAM systems, antiaircraft artillery (AAA) positions, and man-portable air defense systems.[586] As discussed previously, peacetime and wartime C2 structures are unclear, but similar to the Strategic Force's line of communication back to the chairman of the SAC, the North Korean Air Force and AAA corps would theoretically report to or receive orders from the Supreme Commander (or the SNFCOM) through the General Staff Department. The existing communication architecture will cause challenges for response times. A recent ROK defense report notes that the KPA is working to develop an automated C2 system for air defense to increase detection accuracy of its radar air defense units and air defense to reduce response times but has made limited progress.[587]

[584] Socialist Constitution of The Democratic People's Republic of Korea. The constitution does not specify the responsibilities of the National Defense Committee or its membership. The 1972 and 1998 constitutions noted that the National Defense Committee would be responsible for mobilization in wartime. Whether this would still be the case today is unknown.

[585] Terrence Roehrig, "The Abilities—and Limits—of North Korean Early Warning," *Bulletin of the Atomic Scientists*, Nov. 27, 2017, https://thebulletin.org/2017/11/the-abilities-and-limits-of-north-korean-early-warning/; Defense Intelligence Agency, *North Korea Military Power*.

[586] "The North Korean SAM Network," *IMINT & Analysis (blog)*, June 12, 2010. IMINT & Analysis is a blog dedicated to open-source military analysis, strategic thinking, and imagery interpretation.

[587] Ministry of National Defense of the Republic of Korea, *2020 Defense White Paper*, p. 34.

Although C2 was recently clarified at the upper levels of the C2 structure with the September 2022 nuclear doctrine legislation, as noted above, Kim Jong Un's nuclear C2 system continues to adapt alongside the evident updates to his nuclear program.[588] A lack of real-time situational awareness and time latency issues in terms of communications pose a real challenge to Kim's ability to rely on the convoluted peacetime C2 structure to work for the most critical component of the country's defense, the nuclear force.[589] Until automated systems can be installed throughout the C2 structure linking higher headquarters to the Strategic Force and Nuclear Force, Kim Jong Un will likely rely on an informal structure of communications that bypasses first-tier commands, such as the General Staff Department and Strategic Force, so he can interact directly with the unit commanders in charge of launching the weapons.[590] The coordinating body for this C2 will be the Office of Military Officers within Kim Jong Un's personal secretariat, possibly in coordination with the State Nuclear Force Command.[591]

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[588] Lewis and Tertrais, *Finger on the Button: The Authority to Use Nuclear Weapons in Nuclear-Armed States*.

[589] In addition to its aged air defense system, North Korea would have to rely on its own human intelligence sources in South Korea and the region, as well as intelligence passed by China and Russia, to have situational awareness of US/ROK actions during a crisis. Even though the regime claims that it has a rudimentary satellite capability, the resolution of the photographs it has made public of South Korea would be useless for military purposes.

[590] Targeting will be particularly challenging for North Korea in any near-term conflict. Because of a lack of situational awareness, Kim Jong Un will likely have little ability to revise target lists. According to Smith and Bernstein:

> Kim Jong Un could not realistically expect to maintain the situational awareness necessary to order iterative nuclear attacks in a timely manner during a potentially fast-moving conflict in which his forces are likely under fire. Target sets might be highly prescribed in order to prevent unintended escalation and to de-conflict fires, but nuclear operators would need some degree of flexibility and discretion if the hope is to execute militarily effective nuclear strikes in highly unpredictable circumstances.

Smith and Bernstein, *North Korean Nuclear Command and Control: Alternatives and Implications.*

[591] The Office of Military Officers is Kim Jong Un's immediate administrative support staff supporting his C2 role over North Korea's armed forces, internal security services, and military intelligence and serves as primary gatekeeper and administrative support with the principals of senior KPA and internal security commands (i.e., Ministry of the People's Armed Forces, General Staff, State Security, Public Security). The Office of Military Officers receives and conveys daily reports to Kim Jong Un and issues any commands, orders, and action items to relevant commanders. Therefore, it has an established rapid channel of communications, which would facilitate sensitive operations during a crisis, however, such an informal structure poses particular risks for accidents and miscalculation, particularly in a period of raised tensions or crisis. For a detailed discussion of Kim Jong Un's personal secretariat, including the role and function of the Office of Military Officers, see Gause, *North Korean House of Cards*.

Delegation and pre-delegation of C2

There are several models about how C2 might operate inside North Korea during a conflict.[592] The model outlined above is called "automaticity," in which all decision-making begins and ends with Kim Jong Un. It best fits the leadership culture in North Korea, in which all decision-making authority belongs to the Supreme Leader. But for its deterrent to work, North Korea needs to be able to launch a preemptive strike if the regime comes under threat and needs a viable second-strike capability if it comes under attack from hostile forces. In both cases, Kim Jong Un might be killed or lose contact with his strategic forces. Under such circumstances, a second level of C2 in which launch authority is transferred within the senior leadership or devolved down the chain of command would help ensure operational resilience, responsiveness, and flexibility.[593]

The September 2022 nuclear doctrine legislation appears to obliquely address the need for delegation of authority for the nuclear force if the "command and control system over the state nuclear forces is placed in danger owing to an attack by hostile forces."[594] In this case, "command and control system" most likely refers to Kim Jong Un. If the US-ROK forces launch a decapitation strike or if Kim Jong Un becomes incapacitated or dies during a crisis, the regime needs to ensure that it can launch a nuclear preemptive or retaliatory strike. A recent study of North Korean C2 outlines the four models for the transfer of authority.[595]

- **Devolution** is a model that is institutionalized before a crisis as part of a succession plan to ensure that C2 of the nuclear force is not lost during a transfer of power if

[592] Smith and Bernstein, *North Korean Nuclear Command and Control: Alternatives and Implications*.

[593] In the open-source literature on North Korean C2, there is a wide span of opinion on who might be the recipient of delegated authority over the nuclear force if Kim Jong Un dies or becomes incapacitated. Some believe that control will move to someone or group of people within Kim's inner circle. Ri Pyong-chol, the KWP secretary for munitions, is one candidate, as are Kim Yo-jong and Kim Sol-song, Kim's sister and half-sister and key gatekeepers within his personal secretariat. Others believe that authority could devolve down to the CMC. In 2021, the party bylaws were amended to allow the KWP CMC to convene a meeting with only necessary members regardless of a quorum, depending on the nature of the issue. This might be a signal to North Korea's adversaries warning that a decapitation strike could lead the remaining members of the CMC to use nuclear weapons. See Cheon, *DPRK'S NC3 System*; and Hwang, "North Korea's Nuclear Command and Control Estimate: Variables and Trends."

[594] "The Law of the Supreme People's Assembly of the DPRK on the State Policy on the Nuclear Force."

[595] The models are described in more detail in Smith and Bernstein, *North Korean Nuclear Command and Control: Alternatives and Implications*; and Paul Bernstein and Shane Smith, "Through a Glass, A Little Less Darkly: North Korean Nuclear Command and Control in Light of Recent Developments," 38North, Nov. 14, 2022.

something happens to Kim Jong Un. It describes the designation of an individual who would take over decision-making tied to nuclear C2.

- **Delegation** is a more operationally focused model in which Kim Jong Un can transfer employment decision-making for the nuclear force to the military. This model assumes that Kim Jong Un will maintain control of the nuclear force entering a crisis but can transfer authority at any point thereafter.
- **Pre-delegation** is similar to the delegation model but likely takes place at the beginning of a crisis instead of during a crisis/conflict as a result of facts on the ground. A certain amount of anticipation and planning goes into pre-delegation. A set of rules probably goes along with this model, which assumes that the regime needs flexibility in case the Supreme Leader becomes incapacitated or loses communications in the early stages of a crisis/conflict.
- **Hybrid (pre-)delegation** is a model that is tied to the range of North Korean weapons options and tries to mitigate the risks of delegation and pre-delegation to lower echelon units. C2 for tactical nuclear weapons could be delegated to frontline and specialized units, whereas control of strategic weapons to be employed off the peninsula would remain under centralized control.

These models reflect the operational transfer of authority. In practice, however, several questions remain regarding how any devolution or delegation model would work given the politics and culture of the regime. These models suggest a permanently designated second-in-command or at least alternative positions within the regime that would assume authority. Even in a crisis, this could cause tension within the regime by establishing an alternate center of power, undermining Kim Jong Un's position. Pre-delegation or some form of hybrid model may be the most likely models, whereby at the outset of a crisis, a set of orders will be shared with select authorities alongside a set of specific conditions to launch retaliatory strikes.[596] How the designated authority(ies) would act on or interpret Kim Jong Un's final orders introduces still more uncertainty into understanding how North Korea would seek to ensure nuclear C2 in a crisis.

[596] Pre-delegation already exists within North Korea's C2 structure with respect to C2 of the submarine force. Submarine commanders receive orders and are largely out of contact with central command until completion of their missions. See Gause, "Command and Control of the North Korean Armed Forces."

What nuclear weapons–related R&D has North Korea undertaken?

North Korea is pursuing a nuclear deterrent that can credibly threaten targets anywhere in the world. To that end, North Korea's nuclear program R&D is focused on developing the infrastructure necessary to develop and produce nuclear weapons and means of delivery and conducting tests to improve the capability of North Korea's ballistic missiles. Despite its weak economy and isolation from much of the international community, North Korea has prioritized and grown its nuclear and missile R&D programs. Although initially reliant on foreign support, North Korea's domestic nuclear R&D capabilities have grown to the point of being able to produce weapons and missiles; however, considerable debate remains regarding how much foreign support North Korea's weapons and missile programs continue to receive. Sanctions and international pressure have curtailed North Korea's nuclear progress and access to foreign support and material, but North Korea has demonstrated that it can continue to develop new capabilities and make technological progress despite these barriers. North Korea can indigenously produce fissile material and is demonstrating increasingly capable ballistic missiles.

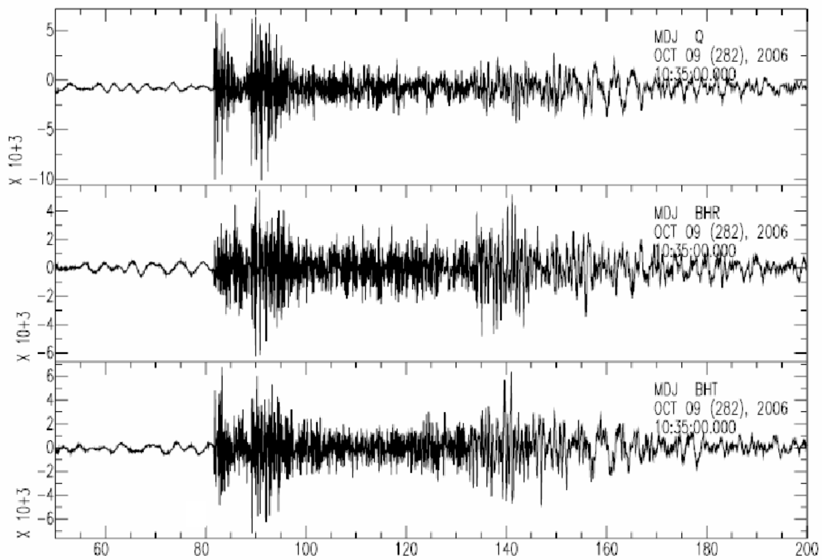
North Korea has gone to great lengths to obscure the overall organization and components of its weapons program. This paper draws on open-source reporting and analysis using North Korean media reporting, declassified intelligence, reports from the IAEA, satellite imagery, and other sources.

As discussed in a previous section, North Korea offers glimpses into its nuclear program priorities in official regime statements and observable activities. North Korea's R&D activities include projects that advance its warhead development and missile programs, including the following:

1. Development of facilities and infrastructure for the production of fissile uranium and plutonium
2. Design of nuclear weapons, including work toward nuclear fusion and developing a thermonuclear capability
3. Development of nuclear weapons delivery systems
4. Testing of nuclear weapons delivery systems

This section will provide an overview of what is known about North Korea's R&D efforts and associated facilities.

Figure 41. Seismic waves of 2006 North Korean nuclear test



Source: Wikimedia Commons, via Japan Meteorological Agency.

Fissile material production

As discussed above, all North Korea's fissile material is believed to be produced at the Yongbyon Nuclear Scientific Research Center. Since at least 2009, North Korea has undertaken several projects to update and expand its fissile material production capacity at the Yongbyon complex. In addition to construction efforts to keep North Korea's 5 MWe reactor operational, several other components of North Korea's nuclear weapons–related facilities have been built. These include a new experimental light water reactor (ELWR), which has been under construction since 2010; a facility to make uranium hexafluoride gas (the feedstock for uranium enrichment); new reactor fuel fabrication facilities; construction around the Radio Chemical Laboratory (RCL); and what appear to be new tritium separation facilities.[597]

The amount of construction that North Korea has undertaken to build up its infrastructure at Yongbyon indicates that North Korea is seeking to ensure its capacity to continue producing fissile material and enhance its capability to pursue thermonuclear weapons. North Korea also

[597] "Estimating North Korea's Nuclear Stockpiles: An Interview with Siegfried Hecker."

seeks to modernize its fissile material production capability. These facilities will be discussed in greater detail below.

Nuclear forensics and covert testing

Much of what the international community knows about North Korea's nuclear tests is from nuclear forensics, or the observable data collected and assessed following any international nuclear explosion. Data gathering is made possible through hundreds of monitoring stations in place under the Comprehensive Nuclear-Test-Ban Treaty.[598]

Forensic seismologists assess seismic wave data (see Figure 41) to distinguish manmade events—possibly covert nuclear tests—from naturally occurring earthquakes. From this information, they can determine how deep in the earth the explosion originated, the approximate location of the explosion, and even the approximate yield of the weapon.[599]

In addition to using seismology, there are stations that can "sniff" radionuclide particles and noble gases such as xenon and krypton to detect covert tests and can even indicate whether the fissile material in the test was uranium or plutonium.[600] Other stations can detect low-frequency sound waves in the air and in the ocean that may indicate a nuclear test.

[598] This treaty has not been ratified by several required countries (including the United States) and therefore has not officially entered into force. However, about 90 percent of the 337 required facilities are up and running, and the treaty's function has proven effective following its monitoring of North Korean nuclear tests. "Overview of the Verification Regime," Comprehensive Test Ban Treaty Organization Preparatory Commission, https://www.ctbto.org/our-work/verification-regime, accessed Mar. 2, 2023.

[599] Alexandra Witze, "How Earthquake Scientists Eavesdrop on North Korea's Nuclear Blasts," *Science News*, July 25, 2017, https://www.sciencenews.org/article/earthquakes-north-korea-nuclear-testing.

[600] Richard L. Garwin and Frank N. von Hippel, "A Technical Analysis: Deconstructing North Korea's October 9 Nuclear Test," *Arms Control Today*, https://www.armscontrol.org/act/2006-11/features/technical-analysis-deconstructing-north-korea%E2%80%99s-october-9-nuclear-test.

Nuclear weapons design

The weapons development component of North Korea's nuclear program is opaque.[601] Generally, states keep the design and performance characteristics of their nuclear arsenals secret.[602] As one expert noted, there are three distinct streams of evidence that shed light on North Korea's nuclear weapons program: seismic and other observational data, insider and defector accounts, and official North Korean statements. By comparing these three streams, experts have determined that North Korea likely has four nuclear weapons designs: three relatively simple implosion devices and one two-stage or thermonuclear device.[603]

North Korea's recent R&D efforts appear to prioritize developing warheads that are small enough to be mated with missiles to ensure that they can be delivered to their targets. North Korea has consistently messaged that warhead miniaturization and fielding tactical nuclear weapons are a priority.

North Korea has released limited information about its nuclear weapons designs publicly through KCNA. For example, in March 2016 KCNA published photos of what the regime called a miniaturized nuclear weapon. In September 2017, North Korean media released photos of what they called a two-stage thermonuclear (hydrogen) bomb. This announcement coincided with North Korea's claims that it had also managed to mate a weapon with a missile.[604] The photos of the purported two-stage device were taken in front of a diagram that shows how the warhead would fit into one of the DPRK's missiles. North Korea's claims have not been independently verified, and experts have not confirmed whether these were the actual designs that North Korea tested or the types of warheads that make up Pyongyang's nuclear arsenal.[605]

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[601] Stephan Haggard and Tai Ming Cheung, "North Korea's Nuclear and Missile Programs: Foreign Absorption and Domestic Innovation," *Journal of Strategic Studies* 44, no. 6 (2021): 802–829, doi: 10.1080/01402390.2021.1993828, p. 815.

[602] "Hinge Points: An Inside Look at North Korea's Nuclear Program," James Martin Center for Nonproliferation Studies, https://nonproliferation.org/hinge-points-weaponization/.

[603] "Evidence About North Korea's Nuclear-Weapon Designs," James Martin Center for Nonproliferation Studies, Oct. 30, 2019, https://nonproliferation.org/evidence-about-north-koreas-nuclear-weapon-designs/.

[604] "Evidence About North Korea's Nuclear-Weapon Designs."

[605] "Hinge Points: An Inside Look at North Korea's Nuclear Program."

Figure 42. Kim Jong Un inspects purported nuclear fission bomb

Source: KCNA (official North Korean media).

Since at least 1991, there has been evidence in North Korean media and scientific journals, such as the *Journal of Kim Il Sung University*, that the country has been pursuing nuclear fusion.[606] Nuclear fusion is a dual-use technology that could be used for both civilian energy production and acquiring weapons-related capabilities.[607] As an incremental step, North Korea may also be using tritium to pursue a boosted fission weapon—a more sophisticated design than an ordinary fission weapon but less technically challenging and often lower in yield than a thermonuclear weapon.

In 2010, North Korea announced that it had achieved fusion, and in 2016, North Korea announced that it had tested a hydrogen bomb. Both claims were met with skepticism, given the relatively low yields detected by outside observers, as well as skepticism about whether North Korea is capable of producing the isotope tritium, which can act as a booster in fission weapons and is required in hydrogen bombs alongside deuterium. Tritium is produced from lithium in nuclear reactors. Where or how North Korea produces tritium is unclear, although one expert suspects that it is necessarily produced at Yongbyon Nuclear Research Center's 5 MWe reactor. Whether North Korea uses tritium for boosted fission weapons or thermonuclear weapons is also unclear.[608]

606 Hyuk Kim, "North Korea's Nuclear Fusion Research," James Martin Center for Nonproliferation Studies, Feb. 15, 2022, https://nonproliferation.org/north-koreas-nuclear-fusion-research/.

607 Kim, "North Korea's Nuclear Fusion Research."

608 Hecker, Braun, and Lawrence, "North Korea's Stockpiles of Fissile Material," p. 743.

Deuterium, tritium, and lithium-6

Deuterium and **tritium** are isotopes of the element hydrogen. All hydrogen isotopes have one proton, but deuterium additionally has one neutron and tritium has two.[609] When tritium and deuterium fuse together they release an intense amount of energy and are therefore useful in boosted fission weapons and hydrogen bombs (named for the fusion generated by hydrogen isotopes) as well as nuclear energy reactors.[610]

Lithium-6 is a naturally occurring soft metal that, when used inside a reactor, can form tritium, which is extremely rare in nature. Lithium-6 can also be used inside some nuclear weapons alongside deuterium to act as a nuclear explosion booster.[611] Lithium-6 makes up about 7 percent of natural lithium and must first be enriched to 40 to 95 percent.[612]

Tritium production therefore requires access to lithium. North Korea is believed to have large reserves of lithium ore in Soonung, North Hamgyong province, and Notan-ri in Kangwon.[613] To provide the requisite tritium for a weapons program, North Korea would need to master the technologies of lithium-6 enrichment and tritium separation from irradiated lithium targets.[614] For comparison, the United States and the Soviet Union mastered these technologies during

[609] "DOE Explains...Deuterium-Tritium Fusion Reactor Fuel," Department of Energy, https://www.energy.gov/science/doe-explainsdeuterium-tritium-fusion-reactor-fuel, accessed Mar. 2, 2023.

[610] David Albright et al., *North Korea's Lithium 6 Production for Nuclear Weapons*, Institute for Science and International Security, Mar. 17, 2017, https://isis-online.org/uploads/isis-reports/documents/North_Korea_Lithium_6_17Mar2017_Final.pdf.

[611] Albright et al., *North Korea's Lithium 6 Production for Nuclear Weapons*.

[612] Albright et al., *North Korea's Lithium 6 Production for Nuclear Weapons*.

[613] Minsoo Kim, Sangjoon Lee, and Sunyoung Chang, "DPRK's 4th Nuclear Test and Its Tritium Production," *Korea Institute of Nuclear Nonproliferation and Control* (2016), https://www.kns.org/files/pre_paper/35/16S-663%EA%B9%80%EB%AF%BC%EC%88%98.pdf.

[614] Plants for lithium enrichment are controlled by the Nuclear Supplies Group, as are specialized components or equipment for the separation process. Justin V. Hastings, Haneol Lee, and Robert Kelley, "North Korea's Lithium Research Networks and Its Quest for a Hydrogen Bomb," *Korean Journal of Defense Analysis* 30, no. 3 (Sept. 2018), https://www.researchgate.net/publication/327966440_North_Korea%27s_Lithium_Research_Networks_and_its_Quest_for_a_Hydrogen_Bomb.

the 1950s, and experts posit that it would not be surprising if North Korea has acquired some degree of proficiency in these technologies.[615]

In a study published by South Korea's KIDA in 2018 that focused on North Korea's pursuit of a hydrogen bomb, the authors analyzed a subset of North Korean scientific journal articles on lithium-related topics, which yielded 30 articles on lithium research, with a surge in research from 2005 to 2011.[616] Furthermore, under its "2nd Science and Technology and Development Plan (2003-2007)," North Korea is reported to have conducted "Deuterium-Tritium Fusion" and "Separation of Li-6 from Natural Lithium" projects.[617]

Available information strongly indicates that North Korea has built and is operating a lithium-6 production plant that is part of its nuclear weapons effort. The plant is suspected to be at the Hungnam Chemical Complex near Hamhung on North Korea's east coast.[618]

If North Korea can successfully master the associated technologies to achieve fusion and is able to develop a hydrogen bomb, it will lend credence to North Korea's claims that it possesses nuclear weapons that are small enough to mount on an ICBM capable of hitting the United States. As the authors of the 2018 KIDA study note, "the purpose of building hydrogen bombs is not merely to showcase technological sophistication or to boost yields (which is strategically irrelevant), but also to increase the yield of a device relative to its weight, which increases its deliverability."[619]

Nuclear weapons delivery systems

During the Kim Jong Un period, North Korea has significantly increased its ballistic missile testing. Although UN Security Council resolutions prohibit North Korea's development of the means of delivering conventional and nuclear payloads, North Korea has frequently launched ballistic missiles, sometimes obscuring the purpose of the tests by claiming that they are a part

[615] Hecker, Braun, and Lawrence, "North Korea's Stockpiles of Fissile Material," p. 743.

[616] Hastings, Lee, and Kelley, "North Korea's Lithium Research Networks and Its Quest for a Hydrogen Bomb."

[617] Kim, Lee, and Chang, "DPRK's 4th Nuclear Test and Its Tritium Production."

[618] Hastings, Lee, and Kelley, "North Korea's Lithium Research Networks and Its Quest for a Hydrogen Bomb." Hastings, Lee, and Kelley note that the Institute for Science and International Security's conclusion about the plant in Hamhung is based on a handwritten note on a procurement document. They caution that depending on a single source of information is problematic, but they concede that this finding might well be the best evidence to date. They further note that "Hamhung as a location for the production plant would not be particularly surprising, as it is a major center within North Korea for chemical production and chemical research."

[619] Hastings, Lee, and Kelley, "North Korea's Lithium Research Networks and Its Quest for a Hydrogen Bomb."

of North Korea's nascent space program. During the Kim Il Sung and Kim Jong Il periods (1948 to 1994 and 1994 to 2011, respectively), North Korea conducted about 30 ballistic missile tests in total; however, almost 200 ballistic missile tests have been conducted during the Kim Jong Un period. In 2022 alone, North Korea conducted 90 launches of short-, medium-, and long-range missiles. This uptick in testing suggests that ballistic missiles are becoming a key component of North Korean military plans and that North Korea is moving from R&D of ballistic missiles toward an operational capability.

North Korea established the foundations of its ballistic missile program in the 1960s. North Korea had received various weapons, including surface-to-ship and surface-to-air missiles, from the Soviet Union and the PRC. However, similar to the nuclear program as a whole, competition with the ROK[620] and the unreliability of North Korea's relations with the Soviet Union and the PRC were key factors in Kim Il Sung's decision to develop an indigenous ballistic missile program.[621] North Korea's missile program is overseen by ANDS, previously known as the Second Academy of Natural Sciences (SANS). In 1965, North Korea founded the Hamhung Military Academy, which began to train North Korean personnel in rocket and missile development.[622] In 1966, the Second Machine Industry Ministry, under the KWP secretary in charge of military industries, was established to manage the procurement and production of weapons.[623]

Experts believe that North Korea's indigenous ballistic missile program benefited early on from the significant foreign support it received and efforts to reverse engineer weapons obtained in the 1980s, citing the rapidity of North Korea's apparent mastering of certain technologies despite its relatively low testing profile.[624] By the late 1990s, North Korea was known to have engaged in missile technology exchanges with Egypt, Iran, Libya, Pakistan, Syria, and possibly Iraq and to have both openly and covertly obtained ballistic missile technologies, components, and materials from Europe, Japan, Russia, and the PRC.[625] North

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[620] The ROK established a ballistic missile program in the 1970s that it later abandoned at the urging of the United States in exchange for US missiles. Joseph Bermudez, *A History of Ballistic Missile Development in the DPRK*, Center for Nonproliferation Studies, 1999, https://www.nonproliferation.org/wp-content/uploads/2016/09/op2.pdf.

[621] Bermudez, *A History of Ballistic Missile Development in the DPRK.*

[622] Daniel Pinkston, *The North Korean Ballistic Missile Program*, Army War College, Feb. 2008, https://publications.armywarcollege.edu/wp-content/uploads/2022/11/1937.pdf.

[623] Pinkston, *The North Korean Ballistic Missile Program*.

[624] Pinkston, *The North Korean Ballistic Missile Program*.

[625] Bermudez, *A History of Ballistic Missile Development in the DPRK.*

Korea also acquired the services of small numbers of foreign missile designers, engineers, and specialists.[626] Today, however, experts assess that North Korea is less reliant on foreign support for its ballistic missile technology and production and has built out its indigenous capability to develop its weapons systems. Rather, North Korea currently needs access to components and raw materials that are commercially available on the international market.[627]

Under Kim Jong Un, North Korea has focused on advancing its missile capabilities, developing a full spectrum of short-, medium-, intermediate-, and intercontinental-range ballistic missiles[628] as well as SLBMs. Kim's public statements continually emphasize the link between a robust science and technology environment within North Korea and the attainment of its missile technology goals. Indications are that North Korea will continue to incorporate advanced technologies into its ballistic missiles. During its 8th Party Congress (2021), North Korea, for the first time, noted several areas of focus for its missile program. These priorities include precision guidance technology, multiple warhead reentry capability, a sea-launched capability, and hypersonic technology.[629]

North Korea's testing profile and official statements in recent years have reflected the objectives listed at the 8th Party Congress. For example, North Korea has reportedly tested hypersonic missiles three times since 2021 and a new long-range cruise missile.[630] Following the third test of a hypersonic missile in January 2022, North Korea declared its hypersonic missile technology to be "complete." Although this assertion is likely premature, it does indicate that North Korea is likely to continue to develop a hypersonic missile capability and join China, the United States, and Russia in pursuing hypersonic technology. This claim is in keeping with other North Korean statements accompanying missile launch coverage that frequently tout progress made in the maneuverability or precision of the missile or missiles being tested.

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[626] Bermudez, *A History of Ballistic Missile Development in the DPRK.*

[627] Victor Cha and Katrin Fraser Katz, *The Burgeoning North Korea Missile Threat*, CSIS, Apr. 29, 2022, https://www.csis.org/analysis/burgeoning-north-korea-missile-threat.

[628] North Korea has conducted an aggressive testing schedule for its ballistic missiles and in 2022 returned to testing its ICBM capability, which it had paused since 2017.

[629] "On Report Made by Supreme Leader Kim Jong Un at 8th Congress of WPK."

[630] Josh Smith, "Explainer: From Hypersonics to Workhorse Weapons, N.Korea Showcases Missile Diversity," Reuters, Jan. 30, 3022, https://www.reuters.com/world/asia-pacific/hypersonics-workhorse-weapons-nkorea-showcases-missile-diversity-2022-01-31/.

North Korea has made significant strides in its mobile launch platforms, including a rail-mobile capability and solid-fuel SRBMs. Its ICBM development similarly is on track; a March 2022 set of tests indicated that North Korea has made progress toward a multiple reentry capability. However, North Korea appears to be having difficulty with its sea-launched capability. In 2021, North Korea launched an SLBM from its experimental SSB for the first time (it had previously only succeeded in launching SLBMs from a submerged test barge), but it has so far not demonstrated a capability to reliably launch a longer range SLBM nor has it highlighted recent developments toward an operational SSB.

Figure 43. 2019 test of Pukguksong-3 underwater-launched ballistic missile

Source: KCNA.

What sites or facilities does North Korea use for nuclear weapons–related R&D?

North Korea maintains an expansive and relatively comprehensive nuclear weapons R&D, production, and testing infrastructure. One report published in 2014 estimated that the North Korean regime administers approximately 88 sites or facilities related to the country's nuclear (39 sites)[631] and ballistic missile (49 sites) programs.[632]

North Korea has a complex web of both civilian and military research, development, and production units that are spread across state, party, and military apparatuses—discerning or

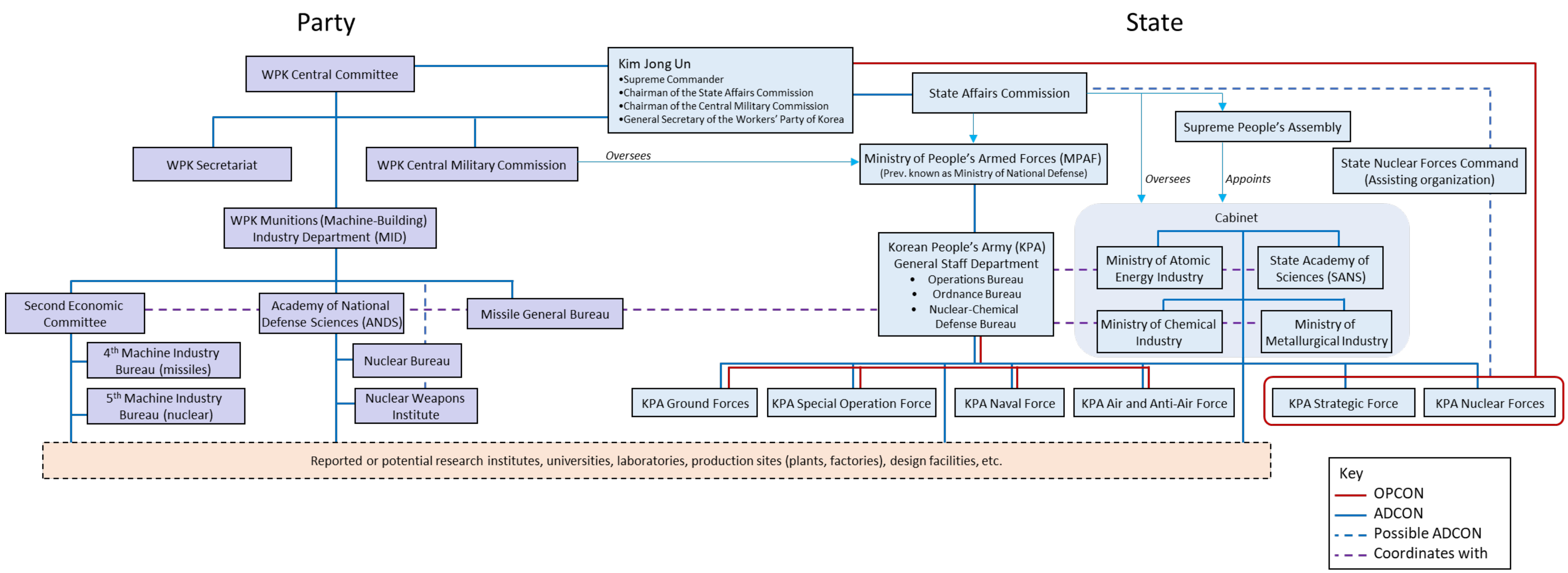
[631] The report designated Yongbyon as one site, but it consists of approximately 19 separate facilities. Timothy Bonds et al., "Appendix B: DPRK and Syrian WMD Sites," in *Strategy-Policy Mismatch: How the U.S. Army Can Help Close Gaps in Countering Weapons of Mass Destruction* (RAND, 2014), https://www.jstor.org/stable/10.7249/j.ctt14bs2zp.15, p. 101.

[632] Bonds et al., "Appendix B: DPRK and Syrian WMD Sites."

identifying clear delineation between civilian and military efforts is difficult. However, this organization is consistent with Kim Jong Un's strategy for technological development (i.e., personnel at multiple facilities may be pursuing similar technologies but approaching their projects from different angles to optimize chances for success, albeit at the cost of efficiency). The use of this kind of parallelism in R&D, despite North Korea's severe resource constraints, underscores the priority that the regime affords to its nuclear weapons program.

Reflecting these dynamics, the organization of nuclear weapons development in North Korea is opaque, with many parts of the regime appearing to have similar roles and responsibilities as they relate to the nuclear program. Like all facets of the North Korean regime, control of the program is highly centralized, with the SAC as the primary source of decision-making authority. Figure 44 provides a notional organizational chart for North Korea's nuclear weapons program.

Figure 44. Notional organizational chart for North Korea's nuclear weapons program



Source: CNA, adapted from Joseph Bermudez, *Overview of North Korea's NBC Infrastructure*, US-Korea Institute, Johns Hopkins School of Advanced International Studies, June 2017, p. 14; and South Korea Ministry of Unification, "Organizational Chart of North Korean Leadership (as of February 2023)," Feb. 2023.

Subordinate entities at the state, party, and military levels all have roles in North Korea's nuclear and missile R&D infrastructure. At the state level, the two primary entities overseeing North Korea's nuclear program are the State Academy of Sciences and the Ministry of Atomic Energy Industry.[633] The Ministry of Atomic Energy Industry, established in 1986, represents North Korea at meetings and international fora, making it the "outward face" of North Korea's nuclear program.[634] The State Academy is considered the central entity in overseeing the program because its duties include administering North Korea's research and production facilities and conducting theoretical and applied research.[635] Subordinate to the Cabinet of the SPA, the State Academy is also reported to have a critical role in providing input into the program and policy decision-making processes.[636]

Several entities across the state, party, and military have their own links to North Korea's R&D institutes. For example, the Munitions Industry Department under the KWP is responsible for nuclear weapons development and production.[637] Subordinate to it are the Nuclear Bureau, Nuclear Weapons Institute, SEC (which oversees North Korea's defense industrial complex), and ANDS.[638] ANDS oversees nuclear weapons–related research and is a primary institute for R&D for the nuclear and ballistic missile programs, although some research is also done at the State Academy of Sciences and the SEC.[639] How these different entities coordinate or differentiate their place within the overall nuclear weapons R&D program is unclear.

Many of the testing sites and production facilities identified in this study have been identified and aggregated by the Nuclear Threat Initiative Program at the James Martin Center for Nonproliferation. This report leverages a database and cross-checks the information, when possible, with other open-source analysis organizations, including Beyond Parallel and 38North, and the IAEA's official reports. Given the lengths that North Korea has gone to obscure the extent of its nuclear and ballistic missile activities, there are two primary caveats when attempting to observe any site or facility related to North Korea's nuclear R&D. First, these sites

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[633] Bermudez, *Overview of North Korea's NBC Infrastructure*, p. 21.

[634] Sanctions and North Korea's diplomatic isolation have reduced the activities of the Ministry in recent years. Bermudez, *Overview of North Korea's NBC Infrastructure*, p. 21.

[635] Bermudez, *Overview of North Korea's NBC Infrastructure,* p. 21.

[636] Other major universities and research institutes that are associated with nuclear education and research include the Energy Science faculty at Kim Il Sung University, the Nuclear Physics and Engineering faculty at Kim Chaek University of Technology, the Nuclear Physics Research Institute of the State Academy of Sciences, and the Nuclear Physics Research Institute Chemical Department at the University of Science. Bermudez, *Overview of North Korea's NBC Infrastructure,* p. 22.

[637] Bermudez, *Overview of North Korea's NBC Infrastructure,* p. 22.

[638] Bermudez, *Overview of North Korea's NBC Infrastructure.*

[639] Haggard and Cheung, "North Korea's Nuclear and Missile Programs."

have not been verified in person since the IAEA last visited North Korea for an inspection visit in 2009, which poses challenges for identifying and maintaining continuous record of North Korea's sites and facilities, even with satellite imagery. Second, the names of these facilities often change or are unmentioned in North Korean public media; therefore, analysts must often track multiple sources (North Korean media, public statements, other activities), cross-referencing locations mentioned with historical data. Both caveats complicate efforts to provide a full and accurate accounting of North Korea's nuclear weapons R&D infrastructure.

Fissile material production facilities

North Korea's processing and enrichment activities are conducted at several facilities at the Yongbyon Nuclear Scientific Research Center.[640] As discussed above, nuclear scientist Siegfried Hecker stated, "Yongbyon is the heart of North Korea's fissile materials production complex." The center is one of the four major nuclear-related organizations under North Korea's General Department of Atomic Energy.[641] The Yongbyon Center is not only a key piece of North Korea's fissile material production but also a central node of North Korea's fissile material research. Nineteen nuclear program–associated facilities are located at the Yongbyon complex.[642] Of these, the Yongbyon Nuclear Research Center has the following 10 research institutes under its jurisdiction:[643]

- Atomic Energy Research Institute (원자력연구소)
- Isotope Production Laboratory (동위원소이용연구소)
- Neutron Physics Research Institute (중성자물리연구소)
- Nuclear Electronics Research Institute (핵전자학연구소)
- Nuclear Materials Research Institute (핵재료연구소)
- Nuclear Physics Research Institute (핵물리연구소)
- Radiation Protection Research Institute (방사선방호연구소)

640 Kristensen and Korda, "North Korean Nuclear Weapons, 2022."

641 "Yongbyon Nuclear Research Center," Nuclear Threat Initiative Database of North Korean Nuclear and Missile Sites, updated Sept. 29, 2021, https://www.nti.org/education-center/facilities/yongbyon-nuclear-research-center/.

642 Bonds et al. citing NTI in Bonds et al., "Appendix B: DPRK and Syrian WMD Sites," p. 102.

643 북한개요 *2009 North Korea Introduction 2009*, Korea Institute for National Unification (South Korea), Sept. 2009, p. 322, cited in "Yongbyon Nuclear Research Center."

- Radiochemistry Research Institute (방사화학연구소)
- Reactor Design Research Institute (원자로설계연구소)
- Uranium Resource Development Institute (우라늄자원개발연구소)

The Yongbyon site is known to house the following facilities and capabilities for producing weapons-grade uranium, plutonium, and possibly tritium. Each entity discussed below represents North Korea's goal of continuing to refine, modernize, and diversify its fissile production capacity.

- **Yongbyon 5 MWe Nuclear Reactor:** The 5 MWe reactor is North Korea's primary gas-cooled reactor for plutonium and tritium reprocessing. Since initial reactor operations in 1986, this reactor has allowed North Korea to pursue nuclear capabilities indigenously. After a brief pause of operations beginning in 2018, open-source analysts and satellite imagery suggest that the reactor has been operating consistently since July 2021.[644]
- **IRT-2000 Reactor:** In 1965, North Korea acquired a small research reactor, known as the IRT-2000 reactor, from the Soviet Union. The IRT reactor required enriched uranium fuel, which the Soviet Union supplied to North Korea until the 1990s. North Korea operated the reactor sporadically until approximately 2007, when it was estimated that Soviet-supplied fuel would have been spent. However, with North Korea's HEU capabilities, some open-source reporting suggests that North Korea can now produce the HEU necessary to fuel the reactor, which would make it another option for tritium production.[645] Evidence of operations at the IRT is inconclusive, but

[644] The Yongbyon reactor's last shutdown took place in early December 2018 following the US–North Korea summit meeting in Singapore and two Inter-Korean summits. In the past, North Korea has temporarily halted overt operations at the reactor during periods of heightened diplomacy. Ankit Panda, "What the Restarting of North Korea's Yongbyon Reactor Means," Carnegie Endowment, Sept. 2, 2021, https://carnegieendowment.org/2021/09/02/what-restarting-of-north-korea-s-yongbyon-reactor-means-pub-85260, Wertz, McGrath, and LaFoy citing "North Korea Restarting Its 5 MW Reactor"; "More Evidence that North Korea Has Restarted its 5MWe Reactor"; Albright and Avagyan, "Steam Venting from Building Adjacent to 5 MWe Reactor: Likely Related to Reactor Restart"; Clapper, "Worldwide Threat Assessment of the U.S. Intelligence Community."

[645] David Albright and Serena Kelleher-Vergantini, *North Korea's IRT Reactor: Has It Restarted? Is It Safe?* Institute for Science and International Security, Mar. 9, 2016, https://isis-online.org/uploads/isis-reports/documents/IRT_Reactor_March_9_2016_FINAL.pdf.

activity at the site was observed in 2016 and 2018, leading to speculation that the IRT had resumed operations.[646]

- **RCL Complex:** The RCL includes a primary fuel reprocessing plant for plutonium reprocessing and extraction. Nearby buildings store and treat radioactive wastes resulting from reprocessing. Past reprocessing campaigns are known to have occurred in 2003, 2005, 2009, and 2016, each having processed a full load of spent fuel, a core of 50 tons from the 5 MWe reactor.[647]
- **Uranium Enrichment Plant:[648]** Originally constructed in 2009 and expanded in 2013, the Uranium Enrichment Plant at Yongbyon has potentially produced approximately 540 kilograms of weapons-grade uranium through the end of 2020, according to one nuclear expert.[649]
- **Extended centrifuge facility** (built 2009–2010): Independent analysts are unable to confirm what is located at this building, but one open-source analysis speculated that the expanded space can house up to 1,000 centrifuges, which would enable production of weapons-grade uranium to expand by as much as 25 percent.[650] Other analysts speculate that the building could be a small pilot or demonstration plant to test more advanced centrifuges, similar to the Pilot Fuel Enrichment Plant in Natanz, Iran.[651]
- **ELWR** (under construction since 2010): The ELWR is not yet operational. If construction is completed, the ELWR would substantially increase North Korea's plutonium production capability:[652] analysts estimate that the ELWR could potentially produce 20 kilograms of weapons-grade plutonium per year if operated with a 70 to

[646] Joseph Bermudez, "Yongbyon: Declassified Part II: Progress on Building IRT-2000 Reactor," Beyond Parallel, Center for Security and International Studies, July 16, 2018, https://beyondparallel.csis.org/yongbyon-declassified-part-ii/.

[647] Olli Heinonen, Frank Pabian, and Jack Liu, "North Korea's Yongbyon Nuclear Complex: Assessing Activity at the Radiochemical Laboratory," 38North, June 25, 2021, https://www.38north.org/2021/06/north-koreas-yongbyon-nuclear-complex-assessing-activity-at-the-radiochemical-laboratory/#_ftn1.

[648] Formerly referred to as the "Fuel Rod Fabrication Plant." Heinonen, "Development of the Yongbyon Uranium Enrichment Plant Between 2009 and 2021."

[649] Heinonen, "Development of the Yongbyon Uranium Enrichment Plant Between 2009 and 2021."

[650] Jeffrey Lewis, Joshua Pollack, and David Schmerler, cited in Heinonen et al., "North Korea's Uranium Enrichment Plant: What to Make of New Construction," 38North, Sept. 21, 2021, https://www.38north.org/2021/09/north-koreas-uranium-enrichment-plant-what-to-make-of-new-construction/.

[651] Heinonen et al., "North Korea's Uranium Enrichment Plant: What to Make of New Construction."

[652] Peter Makowsky, Jack Liu, and Olli Heinonen, "Yongbyon Nuclear Research Center: Ongoing Plutonium Production and New Construction," 38North, Oct. 28, 2022, https://www.38north.org/2022/10/yongbyon-nuclear-research-center-ongoing-plutonium-production-and-new-construction/.

80 percent capacity factor.[653] The ELWR could also be optimized for production of electricity rather than weapons-grade plutonium.

Light water versus heavy water reactors

Light water (H2O) is standard water that is commonly used as a moderator in most nuclear reactors. A **moderator** is any material that slows down a nuclear reaction to the desired speed so that the reaction can be sustained for the ideal time period instead of burning up too fast.

Heavy water (2H2O) is found naturally in seawater in extremely small concentrations and requires extensive enrichment. Heavy water contains two more neutrons than light water, giving it a higher chance of striking and slowing the neutrons of the fission reaction and making it a more effective moderator.[654] The fuel used in heavy water reactors uses more U-238; when a small amount of U-238 is bombarded with protons, it becomes Pu-239, the preferred isotope of **plutonium** used in nuclear weapons. Although both light water and heavy water reactors can produce weapons-grade plutonium, heavy water reactors produce weapons-grade plutonium at a much higher rate and therefore may pose some proliferation concern.[655]

Although the complex at Yongbyon is the only known North Korean centrifuge facility, it is widely believed that North Korea has additional enrichment facilities outside of Yongbyon (see Figure 14).. These sites may be for expanded production, or they could serve as R&D facilities for developing and refining North Korea's uranium enrichment processes and capabilities. In its 2021 annual report, the IAEA lists Kangson as a "suspected clandestine uranium enrichment site."[656] Other suspected facilities reported in the early 2000s include Taecheon Underground Nuclear Facility, Cheonmasan Uranium Enrichment Facility, Hagap, and Yeongjeori.

[653] David Albright, *North Korean Plutonium and Weapon-Grade Uranium Inventories*, Institute for Science and International Security, Jan. 8, 2015, revised Oct. 7, 2015, p.11; Hecker, Braun, and Lawrence, "North Korea's Stockpiles of Fissile Material," p. 748.

[654] Office of the Deputy Assistant Secretary of Defense for Nuclear Matters, "Nuclear Fuel Cycle and Proliferation," in *Nuclear Matters Handbook 2020*, https://www.acq.osd.mil/ncbdp/nm/NMHB2020rev/chapters/chapter15.html.

[655] Office of the Deputy Assistant Secretary of Defense for Nuclear Matters, "Nuclear Fuel Cycle and Proliferation."

[656] "There are ongoing indications of activity at the Kangson location." IAEA Director General, *IAEA Director General's Introductory Statement to the Board of Governors*, June 7, 2021, https://www.iaea.org/iaea-director-

Table 14. **Nuclear enrichment and processing (production) facilities, North Korea**

Facility and Location	Role in North Korea Defense Complex	Last Observed Sign of Activity[657]
Yongbyon Nuclear Scientific Research Center	Includes at least 19 active nuclear facilities for R&D and production of HEU and Pu	
Yongbyon 5 MWe Nuclear Reactor	Pu cooling	Pause in 2018, recent activity beginning July 2021[658]
50 MWe Reactor	N/A	Scrapped
IRT Reactor	U enrichment; tritium	2016
Radiochemical Laboratory	Pu reprocessing	Feb.–June 2021;[659] some maintenance activities in 2022
Uranium Enrichment Plant (renovated facility formerly known as Fuel Rod Fabrication Plant)	U enrichment	2021
Experimental Light Water Reactor (under construction since 2011)	Pu reprocessing – future source	Not operating as of thermal imagery Mar. 2021[660]
Kangson Enrichment Facility (suspected clandestine site as designated by IAEA)	U enrichment	2021[661]

generals-introductory-statement-to-the-board-of-governors-7-june-2021. As noted in a previous section, experts have questioned the role of this facility and its link to North Korea's nuclear program. Heinonen, "New Evidence Suggests Kangson Is Not a Uranium Enrichment Plant," cited in Kristensen and Korda, "North Korean Nuclear Weapons, 2022."

657 Most active satellite imagery reports come from 38North or CSIS Beyond Parallel (Joseph Bermudez).

658 Makowsky, Liu, and Heinonen, "Yongbyon Nuclear Research Center: Ongoing Plutonium Production and New Construction."

659 Jack Liu et al., "North Korea's Yongbyon Nuclear Center: Additional Activity at the Radiochemical Laboratory and Uranium Enrichment Plant," 38North, Mar. 12, 2021, https://www.38north.org/2021/03/north-koreas-yongbyon-nuclear-center-additional-activity-at-the-radiochemical-laboratory-and-uranium-enrichment-plant/; Frank Pabian et al., "North Korea's Yongbyon Nuclear Center: Reprocessing Status Remains Unclear," 38North, Apr. 7, 2021.

660 Joseph Bermudez et al., "Thermal Imagery Indicates Activity at Yongbyon Nuclear Reprocessing Facilities," Beyond Parallel, CSIS, Apr. 15, 2021, https://beyondparallel.csis.org/thermal-imagery-indicates-activity-at-yongbyon-nuclear-reprocessing-facilities/.

661 IAEA Director General, *IAEA Director General's Introductory Statement to the Board of Governors*.

Facility and Location	Role in North Korea Defense Complex	Last Observed Sign of Activity[657]
Taecheon Underground Nuclear Facility (suspected) Taecheon 200 MWe Nuclear Reactor (never finished)	Enrichment and reprocessing	Reactor scrapped
Bakcheon Underground Nuclear Facility (suspected)	U processing	To be confirmed, opened in the 1960s
Cheonmasan Uranium Enrichment Facility (suspected)	U processing	Last mentioned in 2000s, likely not active
Hagap Underground Nuclear Facility (suspected)	U processing	Last mentioned in 2000s, likely not active
Yeongjeo-ri Uranium Enrichment Facility (suspected)	U processing	Last mentioned in 2000s, likely not active; may be missile base

Source: Derived from Nuclear Threat Initiative's database on North Korea's nuclear and missile sites and Bonds et al. "Appendix B: DPRK and Syrian WMD Sites."

Nuclear weapons design facilities

As noted above, the weaponization component of North Korea's nuclear program is difficult to discern, as are the facilities associated with nuclear weapons design. In the past, there have been suspected sites associated with weapons development, but these have not been verified and North Korea has made no statements that offer clues as to where weapons are physically made and stored. Given the evidence collected by satellite imagery and defector reporting and some circumstantial evidence, it is reasonable to assume that some nuclear weapons design work occurs at Yongbyon.[662]

For example, a 2021 academic study notes that as early as the 1970s, the 101 Nuclear Physics Chemistry Institute located at Yongbyon was conducting research on nuclear weapons.[663] The same study reported a cluster of reports in the 1990s that suggested elements of a weaponization program, including evidence of test explosions at Yongbyon in the 1980s that

662 This assumption is speculative. Several of the entities located at Yongbyon have affiliations with other entities elsewhere in North Korea. For example, the Atomic Energy Research Institute is primarily located in Yongbyon, but it has three associated branches: the Pyongyang branch, established in 1987, is the Atomic Energy Research Institute; the Nanam-kuyok branch includes the Radioisotope Laboratory, built in 1980; and the Wonsan branch includes the Radiological Protection Institute. "Atomic Energy Institute," NTI Database of North Korea Nuclear and Missile Sites, https://www.nti.org/education-center/facilities/atomic-energy-research-institute/.

663 Haggard and Cheung, "North Korea's Nuclear and Missile Programs," pp. 815–816.

would have been consistent with development of an implosion device.[664] From the early 1990s to the early 2000s, US and South Korean intelligence services reported on as many as 70 high-explosive tests conducted at the Yongdeok-dong high-explosive test site in North Pyeongan province.[665] In November 1998, South Korean press reported that a high-explosives test site was confirmed to be in the vicinity of Guseong, where evidence of high-explosive tests was captured via satellite.[666] On the site were what appeared to be an assembly plant, a storage facility, and an outdoor test area.[667] Whether these sites are purely for testing purposes of whether design or weaponization is occurring there or elsewhere is not confirmed.

Nuclear weapons delivery system facilities

The organization of North Korea's ballistic missile program and weapons delivery, like that of the nuclear program, includes multiple entities with overlapping roles. The size and scale of the missile program is a matter of debate because it leverages plants and facilities across the full spectrum of North Korea's heavy industry complex.[668] In its database of nuclear- and ballistic missile–associated sites, the Nuclear Threat Initiative lists 49 possible sites, including 25 "missile bases," 22 missile production facilities, and 2 design facilities.[669] Reporting from various South Korean and US media, as well as articles by defecting North Korean missile researchers, similarly indicate that there are around 50 research institutes within the missile complex.[670] Open-source analysis has identified still more potential sites with links to the missile program.

ANDS administers the research institutions associated with the missile program, some of which have been identified through open-source analysis. These include the following design facilities:[671]

- No. 120 (electrical engineering)
- No. 122 (mechanical engineering)

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664 Haggard and Cheung, "North Korea's Nuclear and Missile Programs."

665 "Yongeok-dong High Explosive Test Site," NTI Database of North Korea Nuclear and Missile Sites, https://www.nti.org/education-center/facilities/yongdeok-dong-high-explosive-test-site/.

666 "Yongeok-dong High Explosive Test Site."

667 "Yongeok-dong High Explosive Test Site."

668 Haggard and Cheung, "North Korea's Nuclear and Missile Programs," p. 807.

669 Bonds et al., "Appendix B: DPRK and Syrian WMD Sites," p. 108, citing the Nuclear Threat Initiative database of North Korea's nuclear and missile associated sites.

670 Haggard and Cheung, "North Korea's Nuclear and Missile Programs," p. 807.

671 Haggard and Cheung, "North Korea's Nuclear and Missile Programs."

- No. 130 (precision machinery)
- No. 144 (metallurgical engineering)
- No. 166 (rocket R&D)
- No. 185 (electronic engineering)

The Fourth Machine Industry Bureau under the SEC has purview over North Korea's ballistic missile program within the defense industrial complex. Facilities associated with missile production in North Korea include the following:

- No. 125 Factory "Pyongyang Pig Factory." Press reports suggest No. 125 Factory produces Scud-B and Nodong ballistic missiles and Silkworm surface-to-ship missiles.[672]
- No. 7 Factory. According to defector reporting, No. 7 Factory produces prototypes of missiles and conducts performance tests before the missiles begin mass production at the Man'gyŏngdae Electric Machinery Factory.[673]
- Man'gyongdae Electric Machinery Factory. Site for mass production of missiles.[674]
- January 18th Machine Factory. According to the South Korean Ministry of Unification, this factory produces rocket engines.[675]
- Panghyon Nodongjagu Fabrication and Assembly Plant. This facility is associated with aircraft production, but open-source analysis suggests that it has a potential link to missile production as well. In 2017, Kim Jong Un observed a test launch of the Hwasong-14 ICBM from here.[676]

Solid-fuel engine design and production are associated with the No. 17 Explosives Factory and its associated facilities and factories located in the Hamhung-Hungnam province area. Hamhung-Hungnam province was referred to by one expert as "the heart of the country's

[672] "No. 125 Factory," Nuclear Threat Initiative Database of North Korean Nuclear and Missile Sites, https://www.nti.org/education-center/facilities/no-125-factory/.

[673] "No. 7 Factory," Nuclear Threat Initiative Database of North Korean Nuclear and Missile Sites, https://www.nti.org/education-center/facilities/no-seven-factory/.

[674] Jeffrey G. Lewis and Dave Schmerler, "Identifying DPRK Machine Plants," James Martin Center for Nonproliferation Studies, Jan. 17, 2019, https://nonproliferation.org/identifying-dprk-machine-plants/.

[675] "January 18th Machine Factory," Nuclear Threat Initiative Database of North Korean Nuclear and Missile Sites, https://www.nti.org/education-center/facilities/january-18th-machine-factory/.

[676] Lewis and Schmerler, "Identifying DPRK Machine Plants."

chemical industry."[677] The same expert overlaid the various facilities over satellite imagery to give a sense of the size and scope of facilities in this area.

- No. 17 Explosives Factory (also referred to as Hungnam Explosives Plant) and associated branch facilities. In 2018, an open-source report described the No. 17 Factory as "the most probable site for the manufacture of the latest large solid-propellant rocket engines." The report based this conclusion on the significant number of supporting facilities in the area, including the February 8 Vinylon Complex, the Pongung Chemical Plant, the Hungnam Fertilizer Complex, the Magunpo Solid-Propellant Rocket Engine Test Facility, the Chemical Material Institute of the Academy of Defense Sciences, the Pungdong-dong Explosives Factory, and the State Academy of Sciences' Hamhung Branch Academy.[678]
- Chemical Material Institute of the Academy of National Defense Sciences. Kim Jong Un visited the Chemical Material Institute in 2017. Pictures of his visit depicted conceptual illustrations of the Pukguksong-3 and the Hwasong-13 (also known as the KN-08), as well as the technical parameters for their composite materials.[679]
- Magunpo Solid Rocket Motor Test Facility. First identified as under construction in commercial satellite imagery in 2013, the Magunpo Solid Rocket Motor Test Facility is one of the newest and largest such North Korean facilities openly identified to date. In March 2016, Kim Jong Un "guided" a test of a large solid rocket motor there, disclosing the existence and purpose of the plant.[680]

In addition to plants associated with missile development and production, open-source analyses have located several plants associated with the production of missile launchers. In the 1980s and 1990s, North Korea acquired several TELs and mobile erector launchers from foreign sources. However, international sanctions introduced in the 2000s limited North Korea's access to launcher technology, which resulted in the SEC issuing a policy decision to secure additional and alternate launch platforms, including rail-mobile platforms.[681]

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[677] Joseph Bermudez, "North Korea's Solid-Propellant Rocket Engine Production Infrastructure: The No. 17 Factory in Hamhung." 38North, Jan. 30, 2018, https://www.38north.org/2018/01/no17factory180130/. Of note, several of these facilities are also associated with North Korea's chemical weapons program.

[678] Bermudez, "North Korea's Solid-Propellant Rocket Engine Production Infrastructure."

[679] Michael Ellemen, "Kim's Visit to the Chemical Material Institute: A Peek into North Korea's Missile Future," 38North, Aug. 25, 2017, https://www.38north.org/2017/08/melleman082517/.

[680] "December 2019 Update: The Magunpo Solid Rocket Motor Test Facility," Beyond Parallel, CSIS, Dec. 2019, https://www.csis.org/analysis/december-2019-update-magunpo-solid-rocket-motor-test-facility.

[681] Joseph Bermudez, "What Is the Significance of North Korea's Rail-Mobile Ballistic Missile Launcher?" CSIS, Sept. 29, 2021, https://www.csis.org/analysis/what-significance-north-koreas-rail-mobile-ballistic-missile-launcher.

Table 15. North Korean sites associated with launcher production

Sites Associated with Production of Launchers	Comment
Kusong Tank Factory	Associated with production of missile launchers; last mentioned in KCNA in 2016; evidence of role inconclusive.
Mupyong-ni Arms Plant (PUG)	Associated with production of missile launchers. On July 28, 2017, Kim Jong Un observed the second test of the Hwasong-14 ICBM from this location.
Sinhung Machine Plant (KCNA name)/Sinhung Armored Vehicle Assembly/Repair Plant	Associated with production of missile launch capabilities. Previous analysis suggests that components built at Mupyong-ni were shipped to Sinhung for final assembly.
Pyongsong Automotive Plant	Associated with development of Hwasong-15 ICBM launch vehicles.
Kum Song Tractor Factory	Associated with tracked TELs for surface-to-ship cruise missiles.

Source: Lewis and Schmerler, "Identifying DPRK Machine Plants" and NTI North Korea database.

Test sites

Nuclear test site at Punggye-ri

The Punggye-ri Nuclear Test Facility (see Figure 45) is North Korea's only known nuclear test site and is located in mountainous terrain in North Korea's northeastern region. All of North Korea's six nuclear tests have been conducted in Punggye-ri, the most recent test having occurred in September 2017.[682] As discussed previously, despite the site's presumed closure in 2018,[683] recent satellite imagery reveals occasional construction and cargo truck movement in and around it, implying that the site may still have long-term uses.[684] IAEA reports say that North Korea began restoring test tunnel and entrance support buildings in March 2022.[685]

[682] October 2006, May 2009, February 2013, January 2016, September 2016, and September 2017.

[683] North Korea had publicized the demolition of the tunnel entrances around Punggye-ri to show good faith during the period of diplomatic rapprochement with the US and South Korea. Brian Padden, "North Korea Shuts Down Nuclear Site," Voice of America, updated May 24, 2018, https://www.voanews.com/a/north-korea-shuts-down-nuclear-site-/4407828.html.

[684] Satellite imagery analysts observed renewed activity at the Punggye-ri Nuclear Test Facility as recently as May 2022. Peter Makowsky, Jack Liu, and Olli Heinonen, "Punggye-ri Nuclear Test Site: New Activity at the Command Center Area," 38North, May 5, 2022, https://www.38north.org/2022/05/punggye-ri-nuclear-test-site-new-activity-at-the-command-center-area/.

[685] IAEA Director General, *Application of Safeguards in the Democratic People's Republic of Korea*, GOV2022/40-GC(66)/16, Sept. 2022.

Figure 45. Punggye-ri nuclear test site

Source: USGS Earthquake Hazard Program,
https://earthquake.usgs.gov/earthquakes/eqarchives/poster/2013/NorthKorea.jpg.

Missile test sites

North Korea's steady pursuit toward attaining a credible nuclear weapons delivery capability is evident in the significant increase in the number of missile tests it has conducted, especially since Kim Jong Un assumed power. More than 170 tests have been conducted under Kim Jong Un (compared to 15 tests carried out under Kim Il Sung and 16 tests under Kim Jong Il).[686] In 2022 alone, at least 90 missile tests were conducted (compared to 37 tests in 2019 and 24 tests in 2016).

In addition to the increase in testing frequency, two significant developments in terms of North Korea's ballistic missile testing indicate that North Korea is moving from R&D to testing in preparation for operational deployment. First is the proliferation of testing sites for missile launches across the country. In 1984, North Korea established a missile test site at Tonghae Satellite Launching Ground, near Musudan-ri, where 14 of the 15 known ballistic missile tests

[686] Data attained from the CNS North Korea Missile Test Database, Feb. 2, 2023. https://www.nti.org/analysis/articles/cns-north-korea-missile-test-database/.

held during the Kim Il Sung period occurred.[687] During the Kim Jong Il period, North Korea paused its ballistic missile launches twice—from 1994 to 1998[688] and then again from 1998 to 2006—and most missile tests (16) were conducted from a site near Wonsan. During the Kim Jong Un period, however, North Korea has dispersed its launch sites across the country. Analysts have now observed missile tests at more than 40 distinct locations in North Korea. This observation is an indication that North Korea is moving from R&D of its established ballistic missiles to potentially testing its missile mobility and options for operational employment.

Another indication of North Korea's progress on its missile development is the personnel that attend the launches. For example, as one North Korea expert noted, a testing event in which the only personnel present are from ANDS/SANS means that the system is still in the R&D phase. However, if an event combines personnel from ANDS and the SEC, that often means that the system is moving from development to production and manufacturing. Similarly, if members of the General Staff are present, that is an indicator that the system is moving toward operational capability.[689]

How knowledgeable, educated, and skilled are the scientific and technical personnel who make up North Korea's nuclear weapons program?

North Korea has invested in its science and technology (S&T) infrastructure and prioritized the development of a pool of scientists, engineers, and other technical personnel required for its nuclear and ballistic missile programs. Although initially reliant on access to foreign universities and expertise, North Korea appears to have developed a domestic academic S&T environment, which has allowed it to continue to make progress on its nuclear weapons and ballistic missile programs despite international sanctions intended to limit its access to outside resources and expertise. Kim Jong Un has continued to promote the need for a strong domestic

[687] Shea Cotton, "Understanding North Korea's Missile Tests," Nuclear Threat Initiative, Apr. 24, 2017, https://www.nti.org/analysis/articles/understanding-north-koreas-missile-tests/.

[688] North Korea launched a Taepodong missile in 1998, which prompted international outcry and subsequent talks with the United States.

[689] Michael Madden, NK Leadership Watch, a subsidiary of 38North, cited in Smith, "Explainer: Minds Behind the Missiles: N. Korea's Secretive Weapons Developers."

S&T capability, linking technology and innovation to North Korea's pursuit of economic improvement and national security priorities.

In this section, we attempt to evaluate the and quality and quantity of North Korean scientific and technical personnel working in nuclear-relevant fields, such as physics and engineering. However, the quality and quantity of North Koreans engaged in nuclear-relevant academic study are not fully reflected in the US and international ranking systems used for the other countries in this report. Instead, we will leverage assessments done by North Korea analysts and nuclear experts to help describe the extent of North Korea's science and technical community and its capabilities.

Publicly available data related to North Korea's university systems are limited, and the several journals published through North Korea's top universities have limited distribution outside the country. Because sources such as QS World University Rankings, Scimago Journal Rank, the Times Higher Education World University Rankings, and EduRank rely heavily on citations for their metrics, only a few of North Korea's scientific and technical personnel and universities are ranked or featured. Furthermore, UN sanctions resolutions place prohibitions on North Koreans studying abroad in fields that could further North Korea's nuclear ambitions, limiting the number of academic exchanges North Korean scientists can have with their international counterparts. However, despite these limitations, North Korea has been able to develop and retain a competent scientific talent pool, which has allowed the country to pursue a nuclear weapons capability and a wide variety of delivery systems.

University rankings in nuclear-relevant fields

There are estimated to be about 200 formal S&T institutions (universities, research institutes, laboratories) in North Korea.[690] North Korean subject matter experts consistently identify three universities within North Korea related to the country's science, technology, engineering, and mathematics academia: Kim Il Sung University (KISU), Kim Chaek University of Technology (KCUT), and the University of Natural Science (UNS).[691] QS World University Rankings and Times Higher Education World University Rankings do not include universities in North Korea in their ranking systems. EduRank,[692] however, lists the three "best" universities in North Korea as (1) KISU, (2) KCUT, and (3) Pyongyang University Science and

[690] Jai S. Mah, "North Korea's Science and Technology Policy and the Development of Technology-Intensive Industries," *Perspectives on Global Development and Technology* 19 (2020): 503–524; Bermudez, *Overview of North Korea's NBC Infrastructure*.

[691] Formerly called the University of Science in Pyongsong, UNS is now located in Pyongyang and affiliated with the State Academy of Sciences.

[692] EduRank is an independent metric-based ranking database of 14,131 universities from 183 countries. North Korean university rankings are available at EduRank's site: https://edurank.org/geo/kp/.

Technology (PUST), North Korea's first privately funded university.[693] EduRank bases rankings on the universities' reputations, research performance, and alumni impact, similarly relying heavily on the number of publications and citations attributed to the universities' academic departments. EduRank's ranking system processed more than 6,000 citations received by 828 publications made by the three universities in North Korea, measured the popularity of 17 recognized alumni, and utilized the available links database to account for nonacademic prominence.[694]

In EduRank's ranking system, KISU, KCUT, and PUST all rank relatively low compared to other universities globally and to universities in other countries in Asia. Table 16 shows how these universities rank in terms of overall global ranking and within S&T fields specifically.

Table 16. Top three universities in North Korea as ranked by EduRank

University	Physics	Chemistry	Materials Science	Engineering	World Rank	Universities in Asia
Kim Il Sung University	2,601 of 4,082 (lower quartile)	3,031 of 4,317 (lower quartile)	2,483 of 3,574 (lower quartile)	3,190 of 4,624 (lower quartile)	5,740 of 14,131 (upper quartile)	2,112 of 5,830 (upper quartile)
Kim Chaek University of Technology	3,755 of 4,082 (lowest quartile)	3,994 of 4,317 (lowest quartile)	3,303 of 3,574 (lowest quartile)	4,101 of 4,624 (lowest quartile)	7,477 of 14,131 (mid quartile)	2,914 of 5,830 (mid quartile)
Pyongyang University of Science and Technology	N/A	N/A	N/A	N/A	11,320 of 14,131 (lowest quartile)	4,620 of 5,830 (lowest quartile)

Source: EduRank, accessed Apr. 3, 2023, https://edurank.org/uni/kim-il-sung-university/; https://edurank.org/uni/kim-chaek-university-of-technology/; https://edurank.org/uni/pyongyang-university-of-science-and-technology/.

Within the North Korean university system, KISU is considered the most prominent and well-respected university because it is known to be the central education center for the country's

[693] PUST was founded in 2010 with a reported funding of $35 million from "evangelical Christians and Western-trained scientists." It is reported to have a few hundred students, with the student body comprising students from elite families in North Korea. Michael Alison Chandler, "In North Korea, a Western-Backed University," *Washington Post*, Oct. 8, 2011, https://www.washingtonpost.com/local/education/private-university-in-north-korea-offers-lessons-in-science-and-world-peace/2011/07/25/gIQAQ5lPSL_story.html; Richard Stone, "Pyongyang University and NK: Just Do IT!" 38North, Nov. 1, 2010, https://www.38north.org/2010/11/pyongyang-university-and-nk-just-do-it/.

[694] EduRank, https://edurank.org/geo/kp/.

elite.[695] Kim Jong Un and several members of the Kim family are reported to be graduates of KISU. The university was originally modeled after Soviet universities and was composed of faculty mostly from the Soviet Union, China, Japan, and South Korea.[696] Before the Korean War, North Korea was able to attract approximately 40 percent of Korean scientists—these individuals became what has been described as "the backbone" of North Korea's S&T community.[697] KISU was North Korea's first successful attempt at establishing a research institution for developing scientists and technicians.

Shortly after KISU was founded in 1946, the Kim Chaek Industrial University (now known as Kim Chaek University of Technology) was established in 1948, followed by the Academy of Science of the DPRK in 1952 (now known as State Academy of Science or SAOS) and Pyongsong Institute of Science (now known as UNS) in 1963.[698]

No information is available on the rate of graduation or percentage of graduates per field, although it is widely understood that top-performing students in nuclear-relevant fields are recruited to North Korea's primary defense research institutes, such as ANDS and the Nuclear Weapons Institute.[699]

North Korean scholars studying abroad in nuclear-relevant fields

Current data on North Korean students studying abroad in nuclear-relevant fields are scarce. During the early Cold War period, North Korea sent hundreds of scientists to receive training, mostly to the Soviet Union and Japan. North Korea also recruited scientists from South Korea before the start of the Korean War.[700] When North Korea expanded its nuclear program in the 1980s, scientists continued to study abroad in the Soviet Union and former Eastern Bloc countries. Since the mid-2000s, UN Security Council resolutions have prohibited the provision

[695] EduRank lists 15 well-known alumni from KISU, including the country's leaders Kim Jong Il and Kim Jong Un as well as several other members of the Kim family and prominent elites who hold senior state and/or party positions. "15 Notable Alumni of Kim Il Sung University," EduRank, accessed Apr. 3, 2023, https://edurank.org/uni/kim-il-sung-university/alumni/.

[696] Andrei Lankov, "Kim Il Sung University," *Korea Times*, Nov. 3, 2008, http://www.koreatimes.co.kr/www/news/opinon/2009/08/166_33770.html.

[697] Mah, "North Korea's Science and Technology Policy," p. 505.

[698] Haggard and Cheung, "North Korea's Nuclear and Missile Programs"; Joseph Bermudez, "Exposing North Korea's Secret Nuclear Infrastructure I," Jane's Intelligence Review, July 1999.

[699] Bermudez, *Overview of North Korea's NBC Infrastructure*; Haggard and Cheung, "North Korea's Nuclear and Missile Programs"; Mah, "North Korea's Science and Technology Policy."

[700] Mah, "North Korea's Science and Technology Policy"; Haggard and Cheung, "North Korea's Nuclear and Missile Programs."

of “technical training, advice, services, or assistance” related to a list of banned items that includes dual-use and military-related “technology” to North Korea.[701] The 2016 UN Panel of Experts report found that some countries, such as India, Italy, Romania, China, and the Russian Federation, were still hosting North Korean students in possibly nuclear-relevant fields such as physics, material science, and satellite technology, but data on education exchanges are incomplete.[702]

Today, it is suspected that North Koreans continue to study abroad and participate in academic exchanges, but UN sanctions and the regime’s attempts to obscure the activities of its scientists make it difficult to gauge with any certainty the number of students and the fields in which they are studying. Similarly, data on student visas and published exchange program statistics are unreliable.[703] The most recent data from the UN Educational, Scientific and Cultural Organization counts 1,153 North Korean tertiary-level students abroad; the top five destination countries are France (140), Thailand (92), Denmark (67), Germany (59), and Canada (54).[704]

Publication volume and quality in nuclear-relevant fields

Analysts have attempted to track and assess the quality of North Korea’s S&T community by accessing North Korea’s S&T journals and evaluating their content against international S&T standards. North Korea has scientific publishing houses that produce technical journals in a variety of fields, including physics, chemistry, geology, agricultural science, information science, medicine, and others.[705] KISU, KCUT, and UNS each produce their own monthly scientific journals.[706] Although the articles in these journals appear to be authored solely by

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[701] Resolutions 1718 (2006) and 1874 (2009); Letter Dated 1 November 2006 from the Chairman of the Security Council Committee Established Pursuant to Resolution 1718 (2006) Concerning the Democratic People’s Republic of Korea Addressed to the President of the Security Council, S/2006/853, Nov. 7, 2006, pp. 8–9.

[702] United Nations Panel of Experts, *UN Panel of Experts Report Submitted Pursuant to Resolution 1874 (2009)*, S/2017/150, Feb. 27, 2017, https://documents-dds-ny.un.org/doc/UNDOC/GEN/N17/024/94/PDF/N1702494.pdf?OpenElement.

[703] Tae-jun Kang, “How North Korea Uses ‘Students’ and ‘Trainees’ Overseas to Bypass UN Sanctions,” The Diplomat, Jan. 4, 2020, https://thediplomat.com/2020/01/how-north-korea-uses-students-and-trainees-overseas-to-bypass-un-sanctions/.

[704] Database showed unavailable for North Korean students studying abroad in China. “Global Flow of Tertiary-Level Students,” UNESCO Institute for Statistics, accessed Apr. 13, 2023, http://uis.unesco.org/en/uis-student-flow.

[705] There are 41 identified journals that are publicly accessible, but most are only in the Korean language. “DPRK S&T Journals,” 38North, Mar. 17, 2023, https://www.38north.org/resources/2023/03/journals/dprk-st-journals/.

[706] Jonathan Pollack and Scott LaFoy, “North Korea’s International Scientific Collaborations,” KCNA.

North Koreans, they do not include authors' affiliations, and, as one analyst has noted, they have other anomalies when compared to other peer journals, such as a lack of citations.[707] Analysts who have studied datasets of North Korean publications have also noted the following:

- Until the 1990s, the citations in the journals in the dataset were drawn primarily from Soviet, Chinese, and Japanese sources as well as a few West German sources. After the North Korean scientific establishment gained access to the internet and international scientific databases, the pattern of citations has become global.[708]
- Earlier North Korean publications also have begun to appear frequently in citations.[709]

In a separate analysis of North Korean publications, researchers at Hallym University in South Korea searched the Web of Science database for scientific publications with North Korea–affiliated authors up to 2016.[710] Of the 318 publications identified, only about 15 percent were listed under solely North Korean authors; the rest were international collaborations. These collaborations were with academic institutions in China (197), Germany (51), Australia (10), the United States (5), and Italy (4). Other notable insights reported in this study include the following:[711]

- New publications in the dataset surpassed double digits in one year for the first time in 2006, with a consistent upward trend.
- The number of publications exceeded 50 in both 2015 and 2016.
- Most of the North Korean authors were affiliated with KISU, KCUT, SAOS, or UNS, but several other North Korean institutions were also represented in the dataset.
- The main publication topics in the dataset were in physics, mathematics, materials science, chemistry, engineering, and biochemistry.

The findings from these studies suggest that in the last 20 years North Korea has attempted to increase its access to international academia and expand its own S&T reputation. The uptick in North Korean scholarly publications after 2011 corresponds with Kim Jong Un's public statements emphasizing the need to enhance North Korea's indigenous S&T capability and

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[707] Pollack and LaFoy, "North Korea's International Scientific Collaborations"; Stephen Mercado, "North Korea's Science and Technology Journals: Getting to Know the Scholars (Part 1)," 38North, June 9, 2022, https://www.38north.org/2022/06/north-koreas-science-and-technology-journals-getting-to-know-the-scholars-part-1/.

[708] Pollack and LaFoy, "North Korea's International Scientific Collaborations."

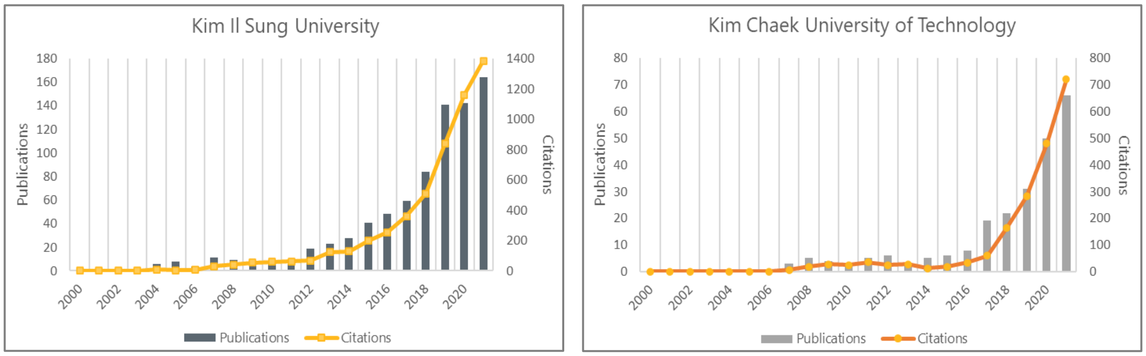
[709] Pollack and LaFoy, "North Korea's International Scientific Collaborations."

[710] Geum Hee Jeong and Sun Huh, "Bibliometric Analysis of Publications from North Korea Indexed in the Web of Science Core Collection from 1988 to 2016," *Science Editing* 4, no. 1 (2017), pp. 24–29.

[711] Jeong and Huh, "Bibliometric Analysis of Publications from North Korea."

encouraging scientists to attend international conferences and study abroad.[712] These findings similarly track with the data reported in EduRank, which also show a significant upward trend in North Korean publications and citations at KISU and KCUT (see Figure 46).

Figure 46. Increasing trend of North Korean university publications and citations

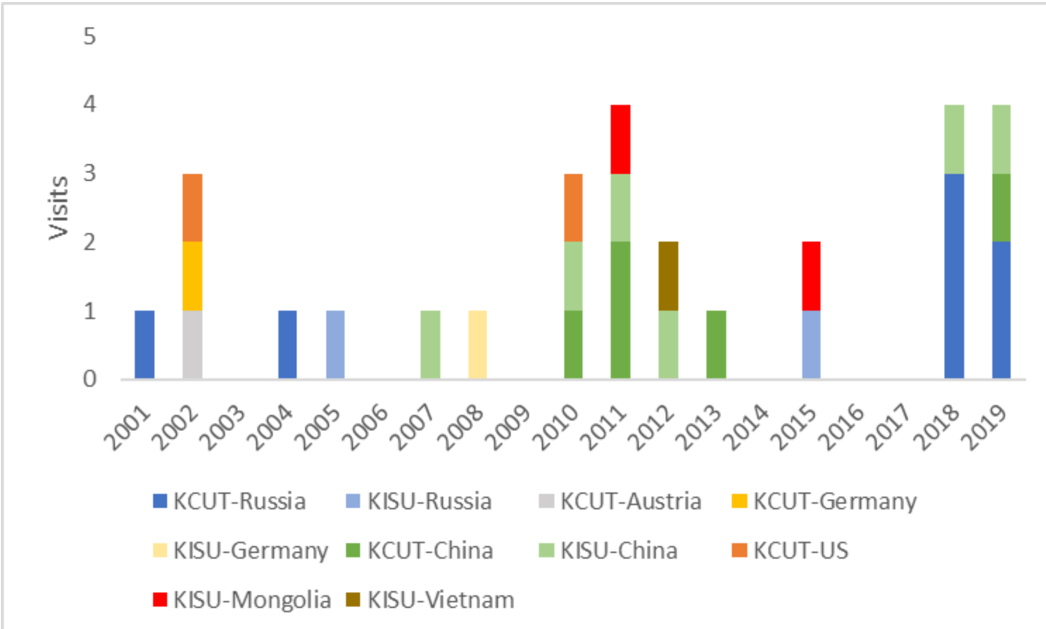


Source: EduRank, accessed Apr. 13, 2023, https://edurank.org/uni/kim-chaek-university-of-technology/, https://edurank.org/uni/kim-il-sung-university/.

During the Kim Jong Un period, North Korea analysts have also reported an increase in North Korean universities seeking to build international institutional relationships, particularly KISU and KCUT. North Korean state media have regularly reported on forms of international scientific collaboration, including university delegation visits, university cooperation agreements, and international conferences. Figure 47 shows the frequencies of North Korean university delegation visits to other countries from 2001 to 2019.

712 Hak-moon Byun, "The Current State of Science and Technology Policy of Kim Jong-Un Regime," (Presented at the Fourth Research Forum for Unification for Science and Technology, Jan. 18, 2017) (in Korean).

Figure 47. University delegation visits



Source: CNA, data from Pollack and LaFoy, "North Korea's International Scientific Collaborations"; South Korea Ministry of Unification, *Biographical Data of North Korean Leadership, By Individual*, Oct. 2022.
Note: This graph is not comprehensive and represents only what has been reported in public sources such as North Korean state media reports or South Korean Ministry of Unification databases.

As seen in Figure 47, available data suggest that North Korea doubled its efforts to build institutional relationships after 2009, which is also when North Korea ceased its cooperation with the IAEA and prohibited future facility inspections from external parties. Although the intent for knowledge exchange and university collaboration was likely enhancing R&D for North Korea's domestic economy and infrastructure as well as its defense program pursuits, this move was reflective of North Korea's pivot toward accelerating its R&D efforts overall. It is also noteworthy that the recent university delegation visits in 2018 and 2019 are only to Russia and China, who are often suspected of providing various forms of relief or assistance to North Korea.

Insights from expert visits to North Korea's nuclear weapons R&D-related facilities

Very few US and IAEA experts have had the opportunity to see North Korea's nuclear weapons R&D facilities in person. Their observations are informative and provide some qualitative insight into North Korea's scientific and technical bandwidth and potential capabilities. How much North Korea's R&D facilities continue to benefit from foreign support is unclear; North Korea's early nuclear and missile programs benefited from technology and knowledge transfer from the Soviet Union and Pakistan and later the PRC. How well North Korea's domestic S&T capability has been able to adjust to less access to foreign expertise is similarly opaque. However, common across the insights described below is the acknowledgment that North Korea's S&T capability in the nuclear domain has made progress over time and that North Korea's S&T personnel have outperformed outside observer expectations.

As has been noted several times above, former director of Los Alamos National Laboratory Siegfried Hecker has visited North Korea on more than 30 occasions, usually at North Korea's invitation, and was allowed to visit Yongbyon 2 or 3 times. In his account of his first visit in 2004, Hecker recalls that he was given a glass jar by Ri Hong Sop, then director of North Korea's Yongbyon Nuclear Complex, that he felt contained plutonium, but he had no instrumentation at the time to fully verify what it was.[713] This was North Korea's first attempt to convey to an established nuclear expert that it had a "deterrent."[714] At the time, Hecker noted that he was not convinced that North Korea could produce plutonium because North Korea did not have a working light water reactor, which is necessary to achieve nuclear weapons development. In 2009, Pyongyang announced that it would pursue uranium enrichment domestically. Hecker anticipated that the enrichment program would be at only an early R&D stage when he visited in January 2010. In November 2010, Hecker and his colleagues were taken to a uranium enrichment facility and he "was stunned by the sight of 2,000 centrifuges in two cascade halls and an ultramodern control room."[715] Hecker further observed:

> How North Korea managed to obtain all these materials is a troubling question for the global nonproliferation regime. Indeed, there is no evidence that North Korea can produce high-strength aluminum or steel alloys on its own, or that ring magnets, bearings, and vacuum valves were manufactured indigenously.[716]

[713] Dr. Hecker also commented in a seminar that this was an extremely small amount of plutonium. Siegfried Hecker, "A Full Spectrum Look at North Korea's Nuclear Program: From Above, on the Ground, and in Person," (Remarks at James Martin Center for Nonproliferation Studies at the Middlebury Institute of International Studies at Monterey, Nov. 20, 2022), https://www.youtube.com/watch?v=3Bz896ZZhZg; Siegfried S. Hecker with Elliott A. Serbin, *Hinge Points: An Inside Look at North Korea's Nuclear Program* (Stanford University Press, 2023).

[714] Siegfried S. Hecker, "Lessons Learned from the North Korean Nuclear Crises," *Daedalus* 139, no. 1 (2010): 44–56.

[715] In November 2010, Hecker traveled to North Korea with John W. Lewis and Robert Carlin. Siegfried S. Hecker, "What I Found in North Korea," *Foreign Affairs*, Dec. 9, 2010, https://www.foreignaffairs.com/articles/northeast-asia/2010-12-09/what-i-found-north-korea.

[716] Hecker, "What I Found in North Korea."

Robert Carlin, former chief State Department negotiator to US-DPRK talks who has also been to North Korea more than 30 times, reflected similarly on the 2010 visit when he was taken to the uranium enrichment facility with Hecker:

> The number of centrifuges stunned us all. No one knows why and how. But North Korea was able to pull it off in secret. The intelligence community probably did a study thereafter on how they missed it.[717]

After the November 2010 visit, Hecker and Carlin privately briefed then secretary of state Hillary Clinton that the display of these centrifuge facilities reflected the North Koreans' ability to produce nuclear bombs even if their ELWR never worked and to reach such scientific thresholds without much foreign aid or instruction.[718]

Physicist and former arms control inspector David Albright, who has been to North Korea twice, also presents a changed perspective as someone who was an early skeptic of North Korea's ability to pursue a nuclear weapons program. His monograph in 2013 reflected his strong doubt in the North Koreans' ability to build a functioning centrifuge facility given the wide range of materials and equipment needed to make certain components and their domestic limitations in sustaining it.[719] In 2016, Albright's testimony to Congress on North Korea's demonstrated progress and commitment included that he had too quickly dismissed the potential use of a separate uranium enrichment facility in estimating North Korea's overall weapons inventory.[720]

The published real-time observations and reflections of nuclear experts such as Hecker and Albright reveal the experts' early common perspective of reasonably doubting North Korea's S&T capabilities to pursue a formal nuclear weapons program. As North Korea continued to display and demonstrate further advancement, however, these experts have attested to the North Koreans' scientific achievements and ability to accomplish more than what was generally thought possible.

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717 Robert Carlin, "A Full Spectrum Look at North Korea's Nuclear Program: From Above, on the Ground, and in Person," (Remarks at James Martin Center for Nonproliferation Studies at the Middlebury Institute of International Studies at Monterey, Nov. 20, 2022), https://www.youtube.com/watch?v=3Bz896ZZhZg.

718 Hecker, *Hinge Points*.

719 David Albright and Olli Heinonen, "In Response to Recent Questionable Claims About North Korea's Indigenous Production of Centrifuges," *India & Global Affairs,* Oct. 18, 2013.

720 David Albright, President of the Institute for Science and International Security, Testimony Before the House Foreign Affairs Subcommittee on Asia and the Pacific, *North Korea's Perpetual Provocations: Another Dangerous, Escalatory Nuclear Test*, Sept. 14, 2016.

What nuclear weapons and delivery systems does North Korea possess, where are they deployed, and how capable are they?

This section examines North Korea's nuclear weapons and delivery systems, their deployment locations, and their capabilities.

Land-based strategic forces

North Korea is developing a diverse inventory of ground-based strategic ballistic missiles and multiple delivery systems. These include ICBMs as well as intermediate-range ballistic missiles (IRBMs) and medium-range ballistic missiles (MRBMs). In the last decade, North Korea has prioritized developing ground- and sea-based delivery systems in what appears to be an attempt to make its missile forces more survivable.

Although North Korea has yet to demonstrate the technical ability to mate a nuclear warhead to an ICBM or the ability for a nuclear-equipped ballistic missile to withstand reentry into the earth's atmosphere, outside technical experts assess that most of its ballistic missiles are able to or are being configured to carry both conventional and nuclear warheads. North Korea has also worked to develop more solid-fuel ballistic missiles and is converting older liquid-fuel missiles to solid-fuel missiles. Solid-fuel ballistic missiles are easier to store, transport, and load onto launchers, making them more readily available in a crisis or contingency. The utilization of solid-fuel ballistic missiles is a further contribution to North Korea's strategy of dispersing and obscuring its missile forces to complicate the opposing force's detection and targeting efforts. Table 17 provides an overview of North Korea's ground-based strategic forces.

Table 17. Ballistic missile systems for strategic nuclear use

Name/Type	US Desig.	Launcher	Year Tested	Characteristics
Short-range ballistic missiles (SRBMs) <1,000 km range				
Hwasong-5 SRBM (liquid propellant)	SS-1C Scud-B	Less than 100	1986 (deployed)	Range: 300-320 km
Hwasong-6 SRBM (liquid propellant)	SS-1D Scud-C	Less than 100	1992 (deployed)	Range: 500 km
Hwasong-11 variant (solid propellant)	KN-23	Undetermined	2019 (road) Sept. 2021 (rail)	Wheel, tracked, and rail-based Range: 690 km
Hwasong-11B (solid propellant)	KN-24	Undetermined	2019	Payload: 500 kg Range: 400 km
Hwasong-11 variant (solid propellant)	KN-25	Undetermined	2019-2020	Range: 380 km

Name/Type	US Desig.	Launcher	Year Tested	Characteristics
Medium-range ballistic missiles (MRBMs) 1,000-3,000 km range				
Hwasong-7 MRBM (liquid propellant)	Nodong-1	Fewer than 50	1990-2016	Operational Range: 1,300 km
Hwasong-9 MRBM (liquid propellant)	Scud-ER, KN-04	Undetermined	1994-2016	Probably operational Payload: 500 kg Range: 1,000 km
Pukguksong-2 MRBM (solid propellant)	KN-15	Undetermined	2019 (deployed)	Probably operational Range: 1,200-1,300 km
Intermediate-range ballistic missiles (IRBMs) 3,000-5,000 km range				
Hwasong-10 (liquid propellant)	Musudan	10-50	2016	Range: 3,000+ km
Hwasong-12 IRBM (liquid propellant)	KN-17	Undetermined	2017	Range: 3,700+ km
Intercontinental ballistic missiles (ICBMs) 5,000+ km range				
Hwasong-13 ICBM (liquid propellant)	KN-08	At least 6	*Never tested, displayed in 2012 parade*	Range: 5,000+ km
Hwasong-14 ICBM (liquid propellant)	KN-20	Undetermined	2017	Range: 7,000-8,000 km
Hwasong-15 ICBM (liquid propellant)	KN-22	Undetermined	2017	Range: 13,000 km
Hwasong-17 ICBM (liquid propellant)	KN-28	At least 9	2022	MIRV potential Range: 15,000 km

Sources: Defense Intelligence Agency, "North Korea's Military Capabilities," 2021; "Developments in North Korea's Nuclear and Ballistic-Missile Programmes," IISS, 2021; Kristensen and Korda, "North Korean Nuclear Weapons, 2022."

Deployment locations

The KPA's Strategic Force is responsible for operating ballistic missiles, and the KPA's Nuclear Force is likely responsible for storing, transporting, and integrating the nuclear warheads. Very little information is available on the number, deployment, and organization of the KPA's missile operating bases. An ongoing project at the Center for Strategic and International Studies has identified 13 of the 20 undeclared missile operating bases based on satellite imagery, defector interviews, and media reporting.[721] These include the following:

[721] Joseph S. Bermudez Jr., Victor Cha, and Lisa Collins, "Undeclared North Korea: Missile Operating Bases Revealed," CSIS, Nov. 12, 2018, https://beyondparallel.csis.org/north-koreas-undeclared-missile-operating-bases/.

- Sakkannmol (삭간몰) Missile Operating Base – KPA strategic force unit with SRBMs and possibly MRBMs.[722]
- Sino-ri (신오리) Missile Operating Base – KPA strategic force regiment with Nodong MRBMs.[723]
- Sangnam-ni (상남리) Missile Operating Base – KPA strategic force unit with Hwasong-10 IRBMs.
- Yusang-ni (유상리) Missile Operating Base – previously equipped with Hwasong-13, Hwasong 14, or Hwasong-15 ICBMs.[724]
- Hoejung-ri (회중리) Missile Operating Base – KPA strategic force regiment equipped with ICBMs.[725]
- Kal-gol (갈골) Missile Operating Base – equipped with Hwasong-6 SRBMs.[726]
- Kumchon-ni (금천리) Missile Operating Base – KPA strategic force ballistic missile unit previously equipped with Hwasong-6 SRBMs; may be equipped with MRBMs.[727]

These missile operating bases are organized in three "belts"[728]—the Tactical, Operational, and Strategic or Strategic Rear—based on their physical distance from the DMZ, as depicted in Figure 48.

[722] Joseph Bermudez, Victor Cha, and Lisa Collins, "Undeclared North Korea: The Sakkanmol Missile Operating Base," CSIS, Nov. 12, 2018, https://beyondparallel.csis.org/undeclared-north-korea-sakkanmol-missile-operating-base/.

[723] Joseph Bermudez, Victor Cha, and Lisa Collins, "Undeclared North Korea: The Sino Ri Missile Operating Base," CSIS, Nov. 12, 2018, https://beyondparallel.csis.org/undeclared-north-korea-the-sino-ri-missile-operating-base-and-strategic-force-facilities/.

[724] Joseph S. Bermudez Jr., Victor Cha, and Jennifer Jun, "Undeclared North Korea: The Yusang Ni Missile Operating Base," CSIS, Feb. 18, 2021, https://beyondparallel.csis.org/undeclared-north-korea-the-yusang-ni-missile-operating-base-update-since-2019/.

[725] Joseph S. Bermudez Jr., Victor Cha, and Jennifer Jun, "Undeclared North Korea: Hoejung-ni Missile Operating Base," CSIS, Feb. 7, 2022, https://beyondparallel.csis.org/undeclared-north-korea-hoejung-ni-missile-operating-base/.

[726] Joseph S. Bermudez Jr., Victor Cha, and Dana Kim, "Undeclared North Korea: Kal-gol Missile Operating Base," CSIS, updated Jan. 12, 2021, https://beyondparallel.csis.org/undeclared-north-korea-the-kal-gol-missile-operating-base/.

[727] Joseph S. Bermudez Jr. and Victor Cha, "Undeclared North Korea: The Kumchon-ni Missile Operating Base," CSIS, Sept. 6, 2019, https://beyondparallel.csis.org/undeclared-north-korea-the-kumchon-ni-missile-operating-base/.

[728] Some sources describe the North Korean missile deployment organization as having two belts instead of three.

The Tactical Belt, about 50 to 90 kilometers north of the DMZ, is reportedly equipped with the Scud family of SRBMs and may also field recently enhanced KN-23/24/25 SRBMs.[729] The Operational Belt is about 90 to 150 kilometers north of the DMZ and has been equipped with MRBMs or systems that cover all of South Korea and Japan.[730] The bases in the Strategic Belt likely house Hwasong-11/-12/-14/-15/-17 IRBMs and ICBMs. The dispersed and concealed nature of the ballistic missile units reflects North Korea's constantly ready posture to defend itself from outside aggression.[731]

Figure 48. North Korea's ballistic missile "belts"

Source: CNA using Mapbox OpenStreet Map base, adapted from Joseph S. Bermudez Jr., "General Arrangement of North Korea's Ballistic Missile 'Belts,' 1999-2018."

Nonstrategic nuclear weapons

As discussed earlier, North Korea is also pursuing the development of "tactical nuclear weapons" as part of its military modernization.[732] These may include land-attack cruise missiles (LACMs), which are often described in North Korean media as part of North Korea's nuclear combat force and counterattack capability, although whether they would primarily carry conventional or nuclear warheads is unclear.[733] Table 18 provides an overview of North Korea's nonstrategic nuclear weapon capabilities. North Korea is also reportedly exploring the utilization of unmanned aerial vehicles and satellites to project new strategic nuclear capabilities.[734]

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[729] Bermudez, Cha, and Collins, "Undeclared North Korea: Missile Operating Bases Revealed."

[730] Bermudez, Cha, and Collins, "Undeclared North Korea: Missile Operating Bases Revealed."

[731] Bermudez, Cha, and Collins, "Undeclared North Korea: Missile Operating Bases Revealed."

[732] Kim Jong Un, "Policy Speech at Seventh Session of the 14th SPA of DPRK."

[733] "Strategic Cruise Missile Launching Drill Conducted," KCNA, Feb. 24, 2023, http://kcna.kp/en/article/q/59ff167348aa7bab60621a1741c8f65d6355d4ad4e609752aeac8f1b69c2c08a.kcms.

[734] In March and April 2023, North Korean state media reported Kim Jong Un overseeing the test of an underwater drone that could trigger a "superscale radioactive tsunami." "Underwater Strategic Weapon System Test Held,"

Although these claims are likely hyperbolic, they do signal North Korea's intent to diversify its nuclear delivery methods.

Table 18. Potential nonstrategic nuclear weapons

Name/Type	Launcher Type	Year Tested	Range
Hwasal 1 LACM (solid propellent)	Road-mobile TEL	Sept. 2021	1,500 km
Hwasal 2 LACM (solid propellent)	Road-mobile TEL	2022-2023	2,000 km

Sources: H. Van Diepen, "North Korea Launches Four 'Hwasal-2' LACMs to Show Strong Deterrence and Rapid Response," 38North, Mar. 1, 2023. https://www.38north.org/2023/03/north-korea-launches-four-hwasal-2-lacms-to-show-strong-deterrence-and-rapid-response/.

The deployment locations of tactical nuclear weapons are unknown. Given the short range of such systems, tactical nuclear weapons would likely be stored at missile facilities in the southern region of North Korea.

Figure 49. Kim Jong Un inspecting warheads for "new tactical nuclear weapons"

Source: "Respected Comrade Kim Jong Un Guides Work for Mounting Nuclear Warheads on Ballistic Missiles," *Rodong Sinmun,* Mar. 28, 2023.

Sea-based strategic forces

North Korea has nascent sea-based nuclear capabilities, including tested SLBMs, at least one operational SSB, and several underwater launch platforms. Satellite imagery analysts first

KCNA, Mar. 28, 2023, https://kcnawatch.org/newstream/1680069932-922073781/underwater-strategic-weapon-system-test-held/; "Underwater Strategic Weapon System Tested in DPRK," KCNA, Apr. 8, 2023, https://kcnawatch.org/newstream/1681086859-562336145/underwater-strategic-weapon-system-tested-in-dprk/.

noticed a new type of SSB being built in 2014 at Sinpo South Naval Shipyard, now known as the Gorae/Sinpo class submarine (Sinpo-B). Not much is known about this submarine except that it has been used for recent underwater missile launching tests and it might be able to travel and reach regional targets such as Japan or Guam.[735] A second Sinpo class SSB (Sinpo-C) was being constructed in 2016 but is not yet believed to be operational.[736] In May 2015, North Korean state media announced that Supreme Commander Kim Jong Un had observed an "underwater test-fire of Korean-style powerful strategic submarine ballistic missile."[737] These first tests of an SLBM were later found to have been conducted from submerged barges rather than a submerged submarine. In 2016, North Korea demonstrated an ability to launch an SLBM (Pukguksong-1) from a submerged SSB.

North Korea continues to develop its SLBM capability. New SLBMs Pukguksong-4 and Pukguksong-5 were displayed in the October 2020 and January 2021 military parades, respectively, but have yet to be tested. In September 2022, North Korea tested an SRBM from an underwater platform in a reservoir area.[738] One North Korea military and missile expert assessed at the time that this test was an effort to validate preliminary concepts for creating new underwater ballistic missile silos.[739] According to official North Korean sources, in March 2023, North Korea successfully conducted two "strategic cruise missile" launch tests from the SSB, the first display of submarine-launched cruise missiles (SLCMs).[740] North Korea currently has a large inventory of Romeo and Sang-O class submarines that could be retrofitted with these SLCMs. The recent tests of configuring models of land-based cruise missiles in sea settings or utilizing SLBM models for land-based launches demonstrate North Korea's pursuit of maximizing its conventional platforms to diversify its naval second-strike capability.

The Sinpo-B and Sinpo-C submarines are often seen based in the Sinpo South Shipyard, near Mayang Island (Mayang-do) Naval Base (three kilometers from North Korea's mainland coast),

[735] H. I. Sutton, "Analysis-Sinpo Class Ballistic Missile Sub," Covert Shores, Aug. 27, 2016, http://www.hisutton.com/Analysis%20-%20Sinpo%20Class%20Ballistic%20Missile%20Sub.html.

[736] Liu and Heinonen, "Sinpo South Shipyard: Possible Preparations for New Submarine Launch."

[737] "Kim Jong Un Watches Strategic Submarine Underwater Ballistic Missile Test-Fire," KCNA, May 9, 2015, https://kcnawatch.org/newstream/1451904234-248134142/kim-jong-un-watches-strategic-submarine-underwater-ballistic-missile-test-fire/.

[738] "Respected Comrade Kim Jong Un Guides Military Drills of KPA Units for Operation of Tactical Nukes," KCNA, Oct. 10, 2022, https://kcnawatch.org/newstream/1665472027-165633397/respected-comrade-kim-jong-un-guides-military-drills-of-kpa-units-for-operation-of-tactical-nukes/.

[739] Joseph S. Bermudez Jr. and Jennifer Jun, "Missile Test from Taechon Reservoir: SRBM, not SLBM," Beyond Parallel, CSIS, Oct. 12, 2022, https://beyondparallel.csis.org/missile-test-from-taechon-reservoir-srbm-not-slbm/.

[740] "Strategic Cruise Missile Launching Drill Conducted," KCNA, Feb. 24, 2023, https://kcnawatch.org/newstream/1677190215-80977370/strategic-cruise-missile-launching-drill-conducted/.

the largest submarine base of the Korean People's Navy (KPN).[741] The KPN has fleet commands on both the west and east coasts and roughly 9 to 10 navy bases along both coasts. Table 19 provides an overview of North Korea's sea-based capabilities.

Table 19. Potential sea-based nuclear systems

Name/Type	US Desig.	Launcher Type	Years Tested	Characteristics (Yield, Range)
Pukguksong-1 SLBM (solid propellant)	KN-11	Sinpo-B SSB[a] with 1-2 launch tubes	2014–2016 (success in Aug 2016)	Payload: 1000-1500 kg Range: 1,200 km
Pukguksong-3 SLBM (solid propellant)	KN-26	Submerged launch platform; SSB (not yet tested)	2017–2019 (success in Oct 2019)	Payload: Unknown Range: 1,900 km
SLBM based on SRBM (solid propellant)	KN-23	Sinpo-B SSB with 1-2 launch tubes	Oct. 2021 Sept. 2022	Payload: Unknown Range: 450 km
Pukguksong-4 (solid propellant)	—	*SSB anticipated*	*Yet to be tested; displayed in Oct 2020 military parade*	
Pukguksong-5 (solid propellant)	—	*SSB anticipated*	*Yet to be tested; displayed in Jan 2021 military parade* Potential range: 3,000+ km	
Hwasal-1/2 SLCM (solid propellent)	—	Sinpo-B SSB	Feb. 2023	Range: 1,500 km

Sources: Defense Intelligence Agency, *North Korea Military Power,* 2021; "Asia," in *IISS Military Balance* (Taylor and Francis, 2023); Kristensen and Korda, "North Korean Nuclear Weapons, 2022"; Ankit Panda, "How North Korea's Submarine-Launched Cruise Missiles Ratchet Up Risk of Conflict," NK News, Mar. 13, 2023, https://www.nknews.org/pro/how-north-koreas-submarine-launched-cruise-missiles-ratchet-up-risk-of-conflict/.

[a] North Korea likely has only one operational Sinpo-B SSB as of 2023.

Air-launched strategic forces

North Korea does not have an air-launched nuclear missile or bomb capability because most of its air force consists of aging aircraft and obsolete air-to-surface weapons platforms. The KPA Air Force currently operates one type of light bomber, the Ilyushin Il-28/H-5 *Beagle*, which

[741] Joseph S. Bermudez Jr. and Victor Cha, "Sharp Focus: A Unique View of the Mayang-do Submarine Base," CSIS, July 7, 2021, https://beyondparallel.csis.org/sharp-focus-a-unique-view-of-the-mayang-do-submarine-base/.

could be adapted to carry future medium- to long-range missiles.[742] In October 2022, state media reported live-fire exercises under Kim Jong Un's onsite guidance involving the KPA Air Force attacking a simulated enemy base using "air-to-surface medium-range guided bombs and cruise missiles"[743]—these weapons have not been previously associated with or seen successfully demonstrated with any of the current air force aircraft. Although advancing an air-launched missile capability was not one of the specified goals put forward by Kim Jong Un, the possibility of a strategic bombing capability, or the conversion of North Korea's current air capability, should not be overlooked.

North Korea's nuclear capabilities

North Korea continues to pursue a nuclear weapons program to establish a deterrent in Northeast Asia. Although North Korea has yet to demonstrate the successful integration of a nuclear warhead with any of its missile systems, intelligence agencies, missile experts, and scientists assess that it has succeeded in developing enough critical parts of a nuclear weapon to be considered a state with WMDs that can threaten the US, its allies, and partners.

North Korea appears to be making progress toward organizing its nuclear forces and missile capabilities to carry out a range of short- and long-range missions. As observed by one South Korean defense analyst:

> The North Korean Strategic Force will focus on the conventional power long-range strike mission of the South Korean rear area and the Nuclear Force will focus on nuclear strike missions centering on the operation of ballistic missiles and cruise missiles loaded with nuclear warheads.[744]

This differentiation of the two forces reflects North Korea's preparation for a two-front battlefield. North Korea continues to advance ICBM development to demonstrate US mainland strike capability but is also building up more close-range tactical nuclear weapons capability to protect against any attack in the near geographic proximity.

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[742] Joseph Dempsey, "Does North Korea Harbour Air-Launched Cruise Missile Ambitions?" *International Institute for Strategic Studies (IISS) Military Balance Blog*, Nov. 4, 2022, https://www.iiss.org/online-analysis//military-balance/2022/11/does-north-korea-harbour-air-launched-cruise-missile-ambitions.

[743] "Respected Comrade Kim Jong Un Guides Striking Drills of KPA Units," KCNA, Oct. 10, 2022, https://kcnawatch.org/newstream/1665469970-459633514/respected-comrade-kim-jong-un-guides-striking-drills-of-kpa-units/; "12 N.K. Warplanes Fly in Formation, Apparently Stage Firing Drills: S. Korean Military," Yonhap News, Oct. 6, 2022, https://en.yna.co.kr/view/AEN20221006011352325?section=national/defense.

[744] Shin Seung-Ki, 북한의 신형 고체연료엔진 시험과 초대형 방사포 증정식 평가 및 , Korean Institute of Defense Analysis, Northeast Asia Strategic Analysis , Jan. 27, 2023,
함의 https://www.kida.re.kr/frt/board/frtNormalBoardDetail.do?sidx=2184&idx=820&depth=2&lang=kr.

Conclusion

North Korea remains committed to developing its nuclear weapons and delivery system capability to deter aggression and ensure the security of the Kim family regime. Under Kim Jong Un, North Korea has consistently and steadily made progress toward this goal despite unprecedented international pressure. Although North Korea's full program remains technically incomplete, Pyongyang has demonstrated many capabilities that can be used to target vital US interests in Northeast Asia and the Pacific. Although many questions about the program remain, North Korea has introduced a nuclear doctrine of preemptive use to deter aggression based on its perception of imminent threat. Significant work remains to be done to better understand how North Korea will act.

North Korea also continues to diversify its missile delivery systems as well as its arsenal of short- and long-range ballistic missiles of both solid and liquid propellants. Most of North Korea's ballistic missiles are assessed as able to carry conventional or nuclear payloads. Although it does not yet have a nuclear triad, North Korea is clearly moving toward a dispersed nuclear posture, with an emphasis on developing an array of platforms and launchers that will be difficult to track and detect. Available evidence suggests that North Korea's nuclear scientists and engineers are a competent workforce able to develop and advance North Korea's nuclear missile capabilities to reach its goals despite sanctions and relative isolation.

Iran's Nuclear Program

Unlike the other countries assessed in this report, Iran does not currently possess nuclear weapons, nor does it appear to have an active nuclear weapons program. However, Iran has conducted activities relevant to developing nuclear weapons. These include uranium enrichment and research and (previously) experiments with warhead design, metallurgy, and missile mating. Iran also has the largest ballistic missile inventory in the Middle East, including more than 1,000 close-, short-, medium-, and intermediate-range missiles and a smaller inventory of land-attack cruise missiles.[745] Although these systems are conventionally armed, they could potentially be adapted to deliver nuclear payloads. In addition, Iran has an active space launch vehicle (SLV) program, which could serve as the basis for intercontinental ballistic missile (ICBM) development should Tehran desire to acquire such a system.[746]

Iran's interest in nuclear technology dates to the 1950s, when the Shah's government received US technical assistance under the Atoms for Peace Program. In 1970, Iran ratified the Non-Proliferation Treaty (NPT), thereby limiting its program to peaceful purposes and subjecting its nuclear sites to inspection by the International Atomic Energy Agency (IAEA). This agreement allowed Iran to receive further assistance for its civilian nuclear power program from Western countries. Following the Iranian Revolution, however, Western countries curtailed this support. The new revolutionary government continued to pursue nuclear technology development, eventually completing Iran's first light water nuclear power plant in Bushehr (with Russian assistance) and mastering the nuclear fuel cycle after clandestinely acquiring gas centrifuges through Pakistan's A.Q. Khan network.[747]

In August 2002, the National Council of Resistance of Iran (NCRI), an Iranian opposition group, revealed that Iran's Ministry of Defense and Armed Forces Logistics (MODAFL) maintained an undeclared nuclear weapons program. This program, which was initially managed by the MODAFL's Physics Research Center (PHRC) and later consolidated within a program dubbed the "AMAD Project," became the subject of intense international scrutiny. In June 2003, the IAEA concluded that Iran possessed undeclared nuclear facilities and was pursuing activities outside the NPT safeguards system.[748] These activities included converting uranium ore into

[745] "Arms Control and Proliferation Profile: Iran."

[746] "Iran Missile Overview."

[747] Robert S. Litwak, *Nuclear Crises with North Korea and Iran: From Transformational to Transactional Diplomacy*, (Woodrow Wilson Center, 2019), p. 83.

[748]*Implementation of the NPT Safeguards Agreement in the Islamic Republic of Iran*, Report to the IAEA Board of Governors/2003/75, Nov. 10, 2003.

the gaseous feedstock for centrifuges to enrich uranium at a covert site (Natanz), high-explosive experiments potentially linked to developing triggers for nuclear weapons, and research on missile reentry vehicles capable of carrying nuclear warheads.[749]

Under international pressure, Iran halted its nuclear weapons program in 2003 and signed the more rigorous Additional Protocol to its IAEA Safeguards Agreement. Tehran also entered into a series of protracted negotiations over its nuclear program with the international community. However, Iran refused to curtail its enrichment efforts, maintaining that they were for peaceful purposes only. As a result, the United Nations (UN) Security Council imposed a series of sanctions on Iran, augmenting existing US and European Union (EU) sanctions. Further doubts about Iran's transparency on its nuclear program were raised in 2011 when Iran began producing uranium enriched to nearly the 20 percent level at an undeclared underground facility in Fordow, near the city of Qom. In July 2015, negotiations between Iran and the P5+1[750] resulted in the Joint Comprehensive Plan of Action (JCPOA), a 25-year agreement, some of whose provisions were shorter term, limiting Iran's nuclear capacity and subjecting the country to stringent inspections in exchange for sanctions relief.[751]

In January 2016, all nuclear-related sanctions on Iran were lifted after the IAEA determined that Iran had met the key metrics of the deal. However, doubts about the Iranian government's transparency regarding its nuclear program lingered. In May 2018, the US unilaterally withdrew from the JCPOA, reimposing nuclear-related sanctions on Iran. Subsequently, Iran gradually implemented a series of measures that reduced its compliance with the provisions of the JCPOA. In 2020, the IAEA launched a new investigation into alleged additional undeclared Iranian nuclear activities during the pre-2003 period, which the Israeli government had discovered and revealed through a covert data exfiltration effort. As of 2023, the IAEA's investigations were still ongoing.

Current concerns about Iran's nuclear program mostly focus on the country's enrichment activities, especially Tehran's use of advanced gas centrifuges to generate highly enriched

[749] Litwak, *Nuclear Crises with North Korea and Iran*, p. 83.

[750] The P5+1 includes the five permanent members of the UN Security Council (China, France, Russia, the UK, and the US) plus Germany.

[751] Under the terms of the deal, Iran agreed to limit the numbers and types of centrifuges it could operate, the level of its enrichment, and the size of its stockpile of enriched uranium to no more than 300 kilograms of up to 3.67 percent enriched uranium hexafluoride or its equivalent in other chemical forms until 2031. Iran also agreed to reduce its stockpile of low enriched uranium. UN Security Council Resolution (UNSCR) 2231, which endorses the JCPOA but is technically separate from the agreement, placed additional restrictions on Iran's ballistic missile program and its import and export of conventional arms. According to the US government, Iran has repeatedly violated the provisions of UNSCR 2231, most notably through its continued development of ballistic missiles that can serve as nuclear delivery systems and through the sale of conventional weapons to foreign countries, such as Russia. See, for instance, Wood, "Remarks at a UN Security Council Briefing." For an overview of the provisions of UNSCR 2231, see Robinson, "What Is the Iran Nuclear Deal?"

uranium (HEU) from hexafluoride (UF6) gas. HEU is one of the two types of fissile material (the other is plutonium) that can be used in nuclear weapons. As of 2023, Iran continues to increase the size and enrichment level of its stockpile of HEU.

According to the latest Annual Threat Assessment by the US intelligence community, Iran is not currently undertaking the key nuclear weapons development activities that the community judges would be necessary to produce a nuclear device.[752] However, in July 2019, Iran resumed enriching uranium beyond JCPOA limits.[753]

Furthermore, Iranian officials would probably consider further enriching uranium to at least 90 percent (i.e., weapons grade) if Tehran does not receive sanctions relief, according to the same report.[754] Tehran, meanwhile, continues to maintain that its enrichment program is designed only for the civilian purposes of producing fuel for nuclear reactors and producing medical isotopes.

This chapter provides an overview of Iran's nuclear weapons program. Drawing on Farsi language sources, it outlines Iran's policies on nuclear weapons as articulated by its leaders. Next, it provides several rationales that may explain Tehran's continued interest in nuclear weapons technology. These include deterrence, aspirations to regional power, the quest for national self-sufficiency, and institutional interests. It goes on to discuss what little is known about funding for Iran's nuclear program before detailing the specific nuclear-relevant activities that Iran has engaged in, such as enriching uranium, pursuing the ability to produce plutonium, conducting research into nuclear weapons design, and fielding a wide variety of ballistic and cruise missiles that could potentially be adapted for nuclear delivery.

What are Iran's nuclear weapons policies?

The government of Iran maintains that Iran's nuclear program is for peaceful purposes only and that Iran has no intention of developing nuclear weapons. Ayatollah Ruhollah Khomeini (d. 1989), the Islamic Republic's first Supreme Leader, explicitly stated his opposition to the development and use of weapons of mass destruction (WMDs), including nuclear weapons:

> If the mass production of weapons of mass destruction by the superpowers continues, the world will hurtle towards destruction, and it will involve huge damage to the [world's] countries. Every person, wherever they are, including writers, intellectuals and elites and scientists around the world, should inform

[752] Director of National Intelligence, *2022 Annual Threat Assessment of the U.S. Intelligence Community,* Mar. 8, 2022, p. 15.

[753] Director of National Intelligence, *2022 Annual Threat Assessment of the U.S. Intelligence Community.*

[754] Director of National Intelligence, *2022 Annual Threat Assessment of the U.S. Intelligence Community.*

> people about this danger so that the masses of people stand up against these two powers [the United States and the Soviet Union] and prevent the spread of such weapons.[755]

Khomeini's views on the topic constituted a religious edict, called a *fatwa*, and were widely considered binding on his followers. Ayatollah Ali Khamenei, his successor as Supreme Leader (see Figure 50), has also issued similar edicts. Several of these edicts are listed on the official website of the Atomic Energy Organization of Iran (AEOI), Iran's civilian nuclear agency, including the following:

> I emphasize that the Islamic Republic will never seek nuclear weapons, and it will never renounce the right of its people to use nuclear energy peacefully. Our motto is "Nuclear energy for all, and nuclear weapons for no one."[756]
>
> The Islamic Republic of Iran considers the use of nuclear and chemical weapons and the like to be a great and unforgivable sin. Our slogan is "A Middle East free of nuclear weapons" and we adhere to it. This does not mean renouncing the right to peaceful use of nuclear energy and nuclear fuel production. The peaceful use of this energy is the right of all countries according to international laws.[757]

[755] "Declaration of the Founder of the Islamic Republic of Iran" (in Persian), AEOI, https://www.aeoi.org.ir/?48371/%D8%B5%D9%81%D8%AD%D9%87-%D8%B3%DB%8C%D8%A7%D8%B3%D8%AA-%D9%87%D8%A7%DB%8C-%D8%A7%DB%8C%D8%B1%D8%A7%D9%86-%D9%86%D8%B3%D8%A8%D8%AA-%D8%A8%D9%87-%D8%B3%D9%84%D8%A7%D8%AD-%D9%87%D8%A7%DB%8C-%D9%87%D8%B3%D8%AA%D9%87-%D8%A7%DB%8C.

[756] "Statement of the Leader of the Islamic Republic of Iran" (in Persian), AEOI, https://www.aeoi.org.ir/?48371/%D8%B5%D9%81%D8%AD%D9%87-%D8%B3%DB%8C%D8%A7%D8%B3%D8%AA-%D9%87%D8%A7%DB%8C-%D8%A7%DB%8C%D8%B1%D8%A7%D9%86-%D9%86%D8%B3%D8%A8%D8%AA-%D8%A8%D9%87-%D8%B3%D9%84%D8%A7%D8%AD-%D9%87%D8%A7%DB%8C-%D9%87%D8%B3%D8%AA%D9%87-%D8%A7%DB%8C.

[757] "Statement of the Leader of the Islamic Republic of Iran."

As Khamenei's statements indicate, despite being a signatory of the NPT, Iran is strongly against the perceived monopoly of a few nations, principally in the West, on nuclear technology and know-how, such as nuclear fuel enrichment. In this regard, international concerns regarding Iran's nuclear program are often dismissed as mere excuses for denying Iran its legitimate rights.[758] Mastery of the nuclear fuel cycle has therefore been viewed as an ideological imperative by successive Iranian government administrations.

Figure 50. Iranian Supreme Leader Ali Khamenei

Source: "Supreme Leader, Ali Khamenei Delivers Nowruz Message in his Office," Khamenei.ir, Mar. 20, 2016.

Iranian official parlance often makes a distinction between having the intention to develop weapons and having the technical capacity to do so. Kamal Kharrazi, Khamenei's top foreign policy adviser, admitted in 2022, "It is no secret that we have the technical capability to manufacture a nuclear bomb, but we have made no decision to do so."[759] His views were echoed by Ali Larijani, a conservative politician and former speaker of the Iranian Parliament (called the *Majlis*). Referring to Khamenei's *fatwa* against producing WMDs, Larijani said, "We do not have permission to pursue weapons of mass destruction, including nuclear weapons, but if at some point we decide to do it naturally no one can prevent us." Without naming the United States or Israel, he added, "They also know this."[760]

[758] "The Enemy Knows that Iran Is Not Looking for Nuclear Weapons" (in Persian), Khabar Online, https://www.khabaronline.ir/news/1489205/.

[759] "Second Politician in Tehran Says Iran Can Produce Nuclear Weapons," Iran International, July 18, 2022, https://www.iranintl.com/en/202207183876.

[760] "Second Politician in Tehran Says Iran Can Produce Nuclear Weapons."

Iranian officials have noted that Khamenei's edict prohibiting nuclear weapons could be changed if circumstances warrant. For instance, in an interview with Iranian state television, former intelligence minister Mahmoud Alavi noted:

> The Supreme Leader has explicitly said in his fatwa that nuclear weapons are against sharia law and the Islamic Republic sees them as religiously forbidden and does not pursue them….But a cornered cat may behave differently from when the cat is free. And if they [Western states] push Iran in that direction, then it's no longer Iran's fault.[761]

His views were echoed by former Iranian diplomat and Islamic Revolutionary Guard Corps (IRGC) brigadier general Amir Mousavi, who said in a January 2021 television interview that *fatwas* are not permanent and are issued in accordance with developing circumstances: "Therefore, I believe that if the Americans and Zionists act in a dangerous manner, the *fatwa* might change."[762]

Regardless of official policy, the Iranian government has evidently achieved some (but not all) of the necessary capabilities to develop and deploy nuclear weapons, including the ability to enrich uranium above levels that would be consistent with civilian nuclear power generation. Before 2003, it had also conducted research on weapons design and mating nuclear warheads with ballistic missiles.[763] However, as of 2023, Iran's leadership has not indicated that it has decided to develop or acquire nuclear weapons.[764] Instead, Tehran appears to have opted for a policy of nuclear hedging—that is, maintaining the option to have a weapons program without violating its international commitments.[765]

What factors drive Iran's nuclear program?

Because Iran does not possess nuclear weapons and the Iranian government maintains that its nuclear program is solely for civilian use, the factors that might drive Iran to acquire nuclear weapons remain largely theoretical. Nevertheless, we can assess what these factors might be

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[761] "Iran's Spy Chief Says Tehran Could Seek Nuclear Arms If 'Cornered' by West," Reuters, Feb. 9, 2021, https://www.reuters.com/article/iran-nuclear-int/irans-spy-chief-says-tehran-could-seek-nuclear-arms-if-cornered-by-west-idUSKBN2A91OR.

[762] Maryam Sinaee, "Khamenei Adviser Says Iran Has Not Opted for Nukes but Has Capability," Iran International, July 17, 2022, https://www.iranintl.com/en/202207176618.

[763] *Implementation of the NPT Safeguards Agreement and Relevant Provisions of Security Council Resolutions in the Islamic Republic of Iran*.

[764] Director of National Intelligence, *2022 Annual Threat Assessment of the US Intelligence Community*, p. 15.

[765] Shahram Chubin, "Iran Primer: The Politics of Iran's Nuclear Program," Carnegie Endowment for International Peace, Sept. 1, 2010, https://carnegieendowment.org/2010/09/01/iran-primer-politics-of-iran-s-nuclear-program-pub-41782.

based on Iran's national security priorities and the activities that the Iranian government and military have undertaken in support of these priorities—some of which could potentially have nuclear applications.

Deterrence

If Iran were to develop nuclear weapons, presumably a critical factor influencing its decision to do so would be a desire to deter its adversaries. Iran's leadership views the United States as the country's most significant and enduring threat. Regime elites have concluded that Washington is seeking to overthrow, or at least undermine, the Islamic Republic using a mix of hard and soft power methods, such as subversion, information warfare, economic pressure, and military intervention.[766] Given the centrality of the United States in the regime's threat perceptions, Tehran has accordingly tailored its warfighting strategies to deter or counter technologically superior adversaries by asymmetric means. Nuclear weapons could complement this asymmetric paradigm and would considerably bolster the regime's deterrent capabilities.

Regional aspirations

Iran's regional aspirations could also factor into the regime's perception of the trade-offs associated with acquiring nuclear weapons. Several states near Iran are nuclear powers, including Pakistan, India, Russia, and allegedly Israel. Iran's leadership views Iran as an influential regional power with ambitions to lead not only the region's Shia Muslims but also the entire Muslim world. As such, Tehran might seek to become the world's second Muslim nuclear state, after Pakistan. Alongside these ideological factors, Iran's security interests have become more localized in recent years.[767] The drawdown of US forces from the region, the rise of Sunni extremist nonstate actor groups (such as the Islamic State), and Iran's ongoing rivalry with Israel and some of the Arab Gulf states have all served to focus Tehran's attention on its immediate neighborhood and increase Iran's outreach to regional proxy and client militant groups. As Iran's regional aspirations grow, Iran's leadership could decide to acquire nuclear weapons to enhance Iran's prestige and deter regional threats, including the nuclear capabilities attributed to Israel.[768]

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[766] Defense Intelligence Agency, *Iran Military Power: Ensuring Regime Survival and Securing Regional Dominance*, 2019, p. 12.

[767] Defense Intelligence Agency, *Iran Military Power: Ensuring Regime Survival and Securing Regional Dominance.*

[768] Major General Mohammad Bagheri, the chief of general staff of the armed forces, recently alluded to the regime's shifting regional threat perceptions: "In recent months, the American terrorist military has tried to fill the

Self-sufficiency

Iran's nuclear ambitions may also be byproducts of the regime's ideological predilection for self-reliance. Iran's initial efforts to conduct nuclear weapons–related research and development (R&D) and to acquire enrichment centrifuges from the A.Q. Khan network were part of a broader attempt in the 1980s and 1990s to become more self-reliant in arms and technology.[769] During the Iran-Iraq War, Iran became increasingly isolated and struggled to acquire arms and equipment from foreign suppliers to fight Iraq, which had employed missiles and chemical weapons against the Iranian military as well as civilian targets. Effectively deprived of access to most international arms markets, Iran started to develop its own domestic alternatives to foreign suppliers. This emphasis on self-reliance extends to Iran's civilian nuclear program; distrust of Western intentions and international institutions has often caused Iranian negotiators to push back on any attempts to restrict activities that Tehran views as within its legitimate rights, such as enrichment and development of a conventional ballistic missile capability for deterrent purposes. This distrust stems at least in part from leadership's perception that Western countries are trying to deny Iran access to nuclear technology and discriminating against Iran even though Tehran signed the NPT whereas other nuclear-armed countries (e.g., Pakistan, North Korea, India, allegedly Israel) did not.[770]

Institutional interests

The Iranian government consists of formal and informal networks with overlapping (and sometimes competing) interests and authorities. Some institutions, political groupings, and individuals may advocate for developing nuclear weapons or a threshold capability because they have personal or institutional interests in developing such a program. For instance, Iran's strategic missile forces are managed by the IRGC's Aerospace Force, and IRGC officials have

vacuum left by withdrawing its aircraft carriers, helicopters and destroyers from the Persian Gulf and the Oman Sea by panicking its dependents into compensating by connecting the area usurped by the Zionist regime and its child-killing army (i.e., Israel) to CENTCOM's regional command. The meaning of this action is that, from our point of view, the [facilities] of the United States and its allies will be at the disposal of the usurping Zionist regime, and this will increase the threat to our beloved country." See "General Bagheri's Warning to the American Army and the Zionist Regime" (in Persian), Mehr News, https://www.mehrnews.com/news/5583723/%D9%87%D8%B4%D8%AF%D8%A7%D8%B1-%D8%B3%D8%B1%D9%84%D8%B4%DA%A9%D8%B1-%D8%A8%D8%A7%D9%82%D8%B1%DB%8C-%D8%A8%D9%87-%D8%A7%D8%B1%D8%AA%D8%B4-%D8%A2%D9%85%D8%B1%DB%8C%DA%A9%D8%A7-%D9%88-%D8%B1%DA%98%DB%8C%D9%85-%D8%B5%D9%87%DB%8C%D9%88%D9%86%DB%8C%D8%B3%D8%AA%DB%8C.

769 Chubin, "Iran Primer: The Politics of Iran's Nuclear Program."

770 Chubin, "Iran Primer: The Politics of Iran's Nuclear Program."

advocated for investments in Iran's missile capabilities. Both the MODAFL and the IRGC were allegedly involved in covert efforts to conduct nuclear weapons–related research via the AMAD Project and its successor, the Organization of Defensive Innovation and Research (Persian acronym SPND). Presumably, if such efforts were resumed, the MODAFL and IRGC could become institutional advocates.

How is Iran's nuclear program funded?

The covert nature of Iran's military nuclear activities and the fact that the government relies on a variety of off-budget sources for funding its military make accurately estimating the entire budget for Iran's nuclear program extremely difficult. In 2020, after the assassination of Mohsen Fakhrizadeh, the head of Iran's military nuclear program, Iran's defense minister announced a 256 percent increase in the budget for the SPND (the IRGC organization responsible for nuclear research), but the original budget of the organization was not revealed.[771] According to parliamentary legislation for fiscal year 1401 (which began on March 21, 2022), the IRGC would be funded at $22 billion.[772] However, information about how much of this money is allocated for nuclear research is not publicly available. Moreover, the IRGC's actual budget is likely much larger because the Supreme Leader often authorizes transfers to the military budget from Iran's National Development Fund (Iran's reserve fund), private foundations that he oversees, and IRGC-controlled companies.[773]

Information about the budget for the AEOI, the organization that manages Iran's civilian nuclear program, is more readily available although still sparse. The AEOI's budget reportedly averages between $250 and $300 million annually.[774] This amount presumably covers Iran's overt enrichment activities, including the operating costs of the Bushehr nuclear power plant.

[771] David Brennan, "Iran Lifts Nuclear Research Group's Budget by 256 Percent After Scientist Killing," *Newsweek*, Dec. 5, 2020, https://www.newsweek.com/iran-lifts-nuclear-research-group-budget-256-percent-scientist-killing-jcpoa-1554796.

[772] Agnes Helou, "Iran More Than Doubles Revolutionary Guard's Budget in FY22 Bill," *Defense News*, Dec. 16, 2021, https://www.defensenews.com/global/mideast-africa/2021/12/16/iran-more-than-doubles-revolutionary-guards-budget-in-fy22-bill/.

[773] Defense Intelligence Agency, *Iran Military Power: Ensuring Regime Survival and Securing Regional Dominance*, p. 19.

[774] Elnur Baghishov, "Iran's Atomic Energy Organization Discloses Its Annual Budget," Trend, Mar. 14, 2021, https://en.trend.az/iran/nuclearp/3394823.html.

What activities is Iran's nuclear program engaged in?

Before 2003, Iran maintained an active nuclear weapons program and was engaged in fissile material production and research (involving both uranium and plutonium), warhead design, and research on warhead integration with missile delivery systems. As noted, these efforts were abruptly curtailed in 2003 following international scrutiny. The US intelligence community asserts that Iran is not currently undertaking the key nuclear weapons development activities that the community judges would be necessary to produce a nuclear device.[775] However, Iran continues to engage in nuclear activities that contravene the provisions of the JCPOA and that indicate at best ambiguous intent regarding its nuclear intentions. In addition, Iran has acquired a large and diverse inventory of ballistic missiles that are designed to carry conventional payloads but could be adapted for nuclear use.

Fissile material production

One of the obstacles to producing nuclear weapons is obtaining enough fissile material—either weapons-grade HEU or plutonium—for the weapon's core. The AEOI (whose responsibilities include nuclear fuel enrichment) is currently producing HEU at levels of 60 percent concentration of U-235, which is well beyond the typical enrichment level for power generation (around 3 to 5 percent) but is not yet weapons grade (at least 90 percent). Before 2003, Iran also had a program to produce plutonium. Of the two options, Iran is currently better postured to produce HEU.[776]

Uranium

Several steps are necessary to produce HEU capable of sustaining a nuclear chain reaction. Natural uranium occurs in two forms: U-238, which accounts for 98.3 percent of the element in nature, and U-235, a lighter fissionable isotope that accounts for only 0.7 percent of the naturally occurring element. Enriched uranium is produced when uranium ore is crushed, refined, and reconstituted into solid form, known as uranium "yellowcake" (see Figure 51), heated and converted to UF6, and enriched, for example using a series (called a cascade) of centrifuges. Enrichment can continue until enough concentrated U-235 is collected: around 3 percent for reactor use and 90 percent or more for nuclear weapons use.[777]

[775] Director of National Intelligence, *2022 Annual Threat Assessment of the US Intelligence Community*, p, 15.

[776] Director of National Intelligence, *2022 Annual Threat Assessment of the US Intelligence Community*, p, 15.

[777] Litwak, *Nuclear Crises with North Korea and Iran*, pp. 83–84.

The AEOI appears to have mastered all the stages of nuclear reactor fuel production.[778] Furthermore, Iran has developed the necessary infrastructure to support each phase of the enrichment process. Iran has three enrichment facilities: an aboveground Pilot Fuel Enrichment Plant (PFEP) at Natanz, an underground Fuel Enrichment Plant (FEP) also at Natanz, and the deeply buried Fordow Fuel Enrichment Plant (FFEP).[779] The FEP, the largest of Iran's enrichment facilities, is designed to hold up to 50,000 gas centrifuges. The other two facilities are much smaller. The FFEP, which was previously operated by the IRGC, has been repurposed as a research center, according to the provisions of the JCPOA (although 1,044 centrifuges remain installed in one of its wings).[780] All three facilities are currently operating under IAEA safeguards. The NCRI revealed the existence of the FEP in 2002, but the FFEP was not publicly revealed until 2009.[781] In addition to its three enrichment facilities, Iran also operates a yellowcake production plant at Ardakan, a UF6 conversion facility in Esfahan, a uranium mine at Gchine, and a uranium production plant for processing uranium ore near Bandar Abbas.

Figure 51. "Yellowcake" uranium

Source: "A Photo of Yellow Cake Uranium, a Solid Form of Uranium," Nuclear Regulatory Commission Flickr, Dec. 1, 2014, https://www.flickr.com/photos/nrcgov/16016668166/.

The provisions of the JCPOA reduced the number of centrifuges installed in Iran to roughly 6,000 from around 19,000 before the deal. The deal also allowed Iran to produce only enriched uranium with its first-generation IR-1 centrifuges. The JCPOA also mandated additional restrictions on Iran's declared enrichment capacity, limiting the country to a uranium stockpile

[778] *Verification and Monitoring in the Islamic Republic of Iran in Light of United Nations Security Council Resolution 2231 (2015)*, Nov. 10, 2022.

[779] Albright, Burkhard, and Faragasso, *A Comprehensive Survey of Iran's Advanced Centrifuges*, p. 8.

[780] "Fordow Fuel Enrichment Plant," NTI, https://www.nti.org/education-center/facilities/fordow-fuel-enrichment-plant/.

[781] Ivan Oelrich and Ivanka Barzashka, "A Technical Evaluation of the Fordow Fuel Enrichment Plant," *Bulletin of the Atomic Scientists*, Nov. 23, 2009, https://thebulletin.org/2009/11/a-technical-evaluation-of-the-fordow-fuel-enrichment-plant/.

of no more than 300 kilograms of UF6 containing 3.67 percent U-235 "or the equivalent in other chemical forms."[782] The JCPOA restrictions on Iran's enrichment capacity, as well as on the mass and U-235 content of the UF6 stockpile, will begin to expire in January 2026. The intention behind these and other limitations was that—until the provision expired—Iran would have required a minimum of one year to produce enough HEU for a nuclear weapon.[783]

However, as noted previously, in May 2018, the United States withdrew from the JCPOA and began to reimpose unilateral sanctions on Iran as part of its maximum pressure campaign. Shortly afterward, Tehran announced that it would take steps to expand its enrichment infrastructure while remaining within the bounds of the JCPOA.[784] In May 2019, Iranian officials announced that the country would cease adhering to some of its JCPOA obligations unless it obtained sanctions relief from the United States and its European partners. Since that time, the number and type of installed centrifuges, the mass and U-235 concentration of Tehran's enriched uranium stockpile, and the number of enrichment locations in Iran have exceeded JCPOA-mandated limits.[785] Iran is also conducting prohibited nuclear R&D, illicit uranium metal production, and centrifuge manufacturing and installation.[786]

[782] Quoted in Paul K. Kerr, "Iran and Nuclear Weapons Production," *In Focus*, Congressional Research Service, updated July 25, 2022, p. 1.

[783] Kerr, "Iran and Nuclear Weapons Production."

[784] Defense Intelligence Agency, *Iran Military Power: Ensuring Regime Survival and Securing Regional Dominance*, p. 19.

[785] Kerr, "Iran and Nuclear Weapons Production," p. 1.

[786] Kerr, "Iran and Nuclear Weapons Production."

JCPOA at a glance

By signing the JCPOA, commonly referred to as the "Iran nuclear deal," Tehran agreed to verifiably constrain its nuclear program to peaceful purposes in exchange for the broad lifting of certain US, EU, and UN sanctions.[787] Although the terms of the agreement are highly complex, some key parts are described below.

Signatories: Iran, US, UK, France, China, Russia, and Germany

UN Security Council adoption date: July 20, 2015

Nuclear restrictions: Uranium enrichment limited to 3.67 percent for 15 years (and enrichment permitted only at the Natanz site); enriched uranium stockpile limited to 300 kilograms for 10 years; reduction of, dismantlement of, and production restrictions on IR-1 centrifuges for 10 years; limits on centrifuge R&D; prohibition of heavy water reactors and accumulation of heavy water for 15 years; among others.

Monitoring and verification: Long-term IAEA presence in Iran and implementation of IAEA Additional Protocol; continuous monitoring of uranium mines and mills (25 years) and centrifuge production facilities (20 years); IAEA access to undeclared sites; among others.

Sanctions relief: In 2016, once the IAEA confirmed that Iran was in full compliance of the treaty, UN, US, and EU nuclear-related sanctions against Iran were lifted. These sanctions are subject to a snapback should Iran's compliance change.

Current status: In May 2018, the US announced its decision to end participation in the JCPOA and stopped performing its commitments because of the Trump Administration's belief that the agreement did not serve US national security interests.[788] Subsequently, the US reimposed all the sanctions that they had previously suspended against Iran.[789] Roughly a year later, Iran announced that it was starting to move away from its JCPOA commitments, gradually increasing its stockpiles of uranium, increasing enrichment levels, and restricting IAEA monitoring access.[790] Although the original signatories, including the US, have met repeatedly to negotiate a renewed version of the deal, progress has stalled.

[787] More information on the JCPOA can be found at "The Joint Comprehensive Plan of Action (JCPOA) at a Glance," Arms Control Association, accessed Mar. 2, 2023, https://www.armscontrol.org/factsheets/JCPOA-at-a-glance; and Paul Kerr and Kenneth Katzman, *Iran Nuclear Agreement and U.S. Exit*, Congressional Research Service, July 20, 2018, https://sgp.fas.org/crs/nuke/R43333.pdf.

According to the September 2022 IAEA quarterly report on Iran:

> Iran has continued the enrichment of UF6 at the Fuel Enrichment Plant (FEP) and the Pilot Fuel Enrichment Plant (PFEP) at Natanz, and at the Fordow Fuel Enrichment Plant (FFEP) at Fordow. As previously reported, Iran has enriched UF6 up to 5 percent U-235 since 8 July 2019 (para. 28), has enriched UF6 up to 20 percent U-235 since 4 January 2021, and has enriched UF6 up to 60 percent U-235 since 17 April 2021. Iran has continued to conduct enrichment activities that are not in line with its long-term enrichment and enrichment research and development (R&D) plan, as provided to the Agency on 16 January 2016 (para. 52).[791]

Of potentially greater concern, Iran has also installed advanced centrifuges at its enrichment facilities in contravention of the JCPOA. According to the September 2022 IAEA quarterly report, Iran has installed 2,782 advanced centrifuges of various types (mostly IR-2m, IR-4, and IR-6 centrifuges). Iran also reportedly has 7,110 IR-1 centrifuges, the older model of centrifuge that Iran originally acquired from the A.Q. Khan network in the 1990s. According to a report by the Institute for Science and International Security, since February 2021, Iran's installed advanced centrifuge nominal enrichment capacity has exceeded the capacity of its IR-1 centrifuges, and today advanced centrifuges account for approximately two-thirds of Iran's total installed enrichment capacity.[792]

Various concerns have been raised about Iran's enrichment efforts, not the least of which is that Iran appears to be enriching uranium above 60 percent in contravention of the JCPOA provisions. Uranium enriched above 60 percent has no practical civilian purpose, but it could vastly reduce the amount of time required for Iran to achieve a nuclear breakout capability. Furthermore, critics have pointed out that Iran's domestic enrichment efforts are not rational from a purely economic perspective. Russia is currently fueling Iran's only nuclear power

[788] Congressional Research Service, *Iran's Nuclear Program and U.N. Sanctions Reimposition*, accessed Mar. 2, 2023, https://crsreports.congress.gov/product/pdf/IF/IF11583.

[789] Kerr and Katzman, *Iran Nuclear Agreement and U.S. Exit*; "Trump Administration to Reinstate All Iran Sanctions," BBC, Nov. 3, 2018, https://www.bbc.com/news/world-us-canada-46071747.

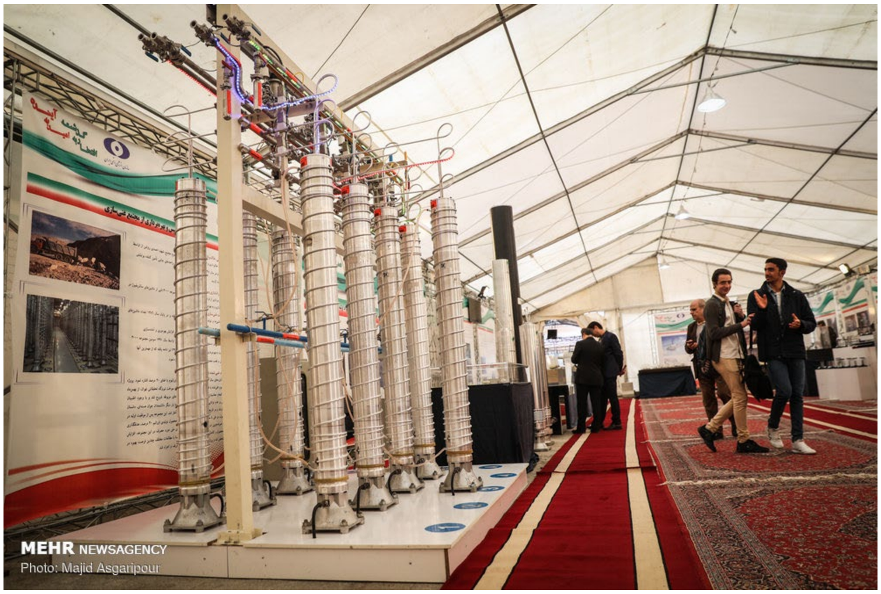
[790] Tamer El-Ghobashy, Michael Birnbaum, and Carol Morello, "Iran Announces It Will Stop Complying with Parts of Landmark Nuclear Deal," *Washington Post*, May 8, 2019, https://www.washingtonpost.com/world/iran-to-take-steps-to-reduce-its-commitment-to-landmark-nuclear-deal/2019/05/07/90cc3b1c-70fe-11e9-9331-30bc5836f48e_story.html.

[791] *Verification and Monitoring in the Islamic Republic of Iran in Light of United Nations Security Council Resolution 2231 (2015).*

[792] Albright, Burkhard, and Faragasso, *A Comprehensive Survey of Iran's Advanced Centrifuges*.

reactor at Bushehr and is postured to do so for the foreseeable future at a much lower cost than that Iran would incur by enriching the uranium itself.[793]

Figure 52. Iranian centrifuges on display at a defense exhibition in Tehran



Source: Majid Asgaripour, "This Photo Was Taken at the Eqtedar 40 Defence Exhibition in Tehran," Feb. 2, 2019.

Regardless of the implications, the Iranian government is doubling down on its enrichment efforts. The Iranian Parliament, the *Majlis*, passed legislation in December 2020 mandating enrichment goals in accordance with the guidance set by the Supreme Leader. According to the provisions of this legislation, the AEOI is obliged to produce and store at least 120 kilograms of enriched uranium at 20 percent HEU every year. Furthermore, the legislation requires that the AEOI increase the country's monthly enriched uranium output and enrichment capacity with different purity levels by at least 500 kilograms and that it stockpile the enriched materials inside the country. Finally, the law states that the AEOI

> is obliged to start the operation of installing, injecting (uranium) gas, enrichment and stockpiling of materials up to the purity level needed, with at

[793] Furthermore, even if Iran attempted to enrich the requisite low enriched uranium (LEU) itself, it is unlikely that it could produce enough centrifuges to do so. According to a Wisconsin Project on Nuclear Arms Control report, a standard-sized power reactor (1,000 megawatts-electric) such as Iran's reactor at Bushehr requires about 21 metric tons of LEU fuel per year, which would require generating nearly 100,000 separative work units (SWU). Iran's centrifuges now produce about 9,000 SWU. Thus, Iran would have to increase its capacity more than tenfold to have any plausibility as a civilian effort. See "Iran's Nuclear Timetable: The Weapon Potential," Iran Watch, July 21, 2022, https://www.iranwatch.org/our-publications/articles-reports/irans-nuclear-timetable-weapon-potential.

> least 1,000 advanced second-generation centrifuge machines (IR-2m), within a maximum of three months after the ratification of this law. Within the same period of time, the Atomic Energy Organization of Iran is also required to start enrichment and research and Development activities with at least 164 IR-6 centrifuges and increase the number of centrifuge machines to 1,000 within one year after the ratification of this law.[794]

Plutonium

Iran's past efforts to build a heavy water–moderated nuclear reactor and heavy water production plant suggest an interest in acquiring plutonium that could be used for a nuclear weapon. Heavy water reactors have two key features that distinguish them from other types of nuclear reactors. First, they can be fueled with natural uranium. Operators of a heavy water reactor have no need to enrich uranium for fuel. Second, heavy water reactors can produce plutonium as a byproduct of their operation. The plutonium can then be chemically extracted from the reactor's fuel rods. This plutonium could then be used to build a nuclear weapon.

Iran's foray into heavy water and plutonium production began in the 1990s, when Tehran secretly approached several foreign suppliers about the possibility of acquiring a heavy water–moderated reactor. All the suppliers turned Tehran down, so the Iranians decided to build their own Heavy Water Production Plant (HWPP) and experimental IR-40 reactor at Arak, reportedly with foreign assistance.[795] The facilities at Arak remained a secret until 2002, when NCRI revealed their existence. Iran officially admitted to the facilities' existence the following year but claimed that their purpose was solely civilian nuclear power generation.

In 2004, the HWPP commenced production of heavy water.[796] According to the terms of the interim Joint Plan of Action (JPOA), Iran agreed to halt construction on the IR-40 reactor at Arak in return for partial relief of sanctions by the US and the EU. In addition, any spent fuel from Arak is required to be shipped out of Iran for the reactor's lifetime.[797] Per the JCPOA, Iran can continue to produce heavy water, but production is capped at 130 tons for 15 years. By 2016, the reactor had been rendered inoperable in accordance with the provisions of the JCPOA. As of 2017, the AEOI was working with the China National Nuclear Corporation (CNNC)

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794 "Iranian Parliament Bill on Nuclear Program: Full Text in English," NIAC, Dec. 3, 2020, https://www.niacouncil.org/publications/iranian-parliament-bill-on-nuclear-program-full-text-in-english/.

795 "Arak Nuclear Complex," NTI, https://live-nuclear-threat-initiative.pantheonsite.io/education-center/facilities/arak-nuclear-complex/; "Iran's Heavy-Water Reactor: A Plutonium Bomb Factory," Arms Control Association, Nov. 9, 2006, https://www.armscontrol.org/pressroom/2006-11/iran%E2%80%99s-heavy-water-reactor-plutonium-bomb-factory.

796 Heavy water differs from ordinary water (H_2O) in that its hydrogen atom contains a neutron in addition to a proton. In ordinary water the extra neutron is absent.

797 "FACTBOX-The Atomic Restrictions Imposed by the Iran Nuclear Deal," Reuters, July 7, 2019, https://www.reuters.com/article/mideast-iran-usa-restrictions-idUKL8N2462Y6.

to repurpose the facilities at Arak for power generation with low enriched uranium (LEU), thereby eliminating the possibility of plutonium production.[798] Iran also appears to have abided by the provision to ship excess amounts of heavy water abroad either for sale or for storage.[799]

Nuclear weapons work

According to the IAEA, which has conducted two investigations into Iran's past nuclear activities, a "range of activities relevant to the development of a nuclear explosive device were conducted in Iran prior to the end of 2003 as a coordinated effort, and some activities took place after 2003." According to the agency's 2015 *Final Assessment on Past and Present Outstanding Issues regarding Iran's Nuclear Programme*, which summarized the results of the IAEA's first investigation into Iran's nuclear activities, Iran's efforts to develop a nuclear explosive device began in the late 1980s under the auspices of the MODAFL's PHRC, which was affiliated with Sharif University of Technology. The military's efforts were later consolidated within the AMAD Project under the leadership of Mohsen Fakhrizadeh (see Figure 53).[800]

Figure 53. Mohsen Fakhrizadeh

Source: "Mohsen Fakhrizadeh," Tasnimmnews.ir, May 7, 2020.

According to the IAEA, when the AMAD Project's activities were halted in late 2003, its "equipment and work places were either cleaned or disposed of so that there would be little to identify the sensitive nature of the work that had been undertaken."[801] US intelligence assessments concurred with the IAEA's investigations, noting that "Tehran had not restarted its nuclear weapons program as of mid-2007."[802] However, certain covert nuclear weapons–related R&D activities resumed under a new MODAFL entity—the SPND, also led by Mohsen Fakhrizadeh. The US State Department sanctioned the SPND on August 29, 2014, for "engaging in or

798 "Arak Nuclear Complex."

799 "Arak Nuclear Complex."

800 *Final Assessment on Past and Present Outstanding Issues Regarding Iran's Nuclear Programme*.

801 *Final Assessment on Past and Present Outstanding Issues Regarding Iran's Nuclear Programme.*

802 National Intelligence Council, *Iran: Nuclear Intentions and Capabilities*, Nov. 2007.

attempting to engage in activities that have materially contributed to, or posed a risk of materially contributing to, the proliferation of WMD or their means of delivery."[803]

The IAEA's investigation into the military dimensions of Iran's nuclear program found "no credible indications" of activities relevant to weaponization after 2009 or any diversion of nuclear materials for military purposes.[804] However, the IAEA began a second investigation into Iran's nuclear program in 2018, focusing on activities that Iran reportedly conducted before 2003. The Safeguards Investigation, as it became known, stemmed from evidence provided by the Israeli government that Iran had failed to declare all its nuclear materials and activities as legally required according to its Safeguards Agreement with the IAEA. Agency scientists visited three undeclared sites in Iran—Turquzabad, Lavaz-Shian, and Varamin—and took environmental samples that indicated the presence of processed uranium, for which the Iranian government has yet to provide a credible explanation. The IAEA also began to investigate a fourth location—Marivan—based on evidence that suggested that Iran had conducted "explosive experiments with protective shielding in preparation for the use of neutron detectors" at the site.[805] Although Iran subsequently offered explanations for the presence of anthropogenic (human-made) uranium particles at the four sites identified above, the IAEA rejected these explanations for being inconsistent.[806]

In the case of Varamin, the agency concluded that the site "was an undeclared pilot-scale facility for the processing and milling of uranium ore and conversion into uranium oxide and possibly, at laboratory scale, into UF4 and UF6, used between 1999 and 2003."[807]

Nuclear weapons delivery system work

Iran currently does not have any viable nuclear weapons delivery systems in its arsenal. However, Iran has developed systems for the delivery of conventional munitions payloads, including ballistic and cruise missiles, that could be adapted for nuclear use. Iran has not tested or deployed a missile capable of striking the United States, but Iran's work on SLVs—such as the Simorgh—could shorten the timeline required to develop an ICBM because SLVs and ICBMs

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803 "US Government Sanctions Organizations and Individuals in Connection with an Iranian Defense Entity Linked to Iran's Previous Nuclear Weapons Effort," US Treasury Department, Mar. 22, 2019, https://home.treasury.gov/news/press-releases/sm634.

804 *Verification and Monitoring in the Islamic Republic of Iran in Light of United Nations Security Council Resolution 2231 (2015)*, Nov. 10, 2022.

805 "Arms Control and Proliferation Profile: Iran."

806 *Implementation of the NPT Safeguards Agreement in the Islamic Republic of Iran*, Report to the IAEA Board of Governors, GOV/2022/26, May 30, 2022. https://www.iaea.org/sites/default/files/22/06/gov2022-26.pdf.

807 *Implementation of the NPT Safeguards Agreement in the Islamic Republic of Iran,* May 30, 2022.

use similar technologies.[808] The IAEA has also determined that before 2004, scientists affiliated with Iran's military conducted research on the design and integration of nuclear warheads with ballistic missile systems that are currently in Iran's inventory.[809]

Ballistic missiles

Iran currently has the largest inventory of conventionally armed ballistic missile systems in the Middle East.[810] Tehran's determination to possess an extensive domestic missile program in the face of international sanctions is the result of two factors: its experience in the Iran-Iraq War, when Iraq targeted Iranian population centers with Scud missiles, and Iranian leadership's current threat perceptions regarding Israel, the US, and US allies in the Persian Gulf region.[811] In lieu of a modern, capable air force, which the resource-constrained regime would have difficulty acquiring, Tehran has opted for a diverse array of close-range ballistic missiles (CRBMs), short-range ballistic missiles (SRBMs), and medium-range ballistic missiles (MRBMs) that are capable of ranging targets between 2,000 and 3,000 kilometers, including targets in most of the Middle East and southeastern Europe.[812] All of Iran's longer range missiles are operated by the IRGC Aerospace Force (IRGCASF) and are considered primary components of the country's strategic deterrent, designed to dissuade countries such as Israel and the United States from attacking Iran.[813]

The country's missile program has developed along two parallel tracks: a liquid-propellant engine program, managed by the MODAFL's Shahid Hemmat Industrial Group (SHIG), and a solid-propellant engine program, managed by MODAFL's Shahid Bakeri Industrial Group (SBIG). Both organizations have been sanctioned by the US and the UN.

[808] Director of National Intelligence, *2022 Annual Threat Assessment of the US Intelligence Community*, p. 15.

[809] *Implementation of the NPT Safeguards Agreement and Relevant Provisions of Security Council Resolutions in the Islamic Republic of Iran*.

[810] Defense Intelligence Agency, *Iran Military Power: Ensuring Regime Survival and Securing Regional Dominance*, p. 30.

[811] "Iran Missile Overview."

[812] This range is based on performance estimates of the Khorramshahr MRBM. See "Khorramshar," CSIS Missile Threat Project, updated July 31, 2021, https://missilethreat.csis.org/missile/khorramshahr/.

[813] Defense Intelligence Agency, *Iran Military Power: Ensuring Regime Survival and Securing Regional Dominance*, p. 30.

Liquid-fuel versus solid-fuel ballistic missiles

Ballistic missiles use either liquid fuel or solid fuel. Both fuel types have pros and cons.

Liquid-fuel missiles

- Are generally simpler to design and build than solid-fuel missiles.
- Generally produce greater thrust than solid-fuel missiles.
- Typically require their liquid fuel (e.g., liquid hydrogen and oxygen) to remain supercooled until ignition.
- Must be fueled before launch—a process that can take hours.
- Cannot remain fueled for long periods because their fuel is corrosive and may harm vital internal parts.
- Cannot be launched without significant advance notice and may be vulnerable to attack during the fueling process.

Solid-fuel missiles

- Can be launched promptly because they have their fuel stored inside them.
- Use less combustible fuel, which reduces the risk of accident or mishap.
- Accelerate more rapidly after launch, reducing their vulnerability to interception.

In addition, **some advanced liquid-fuel missiles** use non-cryogenic fuels and can be left fueled for years. These modern liquid-fuel missiles offer many of the advantages of solid-fuel missiles.[814]

Iran's more accurate delivery systems are primarily short-range solid-fuel missiles with designs based on artillery rockets, such as the Fateh family of SRBMs. Iran's longer range systems—such as the Shahab series of missiles and their derivatives—are generally less accurate, although the MODAFL has been working on developing precision-guided MRBMs with satellite navigation and terminal vectoring, such as the Emad-1 MRBM.[815] Any of the ballistic missiles in Iran's inventory could be used against area targets, such as cities, subject to range and payload constraints. The IRGCASF routinely conducts tests, exercises, and demonstrations with its ballistic missiles, most notably in the Great Prophet series of joint

[814] See "Iran Missile Overview."

[815] Defense Intelligence Agency, *Iran Military Power: Ensuring Regime Survival and Securing Regional Dominance*, p. 45.

military exercises. It has also used ballistic missiles in combat to strike US, Saudi, and Kurdish targets in the region as well as Islamic State militants in Iraq and Syria. The IRGC has shared ballistic missile technology with its regional militant groups, including Lebanese Hizballah, Yemeni Ansarallah, and several groups associated with the Popular Mobilization Forces in Iraq.

Iran is not a signatory to international regimes to prevent missile proliferation, such as the Missile Technology Control Regime. UN Security Council Resolution (UNSCR) 2231, which endorses the JCPOA, calls upon Iran

> [Not] to undertake any activity related to ballistic missiles designed to be capable of delivering nuclear weapons, including launches using such ballistic missile technology, until the date eight years after the JCPOA Adoption Day or until the date on which the IAEA submits a report confirming the Broader Conclusion, whichever is earlier.[816]

Figure 54. An "Emad" intermediate-range ballistic missile

Source: Mohammad Agah, "Emad - an Iranian-designed, liquid-fuel, intermediate-range ballistic missile. This missile features a newly designed reentry vehicle with a more advanced guidance and control system, making it the country's first IRBM that is precision-guided," Tasnim News Agency, Oct. 11. 2015

[816] UNSCR 2231, 2015, (S/RES/2231 (2015)).

The Iranian government has asserted that conventionally armed ballistic missiles are essential to Iran's defense, are not designed for nuclear use, and are thus outside the purview of UNSCR 2231 and its annexes.[817] Successive US administrations have considered Iran's development, acquisition, and use of ballistic missiles as "provocative and destabilizing" and "inconsistent with" UNSCR 2231 because of the missiles' inherent capability to carry a nuclear warhead.[818]

Other potential delivery systems

Iran also has an extensive inventory of subsonic cruise missiles, some of which could potentially be adapted for nuclear use. Most of the cruise missiles in Iran's inventory are anti-ship cruise missiles, which are designed for use against maritime targets. However, Iran acquired a limited number of Soviet-era Kh-55 (NATO: AS-15 Kent) air-launched land-attack cruise missiles (LACMs) from Ukraine in 2001, which MODAFL affiliates subsequently reverse engineered into a ground-launched land-attack variant called the Meshkat. The Soviet Kh-55 was designed to carry a nuclear warhead that would be launched by strategic bombers from the Soviet Union's Long-Range Aviation fleet.

After this acquisition, Iran developed several other LACMs, including the Soumar and the Hoveyzeh, both of which are highly accurate and can range targets as far as 2,500 kilometers.[819] Theoretically, these LACMs could deliver a nuclear payload because their design is closely related to the Kh-55, which was expressly designed to do so. However, given the payload constraints associated with Iran's LACMs, it would be far easier for Iran to adapt any potential nuclear weapons for delivery by ballistic missiles, which can generally deliver a heavier payload.

Iran could also employ aircraft to deliver a nuclear payload, such as a gravity bomb. However, given the limited capabilities of Iran's air force, any aircraft employed to do so would likely be interdicted before reaching the intended targets.

Missile warhead design

Between 2002 and 2003, the MODAFL appears to have conducted research on nuclear warhead design and the mating of warheads to ballistic missiles. According to documentation allegedly provided by the United States government to the IAEA in 2005,[820] between 2002 and 2003, Iranian engineers affiliated with Project 111 (a component of the AMAD Project) produced

[817] "Appendix E: Iran's Ballistic Missiles and the Nuclear Deal."

[818] Katzman, *Iran's Foreign and Defense Policies*, p. 13.

[819] Shahryar Pasandideh, "Under the Radar, Iran's Cruise Missile Capabilities Advance," War on the Rocks, Sept. 25, 2019, https://warontherocks.com/2019/09/under-the-radar-irans-cruise-missile-capabilities-advance/.

[820] Dafner Linzer, "Strong Leads and Dead Ends in Nuclear Case Against Iran," *Washington Post*, Feb. 8, 2006, https://www.washingtonpost.com/wp-dyn/content/article/2006/02/07/AR2006020702126.html.

components and mock-up parts for engineering a reentry vehicle for a nuclear warhead on a Shahab-3 MRBM. These efforts included a structured and comprehensive program of engineering studies to examine how to integrate a new spherical payload into the existing payload chamber that would be mounted in the reentry vehicle of the Shahab 3. The Iranians also conducted computer modeling studies to evaluate prototypes of missile reentry vehicles, including a prototype firing system for a Shahab-3 payload that would allow the warhead to safely reenter the atmosphere and then explode above a target or upon impact.[821] The IAEA concluded that the documentation that it had received regarding Project 111 research into missile warhead design was both internally consistent and consistent with other supporting information related to Project 111. The Iranian government denied conducting the research, claiming that the documentation was fabricated; however, the IAEA drew the following conclusion:

> The quantity of the documentation, and the scope and contents of the work covered in the documentation, are sufficiently comprehensive and complex that, in the Agency's view, it is not likely to have been the result of forgery or fabrication. While the activities described as those of Project 111 may be relevant to the development of a non-nuclear payload, they are highly relevant to a nuclear weapon programme.[822]

What nuclear weapons–related R&D has Iran undertaken?

Iran's nuclear weapons–related R&D has likely been driven by a mix of factors, including its leadership's threat perceptions, views of conventional imbalance relative to Iran's potential adversaries, and less tangible factors, such as national pride. Iran's R&D efforts have proceeded along three distinct tracks.

The partially overt first track has focused on nuclear fuel enrichment. The Iranian government has stated that in the face of sanctions and other pressure, Iran has no choice but to produce its own fuel to exercise what it sees as its inalienable right to use nuclear energy for peaceful purposes.[823] Before 2009, Iran concealed some aspects of its efforts to produce both enriched

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821 See *Implementation of the NPT Safeguards Agreement and Relevant Provisions of Security Council Resolutions in the Islamic Republic of Iran*. See also Davenport, "IAEA Investigations of Iran's Nuclear Activities."

822 *Implementation of the NPT Safeguards Agreement and Relevant Provisions of Security Council Resolutions in the Islamic Republic of Iran*.

823 *Communication Dated 12 September 2005 from the Permanent Mission of the Islamic Republic of Iran to the Agency*, IAEA Report INFCIRC/657, Sept. 15, 2005, http://www.iaea.org/Publications/Documents/Infcircs/2005/infcirc657.pdf.

uranium and plutonium, reportedly with the primary objective of producing fissile material for nuclear weapons. Iran subsequently agreed to abandon its heavy water plutonium production efforts, limit its uranium enrichment activities, and subject its enrichment facilities to an inspection and verification regime by the IAEA in return for relief from sanctions, in accordance with the provisions of the JCPOA. Following the US withdrawal from the JCPOA, Iran began to renege on its commitments to the treaty. As noted above, by November 2022, Iran was using advanced centrifuges (prohibited under the agreement) to produce HEU enriched to 60 percent U-235 in sufficient quantities to reportedly yield three or four nuclear weapons in a month if the political decision to do so was made.[824] The IAEA has also verified that Iran is conducting uranium metal R&D, including producing laboratory-scale quantities of uranium metal enriched up to 20 percent U-235.[825]

Iran's entirely covert second R&D track focused on nuclear warhead design. This effort was led by the Iranian military and coalesced into the AMAD Project in the late 1990s. The effort was shelved following international scrutiny in 2003, although the SPND, which is affiliated with the MODAFL, continued to conduct sporadic research on aspects of warhead design until at least 2009.

The third R&D track focused on nuclear delivery systems, specifically how a nuclear warhead could be integrated with a Shahab-3 MRBM. This effort was also pursued by the military under the auspices of the AMAD Project and subsequently abandoned in 2003. However, the MODAFL continues to conduct R&D in support of the country's extensive conventionally armed ballistic and cruise missile programs in contravention of UNSCR 2231.

Iran has gone to great lengths to obscure the overall organization and components of its weapons program. This paper draws on open-source reporting and analysis using Iranian government websites and media reporting, declassified intelligence, reports from the IAEA, satellite imagery analysis, and other sources.

Fissile material production

Research on nuclear fuel enrichment is primarily the responsibility of the AEOI's subsidiary research arm, the Nuclear Science and Technology Research Institute (NSTRI), although other government, military, and academic organizations have contributed to Iran's knowledge base in this area. According to NSTRI's website, one of the organization's general objectives is the "development of scientific and technological researches [sic] in power plants and nuclear fuel

[824] Kelsey Davenport, "Iran in 2022: Cusp of Nuclear Threshold," The Iran Primer, United Institute of Peace, Dec. 21, 2022, https://iranprimer.usip.org/blog/2022/dec/21/iran-2022-cusp-nuclear-threshold.

[825] Director of National Intelligence, *2022 Annual Threat Assessment of the US Intelligence Community*, p. 15.

cycle."[826] Other entities that have been involved in fissile material production research include AEOI subsidiaries the Institute for Studies in Theoretical Physics and Mathematics (IPM), the Fuel Fabrication Laboratory, and the Tehran Nuclear Research Centre (TNRC) and its associated Jaber Ibn Hayan Research Department (JIHRD); several Iranian universities, including Iran University of Science and Technology, K. N. Toosi University of Technology, Shahid Beheshti University, and Amirkabir University of Technology; and the SPND, which is affiliated with the MODAFL and which has been associated with "possible military dimensions to Iran's nuclear program" according to the IAEA.[827]

To date, most of Iran's enrichment efforts, and presumably the country's research into enrichment methods and technology, have focused on uranium enrichment using cascades of gas-powered centrifuges, an approach that the AEOI appears to have mastered.[828] Industrial-scale enrichment occurs at one of three AEOI enrichment facilities: an aboveground PFEP at Natanz; an underground FEP, also at Natanz; and the underground FFEP.[829] The FFEP, which was previously operated by the IRGC, has been repurposed as a research center, although 1,044 centrifuges remain installed in one of its wings and it continues to enrich UF6 in its centrifuge cascades.[830]

Iran also established a pilot program to conduct research on laser enrichment and conducted experiments on undeclared natural uranium using the atomic vapor laser isotope separation (AVLIS) method at Lashkar Ab'ad between 2002 and 2003. Laser enrichment, as one source notes, has the potential to dramatically increase the capabilities of a given state to enrich uranium, although to date no state has successfully enriched uranium in sufficient amounts

[826] "History of Establishment of the Nuclear Science and Technology Research Institute," AEOI, https://aeoi.org.ir/en/portal/home/?47916/%D8%B5%D9%81%D8%AD%D9%87-nuclear-science-and-technology-research.

[827] "Organization for Defensive Innovation and Research," Iran Watch, https://www.iranwatch.org/iranian-entities/organization-defensive-innovation-and-research. For a complete list of organizations and entities affiliated with Iran's nuclear program, see "Iran: Facilities," Nuclear Threat Initiative, https://www.nti.org/education-center/facilities/; and "Iranian Entities," Iran Watch, https://www.iranwatch.org/iranian-entities/.

[828] *Verification and Monitoring in the Islamic Republic of Iran in Light of United Nations Security Council Resolution 2231 (2015).*

[829] Albright, Burkhard, and Faragasso, *A Comprehensive Survey of Iran's Advanced Centrifuges*, p. 8.

[830] "Fordow Fuel Enrichment Plant." According to the IAEA, "Iran has estimated that from 21 August 2022 to 21 October 2022: 590.7 kg of UF_6 enriched up to 5% U-235 were fed into cascades at FFEP; 4480.7 kg of UF_6 enriched up to 20% U-235 were produced;45 and 513.8 kg of UF_6 enriched up to 2% U-235 were accumulated as tails." See *Verification and Monitoring in the Islamic Republic of Iran in Light of United Nations Security Council Resolution 2231 (2015).*

using this method.[831] After initially denying that it was conducting laser enrichment experiments, the Iranian government admitted that it had, in fact, conducted experiments at the site. IAEA inspectors determined that the facility at Lashkar Ab'ad was able to produce small quantities of HEU but that the site had never become fully operational. Iran dismantled the laser enrichment facility in 2003 and stored its equipment at the Karaj Agricultural and Medical Center.[832]

As mentioned above, the AEOI had previously conducted research on plutonium enrichment and had constructed the HWPP and experimental IR-40 reactor at Arak for this purpose (see Figure 55), reportedly with foreign assistance.[833] The HWPP began operations in 2004 but ceased operating when Iran agreed to stop work on the IR-40 reactor in accordance with the terms of the interim JPOA in 2013. By 2016, the reactor had been rendered inoperable following the signing of the JCPOA. As of 2017, the AEOI was working with the CNNC to repurpose the facilities at Arak for power generation with LEU, thereby eliminating the plutonium production line.[834] Per the JCPOA, Iran can continue to produce heavy water, but its production is capped at 130 tons for 15 years. Iran has previously shipped excess amounts of heavy water abroad either for sale or storage.[835]

[831] David Albright and Serena Kelleher-Vergantini, *Lashkar Ab'ad: Iran's Unexplained Laser Enrichment Capabilities*, Institute for Science and International Security, July 29, 2013, https://isis-online.org/uploads/isis-reports/documents/Lashkar_Abad_29July2013.pdf.

[832] "Laskar Ab'ad," NTI, https://www.nti.org/education-center/facilities/lashkar-abad/.

[833] "Arak Nuclear Complex"; "Iran's Heavy-Water Reactor: A Plutonium Bomb Factory," Arms Control Association, Nov. 9, 2006, https://www.armscontrol.org/pressroom/2006-11/iran%E2%80%99s-heavy-water-reactor-plutonium-bomb-factory.

[834] "Arak Nuclear Complex."

[835] "Arak Nuclear Complex."

Uranium enrichment

One way to make a nuclear weapon is to use uranium as fissile material or "nuclear fuel." Uranium is a naturally occurring element. Uranium ore is mined from the earth. For most reactor designs and any weapons use, this ore must be enriched so that the end product contains a higher concentration of the fissile isotope of uranium, U-235, than is naturally found. When the ore is mined, less than 1 percent of it is U-235, so it must be separated from the heavier non-fissile U-238 isotope. There are several methods for uranium enrichment, including gaseous diffusion, laser enrichment, and gas centrifuge.[836]

Enrichment levels are usually expressed in percentages in which the number is the percentage of U-235 in a given quantity of uranium.

Mined uranium ore contains only 0.7 percent U-235.

Fuel-grade uranium used to power nuclear reactors requires U-235 enriched to 3 to 5 percent.

Medical and **industrial-grade** uranium used for medical purposes or research often requires U-235 enriched to around 20 percent.

Weapons-grade uranium requires U-235 enriched to at least 90 percent.

This way of expressing progress in the process of transforming natural uranium to weapons-grade or reactor-usable uranium is useful but does not capture an important detail: as the feed stock becomes more enriched (i.e., contains a higher percentage of U-235), the amount of time and energy (measured in separative work units, or SWUs) required to continue enrichment dramatically decreases. Once natural uranium has been enriched to 20 percent, most of the work required to transform it into higher enriched weapons-usable uranium has already been done. Therefore, Iran's decision to enrich uranium above the 20 percent level has triggered proliferation concerns. Uranium enriched to 20 percent *seems* a long way from 90-plus percent weapons-usable uranium, but in terms of the time and effort required to span the 20 percent to 90 percent gap, it is quite close. For this reason, **20 percent or more U-235 is considered highly enriched uranium (HEU).**

The other way to make nuclear weapons is to synthetically derive plutonium through uranium reprocessing.

Figure 55. Arak heavy water reactor

Source: "Arak IR-40 Heavy Water Reactor, Iran," Wikimedia Commons, Oct. 14, 2012, https://commons.wikimedia.org/wiki/File:Arak_Heavy_Water4.JPG.

Since the passage of UNSCR 2231, the UN resolution that endorsed the JCPOA, the IAEA has issued regular reports certifying Iran's compliance with the agreement's provisions.[837] The IAEA's reports verified that Iran has not reconstructed the IR-40 reactor (now renamed the Khondab Heavy Water Research Reactor (KHRR)) based on its original design. The agency also verified that Iran has not produced or tested natural uranium pellets, fuel pins, or fuel assemblies specifically designed for the IR-40 reactor.[838] However, beginning on February 23, 2021, Iran ceased providing information to the IAEA about the AEOI's inventory of heavy water

[836] "Uranium Enrichment," US Nuclear Regulatory Commission, https://www.nrc.gov/materials/fuel-cycle-fac/ur-enrichment.html; Office of the Deputy Assistant Secretary of Defense for Nuclear Matters, *Nuclear Matters Handbook 2020 [Revised]*.

[837] "Arak Nuclear Complex."

[838] *Verification and Monitoring in the Islamic Republic of Iran in Light of United Nations Security Council Resolution 2231 (2015)*.

and the production of heavy water at the KHRR. No IAEA monitoring has taken place at the KHRR since June 11, 2022, when agency monitoring equipment at the site was removed.[839]

Since 1967, the AEOI has also maintained a small light water research reactor, which the US supplied, at the TNRC. The Tehran Research Reactor (TRR) is designed to produce medical isotopes. According to a report by the Nuclear Threat Initiative, the TRR can produce up to 600 grams of plutonium annually.[840] According to a November 10, 2022, IAEA verification and monitoring report:

> Iran has not carried out activities related to reprocessing at the Tehran Research Reactor (TRR), the Jaber Ibn Hayan Multipurpose Laboratory (JHL) and the Molybdenum, Iodine and Xenon Radioisotope Production (MIX) facility or at any of the other facilities it has declared to the Agency.[841]

The AEOI also operates a commercial nuclear reactor, the country's first, at the Bushehr Nuclear Power Plant (BNPP) (see Figure 56). The reactor, which was initially designed by a German company (KraftWerk) and later completed with Russian assistance, became operational in 2012. BNPP is a VVER light water reactor and not especially well suited for covert plutonium enrichment activities.

Scientists affiliated with the AEOI and with Iranian civilian universities have been fairly open about their research involving uranium enrichment. However, the links between the organizations and institutions involved in the more overt aspects of fuel enrichment and those organizations that in the past were reportedly involved in the more covert aspects (i.e., fissile material research and production), such as the SPND, remain opaque. Nevertheless, through mastering the nuclear fuel cycle, Iranian scientists have gained valuable experience that could be applied to fissile material production, particularly as uranium enrichment exceeds levels suitable for civilian purposes.

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839 *Verification and Monitoring in the Islamic Republic of Iran in Light of United Nations Security Council Resolution 2231 (2015)*.

840 "Tehran Research Reactor (TRR)," NTI, https://www.nti.org/education-center/facilities/tehran-research-reactor-trr/.

841 *Verification and Monitoring in the Islamic Republic of Iran in Light of United Nations Security Council Resolution 2231 (2015)*.

Past, present, and future of uranium enrichment

There are a variety of ways uranium can be enriched for use in nuclear reactors, for producing medical isotopes, and for use in nuclear weapons. The most notable are mentioned below. All these methods utilize the difference in mass to separate the desired lighter U-235 isotope from the more abundant and heavier U-238 isotope.

Early methods – In the Manhattan Project, the US used **electromagnetic isotope separation technology**, which was later abandoned because of high costs and energy input requirement.[842] In this method, large magnets were used to push the individual uranium ions into two groups according to their mass.[843] In the Cold War, **gaseous diffusion** was the common method, in which cascades of porous membranes containing holes just large enough for UF6 molecules to pass through were used to separate isotopes. The lighter U-235 molecules passed through the barriers more quickly and could be separated from the heavier U-238 molecules. This method required large energy input and large facilities and has since been abandoned.[844]

Gas centrifuge – This is the most common and efficient method for enriching uranium worldwide.[845] In this process, UF6 gas is placed inside a cylindrical centrifuge and spun at a quick enough rate that the centrifugal forces separate the heavier U-238 from the lighter U-235, with U-238 moving to the outside of the cylinder and U-235 moving to the inside. The slightly lighter gas is collected from the inside and moved to a new centrifuge where it is enriched further. The gas continues to be cascaded down a line of numerous centrifuges until it reaches the desired level at the withdrawal point.[846]

Laser separation – Research to enrich uranium via laser separation is underway, although the capability is not known to be utilized on a meaningful scale by any country. Advocates promise that the method will enrich uranium "at less cost, using less energy, and with a smaller physical footprint" than any other method.[847] Each of these attributes would be beneficial for nuclear energy production while potentially posing nuclear nonproliferation concerns. In this method, light from the laser would photo-ionize or excite one specific isotope of uranium, which would allow it to be separated from other isotopes.[848]

[842] "Module 2: Uranium Enrichment," Nuclear Threat Initiative, accessed Mar. 2, 2023, https://tutorials.nti.org/nuclear-101/uranium-enrichment/.

Figure 56. Bushehr Nuclear Power Plant

Source: Wikimedia Commons via Mehr News Agency, Oct. 6, 2021.

Nuclear weapons design

There is no evidence that Iran is currently conducting research on nuclear weapons design or pursuing the necessary steps to produce a nuclear device. However, Iran conducted a range of activities relevant to the development of an implosion-style nuclear explosive device before the end of 2003 as a coordinated effort first by the MODAFL's PHRC and later under the

843 "Electromagnetic Separation," The Manhattan Project: An Interactive History, Department of Energy, accessed Mar. 2, 2023, https://www.osti.gov/opennet/manhattan-project-history/Processes/UraniumSeparation/electromagnetic.html.

844 "Uranium Enrichment."

845 "Module 2: Uranium Enrichment."

846 "Uranium Enrichment."

847 "Analyzing Emerging Laser Enrichment Technologies for Early Signs of Proliferation Risk," Laboratory for Nuclear Security and Policy, MIT, accessed Mar. 2, 2023, http://lnsp.mit.edu/the-new-enrichment-technologies.

848 "Uranium Enrichment."

auspices of the MODAFL's AMAD Project, led by Mohsen Fakhrizadeh.[849] As noted above, AMAD's activities were brought to a halt in 2003 when news of the program's covert activities was leaked to the public. However, certain covert nuclear weapons–related R&D activities resumed under a new MODAFL entity, the SPND, also led by Mohsen Fakhrizadeh.

Before 2009, the MODAFL's nuclear weapons–related activities included the following:[850]

- Computer modeling of the implosion, compression, and yield of nuclear warheads.
- High-explosive tests simulating a nuclear explosion using nonnuclear material to see whether an implosion device would work.
- Construction of an explosives firing chamber at the Parchin Military Complex designed to conduct hydrodynamic testing.
- Studies on the detonation of high-explosive charges to ensure uniform compression in an implosion device, including at least one large-scale experiment in 2003 and experimental research after 2003.
- Development of a detonation system suitable for nuclear weapons and a diagnostic system needed to monitor the detonation experiments.
- Manufacture of a neutron initiator, which is placed in the core of an implosion device and, when compressed, generates neutrons to start a nuclear chain reaction, along with validation studies on the initiator design from 2006 onward.
- Development of exploding bridgewire detonators (EBWs) used in simultaneous detonation, which are needed to initiate an implosive shock wave in fission weapons.
- Development of high-voltage firing equipment that would enable detonation in the air above a target in a fashion that makes sense only for a nuclear payload.
- Testing of high-voltage firing equipment to ensure that it could fire EBWs over the long distance needed for nuclear weapon testing, when a device might be located down a deep shaft.
- Research into the integration of a new spherical payload onto the Shahab-3 missile, enabling the missile to accommodate the detonation package described above.
- Experiments with protective shielding in preparation for the use of neutron detectors.[851]

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[849] *Verification and Monitoring in the Islamic Republic of Iran in Light of United Nations Security Council Resolution 2231 (2015)*.

[850] The following list is derived from "Iran's Nuclear Timetable: The Weapon Potential," which summarizes the conclusions of the IAEA's 2015 report.

[851] "Arms Control and Proliferation Profile: Iran."

The IAEA has concluded that there are "no credible indications" of activities relevant to weaponization after 2009 nor any diversion of nuclear materials for military purposes. However, a report by the Institute for Science and International Security concluded that Iran has accumulated enough information and experience to be able to design and produce a workable implosion nuclear device consisting of a relatively compact high explosives initiation system, a shock wave generator, and a specialized neutron initiator.[852]

Nuclear weapons delivery systems

Iran currently does not have any viable nuclear weapons delivery systems in its arsenal. However, as noted above, before 2003, Iranian scientists and engineers affiliated with Project 111, a component of the AMAD Project, produced components and mock-up parts for engineering a reentry vehicle for a nuclear warhead on a Shahab-3 MRBM. According to the IAEA, Project 111's research examined how to "integrate a new spherical payload into the existing payload chamber of the re-entry vehicle for the Shahab 3 missile so that such a payload would survive the severe launch and re-entry environments and remain functional until it reached its target."[853]

The IRGCASF has also developed several conventionally armed ballistic and cruise missile systems that, as noted above, could be adapted for the delivery of nuclear payloads. Iran has not tested or deployed a missile capable of striking the United States, but Iran's work on SLVs—such as the Simorgh—could shorten the timeline required to develop an ICBM if Iran's leadership decided to develop one because SLVs and ICBMs use similar technologies.[854] The IAEA has also determined that before 2004, scientists affiliated with Iran's military conducted research on the design and integration of nuclear warheads with ballistic missile systems that are currently in Iran's inventory.[855]

The Aerospace Industries Organization (AIO), which is subordinate to the MODAFL, oversees Iranian aerospace-related R&D. Ballistic missile R&D is managed by two AIO subsidiaries:

[852] David Albright and Sarah Burkhard, *Highlights of Iran's Perilous Pursuit of Nuclear Weapons*, Institute for Science and International Security, Aug. 25, 2021, https://isis-online.org/uploads/isis-reports/documents/Highlights_of_Irans_Perilous_Pursuit_of_Nuclear_Weapons_August_25%2C_2021.pdf.

[853] *Final Assessment on Past and Present Outstanding Issues regarding Iran's Nuclear Programme*.

[854] Director of National Intelligence, *2022 Annual Threat Assessment of the US Intelligence Community*, p. 15.

[855] *Implementation of the NPT Safeguards Agreement and Relevant Provisions of Security Council Resolutions in the Islamic Republic of Iran*.

- SHIG: SHIG focuses on liquid-fuel missiles and according to a report by the Wisconsin Project, it "reportedly imported fuel and materials for the construction of medium-range missiles; reportedly contracted with Russia's Central Aerohydrodynamic Institute (TsAGI) in 1996 for the construction of a wind tunnel for missile design, the manufacture of model missiles, and the development of related computer software; reportedly negotiated with Russia's Inor to procure materials used in building missiles, including high-technology laser equipment, special mirrors, maraging steel, and tungsten-coated graphite material."[856]
- SBIG: SBIG is responsible for the development and production of Iran's solid-propellant ballistic missiles. According to the Wisconsin Project, SBIG "produces the 200-kilometer range Fateh-110 missile and the 40-100 kilometer range Fajr rocket system (a North Korean-designed rocket produced under license); reportedly developed the Sejjil-2 solid-propellant two-stage ballistic missile under the supervision of Sanam Industrial Group (Department 140), which is a subsidiary of the Defense Industries Organization (DIO)."[857]

Figure 57. Simorgh launcher (carrying satellite payload)

Source: Wikimedia Commons via Tasnim News Agency.

SHIG and SBIG have worked in tandem, sometimes sharing technology, to develop Iran's principal "families" of ballistic missiles based on the Shahab (mostly liquid-fuel) and Fateh (mostly solid-fuel) missiles.[858] Both organizations have been sanctioned by the US and the UN.

[856] "Shahid Hemat Industrial Group (SHIG)," Wisconsin Project on Nuclear Arms Control, May 1, 2014, https://www.wisconsinproject.org/shahid-hemat-industrial-group-shig/.

[857] "Shahid Bagheri Industrial Group (SBIG)," Iran Watch, https://www.iranwatch.org/iranian-entities/shahid-bagheri-industrial-group-sbig.

[858] *Open-Source Analysis of Iran's Missile and UAV Capabilities and Proliferation*, IISS Research Papers, Apr. 20, 2021, p. 8.

The MODAFL has also established a cruise missile R&D program under the auspices of the AIO's Samen Al A'emmeh Industrial Group (SAIG). SAIG initially focused on anti-ship cruise missile development [859] but has recently overseen development and production of LACMs. Most of the LACMs produced by SAIG are based on the Soviet Kh-55, several of which the Iranians managed to acquire from Ukrainian black market suppliers in 2001, as noted above.[860]

Figure 58. Hoveyzeh cruise missile at defense exhibition in Tehran

Source: Wikimedia Commons via Fars News.

[859] *Cruise Missiles in the Middle East*, IISS, Sept. 2021, p. 4.

[860] Six missiles were also illegally exported to China. See Tom Warner, "Ukraine Admits Exporting Missiles to Iran and China," *Financial Times*, Mar. 18, 2005, https://web.archive.org/web/20080315013151/https://www.ft.com/cms/s/0/abf8cc64-9753-11d9-9f01-00000e2511c8.html.

What sites or facilities does Iran use for nuclear weapons–related R&D?

Iran has used a mix of civilian and military organizations and facilities to conduct nuclear-related R&D. The more overt aspects of Iran's nuclear program, for instance, those related to nuclear fuel enrichment, have been managed by civilian entities, including the AEOI. Iran's covert military program, which does not appear to be currently active, was managed primarily by the military, although organizations such as the AMAD Project and the MODAFL's SPND both received support from civilian institutions, such as universities. R&D on potential delivery systems, including ballistic and cruise missile systems, has primarily been the responsibility of industrial groups affiliated with the MODAFL.

Fissile material production facilities

The organization within the AEOI that is primarily responsible for conducting research on uranium and plutonium enrichment is the NSTRI. The NSTRI is composed of seven separate research institutes:[861]

- Research Institute of Radiation Applications
- Research Institute of Nuclear Fuel Cycle Materials
- Research Institute of Reactors and Nuclear Safety
- Plasma and Nuclear Fusion Research Institute
- Research Institute of Photonics and Quantum Technology
- Research Institute of Physics and Accelerators
- Nuclear Agriculture Research Institute

Presumably, the Nuclear Fuel Cycle Materials and Physics and Accelerators institutes would be responsible for conducting most of the AEOI's research on HEU gas centrifuge enrichment, although this supposition cannot be confirmed based on available open-source materials.

The AEOI manages the Esfahan Nuclear Fuel Research and Production Center (NFRPC), also known as the Esfahan Nuclear Technology Center, which conducts research on uranium mining, conversion, and fuel production. NFRPC, which is located in Reshandasht, southeast of the Iranian city of Esfahan, consists of a Nuclear Engineering Department, a Metallurgical

[861] Atomic Energy Agency of Iran, "Pizhuheshgah-e olum va fanun-e haste'i," https://www.aeoi.org.ir/?57154/%D9%BE%DA%98%D9%88%D9%87%D8%B4%DA%AF%D8%A7%D9%87-%D8%B9%D9%84%D9%88%D9%85-%D9%88-%D9%81%D9%86%D9%88%D9%86-%D9%87%D8%B3%D8%AA%D9%87-%D8%A7%DB%8C.

Engineering and Fuel Department, a Chemistry Department, and a Miniature Neutron Source Reactor Department.[862] It also operates four small nuclear research reactors, all supplied by China: the Miniature Neutron Source Reactor, the Light Water Sub-Critical Reactor, the Heavy Water Zero Power Reactor, and the Graphite Sub-Critical Reactor. NFRPC also operates the Uranium Chemistry Laboratory, Zirconium Production Plant, and the Uranium Conversion Facility (UCF).

The UCF is a large-scale conversion facility that produces uranium compounds for fuel cycle activities. The UCF processes uranium ore concentrate into UF6, low enriched UF6 into uranium dioxide (UO2), depleted UF6 into uranium tetrafluoride (UF4), low enriched UF6 into low enriched uranium metal, and depleted UF4 into depleted uranium metal.[863] According to the Nuclear Threat Initiative, a November 2011 explosion at NFRPC may have damaged some part of the UCF.[864]

The AEOI also manages two additional organizations that conduct research with potential fissile material production implications:

- IPM: Established by the AEOI in 1989, IPM is an AEOI training facility for nuclear scientists. IPM also conducts research in theoretical and applied particle and high energy physics.[865]
- TNRC: TNRC consists of 11 departments that conduct research on most aspects of the nuclear fuel cycle, including nuclear physics, isotope production, reactor research, analytical chemistry, nuclear electronics, and fusion.[866] TNRC houses the JIHRD, which maintains a lab that conducts research on a wide variety of topics for the AEOI's Nuclear Fuel Production Center. TNRC also houses the TRR, a small-scale 5 megawatt-thermal pool-type light water research reactor.[867]

[862] "Isfahan (Esfahan) Nuclear Fuel Research and Production Center (NFRPC)," NTI, https://www.nti.org/education-center/facilities/isfahan-esfahan-nuclear-fuel-research-and-production-center-nfrpc/.

[863] "Uranium Conversion Facility (UCF)," Iran Watch, https://www.iranwatch.org/iranian-entities/uranium-conversion-facility-ucf.

[864] "Uranium Conversion Facility (UCF)," NTI, https://www.nti.org/education-center/facilities/uranium-conversion-facility-ucf/.

[865] "Institute for Studies in Theoretical Physics and Mathematics (IPM)," NTI, https://www.nti.org/education-center/facilities/institute-for-studies-in-theoretical-physics-and-mathematics-ipm/.

[866] "Tehran Nuclear Research Center (TNRC)," NTI, https://www.nti.org/education-center/facilities/tehran-nuclear-research-center-tnrc/.

[867] "Tehran Research Reactor (TRR)," NTI, https://www.nti.org/education-center/facilities/tehran-research-reactor-trr/.

In addition, several Iranian universities have conducted enrichment-related research on behalf of the AEOI and NSTRI, including the following:

- Amirkabir University of Technology (AKUT): An Iranian higher education technical and engineering institute, AKUT has conducted research relevant to uranium enrichment, the development of a nuclear implosion device, and missile guidance systems. According to the Wisconsin Project on Nuclear Arms Control, AKUT has conducted centrifuge rotor tests; studies on neutron generation and transport, an area of research important to the development of a nuclear implosion device; and research on molecular laser isotope separation versus AVLIS for uranium enrichment.[868]
- Shahid Beheshti University: Shahid Beheshti University has conducted research on the optimal parameters for a cascade of gas centrifuges.[869]
- Iran University of Science and Technology (IUST): IUST faculty members have conducted research for NSTRI on techniques for combining liquids using continuous mixers. IUST Professor Kamran Daneshjou previously served as a project head in the AMAD Project.[870]
- K. N. Toosi University of Technology: The university has conducted research on behalf of NSTRI on activities related to nuclear power generation, including how to effectively use neutron detectors to monitor power in the TRR.[871]

Most of the AEOI's industrial-scale uranium enrichment takes place at three facilities: the PFEP, a test and pilot uranium enrichment facility located at the Natanz Enrichment Complex; the underground commercial FEP, co-located with the PFEP; and the underground FFEP, which was previously operated by the IRGC. Both the PFEP and the FFEP reportedly contribute to the AEOI's enrichment R&D mission, although the precise nature of their contributions is unclear.[872]

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[868] "Amirkabir University of Technology," Iran Watch, https://www.iranwatch.org/iranian-entities/amirkabir-university-technology.

[869] "Shahid Beheshti University," Iran Watch, https://www.iranwatch.org/iranian-entities/shahid-beheshti-university.

[870] "Iran University of Science and Technology," Iran Watch, https://www.iranwatch.org/iranian-entities/iran-university-science-and-technology.

[871] "K. N. Toosi University of Technology," Iran Watch, https://www.iranwatch.org/iranian-entities/k-n-toosi-university-technology.

[872] The PFEP is a designated R&D facility in addition to functioning as a pilot program for uranium enrichment. The FFEP has been repurposed as a research center in accordance with the provisions of the JCPOA, although Iran began to enrich uranium to 60 percent purity at the FFEP as of November 2022, in contravention of the JCPOA. See Parisa Hafezi and Francois Murphy, "Iran Starts Enriching Uranium to 60% Purity at Fordow Plant," Reuters, Nov.

SPND is responsible for developing advanced technology for Iran's armed forces and is associated with the military dimensions of Iran's nuclear program.[873] Although there is no indication that Iran has restarted its nuclear weapons program, SPND has worked previously with various MODAFL production companies—such as the Abzar Boresh Kaveh Company and the Shahid Baba'i Group—to acquire or develop enrichment capabilities.[874]

As noted above, in recent years, the IAEA has discovered undeclared nuclear materials and activities at four additional sites in Iran: Marivan, Varamin, and Lavisan-Shian, which are linked to facilities and activities of the AMAD Project, and Turquz-Abad, which is associated with current storage of AMAD Project equipment and material.[875]

Nuclear weapons design facilities

Before 2009, the SPND and its predecessors (AMAD Project, etc.) conducted a range of activities relevant to the development of a nuclear explosive device. Central to this effort was the Parchin Military Complex, where the Iranian military reportedly conducted secret experiments involving "high-explosive shaped charges with an inert core of depleted uranium" to test the characteristics of an implosion-type nuclear weapon.[876] Iranian activities at the site were revealed in 2004. The following year, IAEA inspectors were granted access to Parchin, and the agency subsequently reported that inspectors "did not observe any unusual activities in the buildings visited."[877] In spring 2013, Iran began paving over portions of the site, leading to allegations that it was sanitizing the location before additional inspections.[878]

Another location that played an important role in nuclear weapons R&D was the Lavizan-Shian Technological Research Center located in Lavizan-Shian, a Tehran suburb. The Lavizan-Shian Technological Research Center houses the Institute of Applied Physics, which is reportedly affiliated with the IUST in Tehran and which previously conducted research into the military applications of Iran's nuclear program, including alleged research on the conversion of UO2

22, 2022, https://www.reuters.com/world/middle-east/iran-enrich-uranium-60-purity-fordow-nuclear-site-tv-2022-11-22/.

873 "Additional Sanctions Imposed by the Department of State Targeting Iranian Proliferators," State Department Media Note, Aug. 29, 2014, https://2009-2017.state.gov/r/pa/prs/ps/2014/231159.htm.

874 "Shahid Baba'i Group," Iran Watch, https://www.iranwatch.org/iranian-entities/shahid-babai-group; "Abzar Boresh Kaveh Co.," Iran Watch, https://www.iranwatch.org/iranian-entities/abzar-boresh-kaveh-co.

875 David Albright, *Iran Building Nuclear Weapons*, Institute for Science and International Security, Dec. 2022, https://isis-online.org/uploads/isis-reports/documents/Iran_Building_Nuclear_Weapons_December_2022.pdf.

876 "Parchin Military Complex (Nuclear)," NTI, https://www.nti.org/education-center/facilities/parchin-military-complex/.

877 "Parchin Military Complex (Nuclear)."

878 "Parchin Military Complex (Nuclear)."

into UF4 (the green salt project), high explosives testing, and the design of a missile reentry vehicle for nuclear-armed warheads.[879]

Malek Ashtar University (MUT), which is affiliated with the Iranian Air Force, has also previously conducted research related to the development of nuclear weapon delivery systems. MUT manages the Research Center for Explosion and Impact, which has carried out studies on shaped (hollow) charges that have applications in the development of nuclear explosives.[880] MUT is also affiliated with the MODAFL's Section for Advanced Development Applications and Technologies, which briefly oversaw aspects of Iran's covert nuclear program after the AMAD Project but before the SPND.[881]

Other Iranian universities that have been linked to Iran's nuclear weapons design efforts in the past include Imam Hussein University, the IRGC's flagship educational institution; AKUT; Shahid Beheshti University; and Sharif University of Technology.[882] Sharif University previously managed the PHRC, which was based at Lavisan-Shian and involved in the acquisition of dual-use materials and equipment that could be used in uranium enrichment and conversion activities.[883]

Nuclear weapons delivery system facilities

As noted, Iran previously conducted research on the integration of nuclear payloads onto MRBMs in the IRGCASF's arsenal. These research efforts were managed by the AMAD Project.[884] The MODAFL has also developed a robust arsenal of conventionally armed ballistic and cruise missiles, some of which could be adapted for nuclear use with additional research and testing.

The AIO, which is subordinate to the MODAFL, oversees Iranian aerospace-related R&D. Ballistic missile R&D is managed by two AIO subsidiaries: SHIG and SBIG, which are responsible for liquid- and solid-fuel missile R&D, respectively. Cruise missile R&D is overseen by the AIO's SAIG. All three AIO groups are headquartered in Tehran. Testing and evaluation of

[879] "Institute of Applied Physics," Iran Watch, https://www.iranwatch.org/iranian-entities/institute-applied-physics.

[880] "Research Center for Explosion and Impact," Iran Watch, https://www.iranwatch.org/iranian-entities/research-center-explosion-and-impact.

[881] *Implementation of the NPT Safeguards Agreement and Relevant Provisions of Security Council Resolutions in the Islamic Republic of Iran*.

[882] See "Iran's Nuclear Program," Iran Watch, https://www.iranwatch.org/weapon-programs/nuclear.

[883] "Sharif University of Technology," Iran Watch, https://www.iranwatch.org/iranian-entities/sharif-university-technology.

[884] *Final Assessment on Past and Present Outstanding Issues Regarding Iran's Nuclear Programme*.

missile systems often occurs at the Semnan Missile Complex, which includes a test range and missile production facility.[885] Iran also routinely conducts live-fire missile tests over international waters in the northern Indian Ocean.[886]

Since April 2021, the AEOI has been enriching UF6 up to 60 percent U-235 at quantities beyond those of viable commercial use. The IAEA has also verified that Iran is conducting uranium metal R&D, including producing laboratory-scale quantities of uranium metal enriched up to 20 percent U-235.[887]

How knowledgeable, educated, and skilled are the scientific and technical personnel who make up Iran's nuclear weapons program?

In this section, we attempt to evaluate the quality of Iranian scientific and technical personnel working in nuclear-relevant fields, such as nuclear physics and engineering. To do so, we utilized data provided by various US and international organizations that use quantifiable metrics to assess academic performance and output by institutions and individual scientists. Included in our assessment are data provided by the United Nations Educational, Scientific and Cultural Organization; the QS World University Rankings; Scimago Journal Rank; the Times Higher Education World University Rankings; and EduRank. We also incorporated data from studies or reports that focused specifically on the state of science, technology, engineering, and mathematics (STEM) research in Iran.

The opacity of Iran's nuclear and high-tech sectors renders it very difficult to evaluate the quality of Iranian academic programs in these areas. Nevertheless, the data that we analyzed present a mixed picture regarding Iranian scientific and technical personnel who work in nuclear-related fields. On the one hand, there is a relatively large number of Iranian universities with relevant programs (36 with physics and astronomy departments, according to the Times Higher Education Rankings).[888] On the other hand, no Iranian university was

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[885] "Semnan Missile Complex," NTI Facilities, https://www.nti.org/education-center/facilities/semnan-missile-complex/.

[886] "Iran Test-Fires Ballistic Missiles on Targets at Sea," France 24, Jan. 16, 2021, https://www.france24.com/en/live-news/20210116-iran-test-fires-ballistic-missiles-on-targets-at-sea.

[887] Director of National Intelligence, *2022 Annual Threat Assessment of the US Intelligence Community*, p. 15.

[888] "World University Rankings 2023 by Subject: Physical Sciences: Iran," Times Higher Education Rankings, accessed Apr. 3, 2023, https://www.timeshighereducation.com/world-university-rankings/2023/subject-ranking/physical-sciences#!/page/0/length/25/locations/IRN/subjects/3060/sort_by/rank/sort_order/asc/cols/stats.

ranked in the top 10 percent of institutions worldwide in relevant fields in either of the two databases that we used. With one notable exception, most were ranked in the middle or below. However, low rankings for Iranian universities are somewhat mitigated by the large number of Iranian students who study abroad in STEM-related fields, including nuclear physics, which expands the pool of available applicants from which institutions such as the AEOI can draw. Therefore, the quality of education in Iran is more likely to be a limiting factor in the country's nuclear development than the quantity of Iranian scientists, technicians, or engineers working in nuclear-related fields.

Figure 59. Sharif University of Technology

Source: Masoud K, Wikimedia Commons, Apr. 12, 2014, https://commons.wikimedia.org/wiki/File:Sharif_University_of_Technology.jpg.

At the same time, Iran is also hemorrhaging qualified scientific and technical personnel to other countries, particularly those in the West, because of poor economic conditions and political instability in the country. Despite these impediments, Iran ranks highly in terms of cited academic output in the nuclear sciences. Iranian scholars working in nuclear-relevant fields are regularly cited in academic journals. In 2021, Iran ranked 22 out of 124 countries in terms of author citations according to a survey by Scimago.[889]

University rankings in nuclear-relevant fields

We compared the quality of the nuclear technology–relevant academic departments at each country's top universities. To make these comparisons, we used two global university ranking databases: QS World University Rankings and the Times Higher Education World University Rankings.[890] Each database divides its categorizations of academic departments and disciplines differently and uses a somewhat different methodology. Neither is a perfect measure of quality. For example, both weight reputation—assessed via survey—heavily. The university department rankings that they provide are therefore driven by perceptions of quality as assessed by a cross section of academics in the field in question. In addition, both databases also use data on publications, meaning that the university department rankings presented here are not independent of the publication-based comparisons depicted in a subsequent section. As a result of these shortcomings, these department rankings should be treated as imperfect measures of quality that nevertheless provide some insight into how the nuclear-relevant training available in Iran compares with that in other countries.

Table 20 represents the 2023 rankings of the top five Iranian universities' physics and astronomy departments (ranked among 621 global schools) and engineering and technology departments (ranked among 533 global schools) according to QS World University Rankings and the Times Higher Education World University Rankings. The Times Higher Education World University Rankings database rates Iranian universities with physics and astronomy departments among 1,307 global schools but does not list rankings for engineering and technology departments.

[889] "Nuclear and High Energy Physics: 2021," Scimago Journal & Country Rank, accessed Apr. 3, 2023, https://www.scimagojr.com/countryrank.php?category=3106&area=3100&year=2021.

[890] "QS World University Rankings by Subject 2023: Physics & Astronomy: Iran," QS World University Rankings, accessed Apr. 3, 2023, https://www.topuniversities.com/university-rankings/university-subject-rankings/2023/physics-astronomy?&countries=ir.; "World University Rankings 2023 by Subject: Physical Sciences: Iran."

Table 20. Top Iranian universities' physics and astronomy and engineering and technology department rankings, 2023

Iranian University	Subject	Ranking Globally	Global Top Percent of Schools
Tehran University	Physics and astronomy	451-500[a] 601-800[b]	73-81%[a] 46-61%[b]
	Engineering and technology	274[a]	51%[a]
Sharif University of Technology	Physics and astronomy	451-500[a] 601-800[b]	73-81%[a] 46-61%[b]
	Engineering and technology	244[a]	46%[a]
Amirkabir University of Technology	Physics and astronomy	401-500[a] 601-800[b]	73-81%[a] 46-61%[b]
	Engineering and technology	366[a]	69%[a]
Iran University of Science and Technology	Physics and astronomy	401-500[b]	31-38%[b]
	Engineering and technology	451-500[a]	85-94%[a]
Babol Noshirvani University of Technology	Physics and astronomy	251-300[b]	19-23%[b]

Sources: [a] "QS World University Rankings by Subject 2023: Physics & Astronomy: Iran"; [b] "World University Rankings 2023 by Subject: Physical Sciences: Iran."

According to QS World University Rankings and the Times Higher Education World University Rankings, no Iranian universities placed in the top 10 percent of global academic institutions in the fields of physics, astronomy, engineering, and technology.[891] The survey by the Times ranked Babol Noshirvani University of Technology in the 19th to 23rd percentile for universities with physics and astronomy departments, but otherwise most leading Iranian universities were rated in the middle or the bottom of the scale in both databases compared to

[891] "QS World University Rankings by Subject 2023: Physics & Astronomy: Iran"; "World University Rankings 2023 by Subject: Physical Sciences: Iran."

their international counterparts.[892] These rankings place Iran in a position roughly comparable to other regional countries but well behind the United States and China.

Although Iranian universities with programs in nuclear-related fields were rated similarly overall in both databases, they were ranked differently individually across the two databases. The Times Higher Education World University Rankings database lists the following top five Iranian universities in the fields of physics and astronomy (in order of precedence): Babol Noshirvani University of Technology, University of Kurdistan, Yasouj University, Amirkabir University of Technology, and University of Kashan.[893] By contrast, the QS World University Rankings database ranks only two Iranian universities in the field of physics and astronomy: Sharif University of Technology and the University of Tehran.[894]

Figure 60. Babol Noshirvani University of Technology

Source: Wikimedia Commons, May 22, 2018, https://commons.wikimedia.org/wiki/File:Babol_Noshirvani_University_of_Technology-Main_Building.jpg.

892 "World University Rankings 2023 by Subject: Physical Sciences: Iran."

893 "World University Rankings 2023 by Subject: Physical Sciences: Iran."

894 "QS World University Rankings by Subject 2023: Physics & Astronomy: Iran."

Even though Iranian universities did not rank as highly in the two databases as their counterparts in the developed world, Iran maintains a relatively large number of universities with programs in the field of physics and astronomy: 36 in total according to the QS World University Rankings. By contrast, other regional countries with civilian nuclear programs tend to have fewer universities with comparable departments: Egypt has 20 such universities, Saudi Arabia has 6, the United Arab Emirates has 4, and Israel has 6.[895] Although data on the number of enrolled students in specific programs at Iranian universities are lacking, the information listed above suggests that Iranian universities are probably producing larger numbers of graduates in nuclear-related fields than other regional countries.

Iranian scholars studying abroad in nuclear-relevant fields

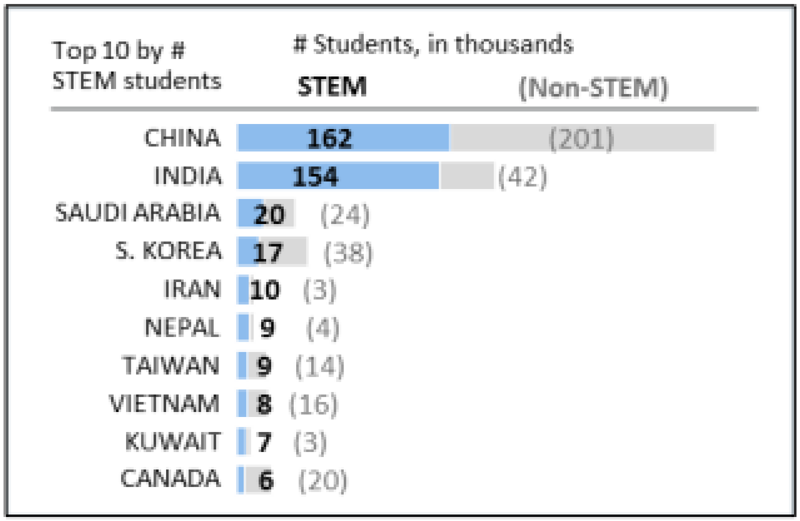
Iran, like China, has large numbers of students studying abroad in foreign universities, especially in STEM fields. Many of these students attend universities in the United States, although Malaysia, Canada, Germany, and the UK are also top destinations.[896] According to a report by the US Congressional Research Service, in the school year 2017–2018, there were approximately 10,000 Iranian citizens studying in STEM fields in the US (see Figure 61). Iran placed fifth overall in terms of foreign students studying in STEM-related fields in the US, behind China, India, Saudi Arabia, and South Korea.[897]

[895] "World University Rankings 2023 by Subject: Physical Sciences: Iran."

[896] "Iran Eases Restrictions on International Education," ICEF Monitor, https://monitor.icef.com/2014/08/from-the-field-iran-eases-restrictions-on-international-education/#:~:text=Up%20to%2080%2C000%20Iranian%20students%20study%20abroad&text=He%20feels%20that%20of%20all,high%20as%2080%2C000%20or%20more.

[897] Congressional Research Service, *Foreign STEM Students in the United States*, Nov. 1, 2019, https://crsreports.congress.gov/product/pdf/IF/IF11347.

Figure 61. Top 10 countries of origin for foreign STEM students in the US, 2017–2018 school year



Source: Congressional Research Service, *Foreign STEM Students in the United States,* Nov. 1, 2019, https://crsreports.congress.gov/product/pdf/IF/IF11347.

A report by the Institute of International Education's Opendoors program provides similar figures for the academic year 2021–2022, noting that of the 9,295 Iranian nationals studying at US universities that year, 48.2 percent were enrolled in engineering programs, 14 percent were enrolled in math or computer sciences programs, and 13.6 percent were pursuing degrees in the physical or life sciences.[898]

Iran's nuclear program has undoubtedly benefited from the pool of Iranian nationals returning from abroad with advanced degrees in STEM-related subjects, particularly physics and nuclear engineering. Both the current and the former president of the AEOI, for instance, earned graduate degrees at US universities. Mohammad Eslami, the current president, earned a master's degree in engineering from the University of Detroit, and Ali Akbar Salehi, the previous head, earned a doctorate in nuclear engineering from the Massachusetts Institute of Technology.[899]

However, in recent decades, Iran has experienced a "brain drain," which has significantly reduced the pool of available academic talent in Iran. Enticed by the prospect of better, higher

[898] "Fields of Study by Place of Origin," Opendoors, accessed Apr. 3, 2023, https://opendoorsdata.org/data/international-students/fields-of-study-by-place-of-origin/.

[899] Ali Akbar Salehi, "Resonance Region Neutronics of Unit Cells in Fast and Thermal Reactors," (PhD thesis, MIT, 1977), https://dspace.mit.edu/handle/1721.1/16333; "«اسلامی گزینه جدید تصدی وزارت راه و شهرسازی +سوابق اجرایی»," ILNA News Agency, 07/28/1397, https://www.ilna.ir/fa/tiny/news-682561.

paying jobs and financial and political stability, many Iranian students traveling abroad for their education now tend to stay abroad after they earn their degrees. According to a report by the Migration Policy Institute, in 2017 fewer than 8 percent of Iranian doctoral students studying in the United States said that they intended to return to Iran, the lowest number for any foreign nationality answering the query in a survey.[900]

Unlike China, which has invested heavily in strategies to retain academic talent, the Iranian government has tended to downplay or ignore the issue of academic flight, suggesting that the problem is likely to persist, especially if the country continues to experience underemployment and political unrest.

Publication volume and quality in nuclear-relevant fields

Despite the impediments noted above, Iranian scholars working in nuclear-relevant fields are regularly cited in academic journals. According to the Scimago Journal and Country Rank, a publicly available portal that assesses countries and institutions according to author citations in international scientific journals, Iran ranked 22 out of 124 countries in the field of nuclear and high energy physics in 2021, with an average of 1.3 citations per article linked to Iranian authors. This ranking placed Iran just below Australia but ahead of Turkey and Taiwan in the international rankings. In terms of regional ranking, Iran claimed the top spot, ahead of Turkey, Israel, Egypt, and other Middle Eastern countries.[901] In the field of aerospace engineering, which is relevant to potential delivery systems, Iran ranked eighth internationally, ahead of France and just behind Italy.[902] These relatively high ratings are probably indicative of the large number of Iranian graduates in STEM-related fields, particularly engineering, and the emphasis placed on publication in Iranian institutions of higher learning.

[900] Hassan Mahmoudi, "Iran Loses Highly Educated and Skilled Citizens During Long-Running 'Brain Drain,'" Migration Information Source, Apr. 22, 2021, https://www.migrationpolicy.org/article/iran-brain-drain-emigration. Similar figures have been noted in other studies. According to a survey conducted by the Washington Institute for Near East Policy, in 2014, 89 percent of Iranian students studying in the United States said that they would prefer to remain in the country rather than return to Iran after graduating. Steven Ditto and Larisa Baste, "Infographic: Iranian Students in the United States," Washington Institute for Near East Policy, Feb. 14, 2014. https://www.washingtoninstitute.org/policy-analysis/infographic-iranian-students-united-states.

[901] "Nuclear and High Energy Physics: 2021."

[902] "Aerospace Engineering: 2021," Scimago Journal and Country Rank, https://www.scimagojr.com/countryrank.php?category=2202&area=2200&year=2021.

What nuclear weapons and delivery systems does Iran possess, where are they deployed, and how capable are they?

Iran currently does not possess nuclear weapons nor is there any evidence that the Iranian government has selected potential deployment locations were it to develop such weapons.

Conclusion

Unlike Russia, China, and North Korea, Iran does not maintain an active nuclear weapons program nor does it have any nuclear weapons in its inventory. The government of Iran maintains that its nuclear program is for civilian purposes only, and its leaders have issued religious edicts prohibiting the development and use of nuclear weapons. However, Iran has conducted activities relevant to developing nuclear weapons, including producing HEU and (previously) experimenting with warhead design, metallurgy, and missile mating. Iran also maintains a significant inventory of ballistic missiles that, although conventionally armed, could potentially be adapted to deliver nuclear payloads.

As of May 2023, Iran's nuclear weapons design and delivery system R&D efforts appear to remain shelved. However, Iran continues to produce HEU in amounts and at levels inconsistent with a purely civilian program. Because the IAEA has found its access to sensitive nuclear sites in Iran curtailed, the agency will no longer be able to certify to what degree Iran remains in compliance with the provisions of the NPT, JCPOA, and UNSCR 2231.

The data that we examined indicate that Iran is moderately capable in terms of fielding qualified personnel to support its nuclear program. The government can draw on a large pool of qualified scientists and engineers who have advanced degrees in nuclear-relevant fields. At least 36 of Iran's 241 accredited universities and colleges maintain degree programs in the related fields of physics and astronomy. Iranian scholars are also well published in the field, ranking 22 out of 124 countries in terms of citations in nuclear and high energy physics. However, Iran also appears to be suffering a brain drain, with many of its thousands of students who are studying abroad choosing to remain abroad after completing their degrees.

Figures

Tables

Abbreviations

AAA	antiaircraft artillery
AEOI	Atomic Energy Organization of Iran
AIO	Aerospace Industries Organization (Iran)
AKUT	Amirkabir University of Technology (Iran)
ALBM	air-launched ballistic missile
ALCM	air-launched cruise missile
ANDS	Academy of National Defense Science (North Korea)
ARWU	Academic Ranking of World Universities
AVLIS	atomic vapor laser isotope separation
BNPP	Bushehr Nuclear Power Plant (Iran)
C2	command and control
CAEP	Chinese Academy of Engineering Physics
CASC	China Aerospace Science and Technology Corporation Limited
CASIC	China Aerospace Science and Industry Corporation
CCP	Chinese Communist Party
CIAE	China Institute of Atomic Energy
CMC	Central Military Commission (China, North Korea)
CNNC	China National Nuclear Corporation
CONUS	continental United States
CRBM	close-range ballistic missile
CSET	Center for Security and Emerging Technology (Georgetown University)
CTBT	Comprehensive Nuclear-Test-Ban Treaty
CTR	Cooperative Threat Reduction
DMZ	demilitarized zone
DOD	US Department of Defense
DFC	Double First Class, Chinese university designation
DPRK	Democratic People's Republic of Korea (North Korea)
EBW	exploding bridgeware detonator
ELWR	experimental light water reactor
EU	European Union
FAS	Federation of American Scientists
FEP	Fuel Enrichment Plant (Iran)
FFEP	Fordow Fuel Enrichment Plant (Iran)
FOBS	fractional orbital bombardment systems

GDP	gross domestic product
HEU	highly enriched uranium, or uranium containing at least 20 percent U-235
HGV	hypersonic glide vehicle
HWPP	Heavy Water Production Plant (Iran)
IAEA	International Atomic Energy Agency, the UN's atomic energy monitoring body
ICBM	intercontinental ballistic missile
IPM	Institute for Studies in Theoretical Physics and Mathematics (Iran)
IRBM	intermediate-range ballistic missile
IRGC	Islamic Revolutionary Guard Corps of Iran
IRGCASF	Islamic Revolutionary Guard Corps of Iran's Aerospace Force
IUST	Iran University of Science and Technology
JCPOA	Joint Comprehensive Plan of Action, known informally as the "Iran Deal"
JIHRD	Jaber Ibn Hayan Research Department (Iran)
JPOA	Joint Plan of Action
KCNA	Korea Central News Agency (North Korea)
KCUT	Kim Chaek University of Technology (North Korea)
KHRR	Khondab Heavy Water Research Reactor (Iran)
KIDA	Korean Institute for Defense Analysis
KISU	Kim Il Sung University (North Korea)
KPA	Korean People's Army (North Korea)
KPN	Korean People's Navy (North Korea)
kt	kilotons (yield)
KWP	Korean Worker's Party (North Korea)
LACM	land-attack cruise missile
LEU	low enriched uranium, or uranium containing less than 20 percent U-235
LOW	Launch on Warning
LPAR	large phased-array radar
MIIT	Ministry of Industry and Information Technology (China)
MIRV	multiple independently targetable reentry vehicle
MOD	Ministry of Defense (Russia)
MODAFL	Ministry of Defense and Armed Forces Logistics of Iran
MRBM	medium-range ballistic missile
MSC	Military Security Command (North Korea)
MT	megatons (yield)
MUT	Malek Ashtar University (Iran)

MWe	megawatt-electric, a measurement of energy
NATO	North Atlantic Treaty Organization
NC3	nuclear command, control, and communications
NCRI	National Council of Resistance of Iran
NDMC	National Defense Management Center (Russia)
NISTEP	National Institute of Science and Technology Policy (Japan)
NFRPC	Nuclear Fuel Research and Production Center (Iran)
NFU	no-first-use declaratory policy
NGO	nongovernmental organization
NINT	Northwest Institute of Nuclear Technology (China)
NPT	Non-Proliferation Treaty
NSNW	nonstrategic nuclear weapon
NSTRI	Nuclear Science and Technology Research Institute (Iran)
OECD	Organisation for Economic Co-operation and Development
PFEP	Pilot Fuel Enrichment Plant (Iran)
PHRC	Physics Research Center (Iran)
PLA	People's Liberation Army (China)
PLAAF	People's Liberation Army Air Force (China)
PLAN	People's Liberation Army Navy (China)
PLARF	People's Liberation Army Rocket Force (China)
PRC	People's Republic of China
PUST	Pyongyang University of Science and Technology
RCL	Radio Chemical Laboratory (North Korea)
ROK	Republic of Korea (South Korea)
R&D	research and development
SAC	State Affairs Commission (North Korea)
SAIG	Samen Al A'emmeh Industrial Group (Iran)
SAM	surface-to-air missile
SANS	Second Academy of Natural Sciences (North Korea)
SAOS	State Academy of Science (North Korea)
SAP	State Armament Program (Russia)
SASTIND	State Administration for Science, Technology, and Industry for National Defense (China)
SEC	Second Economic Committee (Iran)
SBIG	Shahid Bakeri Industrial Group (Iran)
SHIG	Shahid Hemmat Industrial Group (Iran)
SLBM	submarine-launched ballistic missile
SLCM	submarine-launched cruise missile
SLV	space launch vehicle

SNFCOM	State Nuclear Forces Command Organization (North Korea)
SPA	Supreme People's Assembly (North Korea)
SPND	Organization of Defensive Innovation and Research (Iran)
SOE	state-owned enterprise
SRBM	short-range ballistic missile
SSN	ballistic missile submarine
SSBN	ballistic missile submarine, nuclear-powered
SSGN	guided missile submarine
SSN	nuclear submarine
STEM	science, technology, engineering, and mathematics
S&T	science and technology
TEL	transporter erector launcher
THE	Times Higher Education
TNRC	Tehran Nuclear Research Centre
TRR	Tehran Research Reactor
TTP	Thousand Talents Program (China)
U-235	uranium-235, the lighter, fissile isotope of uranium
U-238	uranium-238, the heavier, non-fissile isotope of uranium
UCF	Uranium Conversion Facility (Iran)
UF4	uranium tetrafluoride
UF6	uranium hexafluoride, a gaseous form of uranium that is then enriched and processed for use in reactors or weapons
UO2	uranium dioxide
UN	United Nations
UNS	University of Natural Science (North Korea)
UNSCR	United Nations Security Council Resolution
USSR	Union of Soviet Socialist Republics
UUV	unmanned underwater vehicle
WMD	weapon of mass destruction

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