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NUCLEAR NOTEBOOK

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Hans M. Kristensen and Matt Korda

ABSTRACT

The Nuclear Notebook is researched and written by Hans M. Kristensen, director of the Nuclear Information Project with the Federation of American Scientists, and Matt Korda, a senior research associate with the project. The Nuclear Notebook column has been published in the *Bulletin of the Atomic Scientists* since 1987. This issue examines the status of the US nuclear arsenal. The US nuclear arsenal remained roughly unchanged in the last year, with the Defense Department maintaining an estimated stockpile of approximately 3,708 warheads. Of these, only about 1,744 warheads are deployed, while approximately 1,964 are held in reserve. Additionally, approximately 1,720 retired warheads are awaiting dismantlement, giving a total inventory of approximately 5,428 nuclear warheads. Of the approximately 1,744 warheads that are deployed, 400 are on land-based intercontinental ballistic missiles, roughly 944 are on submarine-launched ballistic missiles, 300 are at bomber bases in the United States, and 100 tactical bombs are at European bases.

KEYWORDS

Ballistic missiles; cruise missiles; nuclear posture review; nuclear weapons; nuclear arsenal; United States; nuclear risk; nuclear notebook

At the beginning of 2022, the US Defense Department maintained an estimated stockpile of approximately 3,708 nuclear warheads for delivery by ballistic missiles and aircraft. Most of the warheads in the stockpile are not deployed but rather stored for potential upload onto missiles and aircraft as necessary. We estimate that approximately 1,744 warheads are currently deployed, of which roughly 1,344 strategic warheads are deployed on ballistic missiles and another 300 at strategic bomber bases in the United States. An additional 100 tactical bombs are deployed at air bases in Europe. The remaining warheads – approximately 1,964 – are in storage as a so-called hedge against technical or geopolitical surprises. Several hundred of those warheads are scheduled to be retired before 2030. (See Table 1.)

In addition to the warheads in the Defense Department stockpile, approximately 1,720 retired – but still intact – warheads are stored under custody of the Energy Department and are awaiting dismantlement, giving a total US inventory of an estimated 5,428 warheads. Between 2010 and 2018, the US government publicly disclosed the size of the nuclear weapons stockpile; however, in 2019 and 2020, the Trump administration rejected requests from the Federation of American Scientists to declassify the latest stockpile numbers (Aftergood 2019; Kristensen 2019a, 2020d). In 2021, the Biden administration restored the United States' previous transparency levels by declassifying both numbers for the entire history of the US nuclear arsenal until September 2020 – including the missing years of the Trump administration. This effort revealed that the United States' nuclear stockpile consisted of 3,750 warheads in September 2020 – only 72 warheads fewer than the last number made available in September 2017 before the Trump administration reduced the US government's transparency efforts (State Department 2021a). We estimate that the stockpile will continue to decline over the next decade-and-a-half as modernization programs consolidate the remaining warheads.

The US nuclear weapons are thought to be stored at an estimated 24 geographical locations in 11 US States and five European countries (Kristensen and Korda 2019, 124). The location with the most nuclear weapons by far is the large Kirtland Underground Munitions and Maintenance Storage Complex south of Albuquerque, New Mexico. Most of the weapons in this location are retired weapons awaiting dismantlement at the Pantex Plant in Texas. The state with the second-largest inventory is Washington, which is home to the Strategic Weapons Facility Pacific and the ballistic missile submarines at Naval Submarine Base Kitsap. However, if counting only weapons that are part of the stockpile, then Washington would be considered the state containing the most nuclear weapons.

Implementing new start

The United States appears to be in compliance with the New Strategic Arms Reduction Treaty (New START) limits. Its 665 deployed strategic launchers with 1,389 attributed warheads counted as of the most recent data exchange

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Table 1. United States nuclear forces, 2022.

Type/Designation	No.	Year deployed	Warheads x yield (kilotons)	Warheads (total available)[a]
ICBMs				
LGM-30 G Minuteman III				
Mk-12A	200	1979	1–3 W78 x 335 (MIRV)	600[b]
Mk-21/SERV	200	2006[c]	1 W87 x 300	200[d]
Total	**400**[e]			**800**[f]
SLBMs				
UGM-133A Trident II D5/LE 14/280[g]				
Mk-4A		2008[h]	1–8 W76-1 x 90 (MIRV)	1,511[i]
Mk-4A		2019	1–2 W76-2 x 8 (MIRV)[j]	25[k]
Mk-5		1990	1–8 W88 x 455 (MIRV)	384
Total	**14/280**			**1,920**[l]
Bombers				
B-52 H Stratofortress	87/46[m]	1961	ALCM/W80-1 x 5–150	500
B-2A Spirit	20/20	1994	B61-7 x 10–360/-11 x 400 B83-1 x low-1,200	288
Total	**107/66**[n]			**788**[o]
Total strategic forces				**3,508**
Nonstrategic forces				
F-15E, F-16C/D, DCA	n/a	1979	1–5 B61-3/-4 bombs x 0.3–170[p]	200
Total				**200**[q]
Total stockpile				**3,708**
Deployed				1,744[r]
Reserve (hedge and spares)				1,964
Retired, awaiting dismantlement				**1,720**
Total Inventory				**5,428**

ALCM: air-launched cruise missile; DCA: dual-capable aircraft; ICBM: intercontinental ballistic missile; LGM: silo-launched ground-attack missile; MIRV: multiple independently targetable re-entry vehicle; SERV: security-enhanced re-entry vehicle; SLBM: submarine-launched ballistic missile.

[a]Lists total warheads available. Only a portion of these are deployed with launchers. See individual endnotes for details.

[b]Roughly 200 of these are deployed on 200 Minuteman IIIs equipped with the Mk-12A re-entry vehicle. The rest are in central storage.

[c]The W87 was initially deployed on the MX/Peacekeeper in 1986 but first transferred to the Minuteman in 2006.

[d]The 200 Mk21-equipped ICBMs can each carry one W87. The estimated remaining 340 W87s are in storage. Excess W87 pits are planned for use in the W78 Replacement Program, previously designated IW-1 but now called W87-1.

[e]Another 50 ICBMs are in storage for potential deployment in 50 empty silos.

[f]Of these ICBM warheads, 400 are deployed on operational missiles and the rest are in long-term storage.

[g]The first figure is the total number of nuclear-powered ballistic missile submarines (SSBNs) in the US fleet; the second is the maximum number of missiles that they can carry. However, although the 14 SSBNs can carry up to 280 missiles, 2 vessels are normally undergoing refueling overhaul at any given time and are not assigned missiles. The remaining 12 SSBNs can carry up to 240 missiles, but 1 or 2 of these vessels are usually undergoing maintenance at any given time and may not be carrying missiles. The life-extended Trident II D5LE is replacing the original missile.

[h]The W76-1 is a life-extended version of the W76-0 that was first deployed in 1978.

[i]All W76-0 warheads are thought to have now been replaced on ballistic missile submarines by W76-1 warheads, but several hundred are still awaiting dismantlement.

[j]The W76-2 is a single-stage low-yield modification of the W76-1 with an estimated yield of 8 kilotons.

[k]Assumes two SLBMs, each with one W76-2, available for each deployable SSBN.

[l]Of these SLBM warheads, approximately 944 are deployed on missiles loaded in ballistic missile submarine launchers.

[m]Of the 87 B-52s, 76 are in the active inventory. Of those, 46 are nuclear-capable, of which less than 40 are normally deployed.

[n]The first figure is the total aircraft inventory, including those used for training, testing, and back-up; the second is the portion of the primary-mission aircraft inventory estimated to be tasked with nuclear missions. The United States has a total of 66 nuclear-capable bombers (46 B-52s and 20 B-2s), but normally only about 50 nuclear bombers are deployed, with the remaining aircraft in overhaul.

[o]Of these bomber weapons, only about 300 are deployed at bomber bases. These include an estimated 200 ALCMs at Minot Air Force Base and approximately 100 bombs at Whiteman Air Force Base. The remaining weapons are in long-term storage. B-52H aircraft are no longer tasked with delivering gravity bombs.

[p]The F-15E can carry up to 5 B61s. Some tactical B61s in Europe are available for NATO DCAs (F-16MLU, PA-200). The maximum yield of the B61-3 is 170 kt, while the maximum yield of the B61-4 is 50 kt.

[q]An estimated 100 B61-3 and –4 bombs are deployed in Europe, of which about 60 are earmarked for use by NATO aircraft. The remaining 100 bombs are in central storage in the United States as backup and contingency missions in the Indo-Pacific region.

[r]Deployed warheads include approximately 1,344 on ballistic missiles (400 on ICBMs and 944 on SLBMs), 300 weapons at heavy bomber bases, and 100 nonstrategic bombs deployed in Europe.

on September 1, 2021 are well below the treaty's limits of 700 deployed strategic launchers with 1,550 warheads (State Department 2021b). This is a decrease of 10 deployed strategic launchers and an increase of 69 deployed strategic warheads over the past 12 months (State Department 2021c). However, these changes do not reflect actual changes in the US arsenal but are caused by normal fluctuations caused by launchers moving in and out of maintenance. The United States has not reduced its total inventory of strategic launchers since 2017 (Kristensen 2020a).

The warhead numbers reported by the State Department differ from the estimates presented in this Nuclear Notebook, though there are reasons for this. The New START counting rules artificially attribute one warhead to each deployed bomber, even though US

bombers do not carry nuclear weapons under normal circumstances. Also, this Nuclear Notebook counts weapons stored at bomber bases that can quickly be loaded onto the aircraft, as well as nonstrategic nuclear weapons in Europe.

Since the treaty entered into force in February 2011, the biannual aggregate data show the United States has cut a total of 324 strategic launchers, 217 deployed launchers, and 411 deployed strategic warheads from its inventory (State Department 2011). The warhead reduction represents approximately 11 percent of the 3,708 warheads remaining in the US stockpile, and approximately 8 percent of the total US arsenal of 5,428 stockpiled and retired warheads awaiting dismantlement. The 2018 Nuclear Posture Review (NPR) States that the United States "will continue to implement the New START Treaty" while it remains in effect (US Defense Department 2018, 73). In 2021, the United States and Russia extended the treaty by mutual agreement, until February 2026.

The United States is currently 35 launchers and 161 warheads below the treaty limit for deployed strategic weapons but has 138 deployed launchers more than Russia – a significant gap that is almost equivalent to the size of an entire US Air Force intercontinental ballistic missile (ICBM) wing. It is notable that Russia has not sought to reduce this gap by deploying more strategic launchers. Instead, the Russian launcher deficit has increased by one-third since its lowest point in February 2018.

If either the US or Russia withdrew from New START, both the United States and Russia could upload several hundreds of extra warheads onto their launchers. This means that the treaty has proven useful thus far in keeping a lid on both countries' deployed strategic forces. Additionally, if New START expired, then both countries would lose a critical node of transparency into each other's nuclear forces. As of March 3, 2022, the United States and Russia have completed a combined 328 on-site inspections and exchanged 23,369 notifications (State Department 2022). (On-site inspections have been paused since early-2020 due to COVID-19.)

The NPR and nuclear modernization

The Biden administration's NPR was expected to be completed in late-January 2022 but has been delayed following the Russian invasion of Ukraine. The conclusions are not known but are expected to broadly follow the Trump administration's 2018 NPR, which in turn followed the broad outlines of the Obama administration's 2010 NPR to modernize the entire nuclear weapons arsenal – although with several important changes.

The most significant change was a recommendation to increase the types and role of US nuclear weapons. The Trump NPR took a confrontational tone, presenting an assertive posture that embraces "great power competition." It also included plans to develop new nuclear weapons and modify others. The report backed away from the goal of seeking to limit the role of nuclear weapons to the sole purpose of deterring nuclear attacks. Instead, it emphasizes "expanding" US nuclear options to deter, and, if deterrence fails, to prevail against both nuclear and "non-nuclear strategic attacks." To be clear, any use of a nuclear weapon to respond to a non-nuclear strategic attack would constitute nuclear first use.

The NPR explained that "non-nuclear strategic attacks include, but are not limited to, attacks on the US, allied, or partner civilian population or infrastructure, and attacks on US or allied nuclear forces, their command and control, or warning and attack assessment capabilities" (US Defense Department 2018, 21). Consequently, US nuclear capabilities will be postured to "hedge against the potential rapid growth or emergence of nuclear and non-nuclear strategic threats, including chemical, biological, cyber, and large-scale conventional aggression" (US Defense Department 2018, 38). To achieve these goals, the NPR stated that "the United States will enhance the flexibility and range of its tailored deterrence options. . . . Expanding flexible US nuclear options now, to include low-yield options, is important for the preservation of credible deterrence against regional aggression," the report claimed (US Defense Department 2018, 34).

The new tailored capabilities included modifying "a small number" of the existing W76-1 90-kiloton two-stage thermonuclear warheads to single-stage warheads by "turning off" the secondary (a technical term representing a part of the warhead) to limit the yield to what the primary (another technical term) can produce (an estimated 8 kilotons). This new warhead (W76-2), the NPR claimed, is necessary to "help counter any mistaken perception of an exploitable 'gap' in US regional deterrence capabilities." The W76-2 was first deployed in the Atlantic Ocean in late 2019 onboard a nuclear-powered ballistic missile submarine (SSBN), the USS Tennessee (SSBN-734) (Arkin and Kristensen 2020). Undersecretary of Defense for Policy John Rood told reporters in December 2019 that the low-yield Trident warhead was "very stabilizing" and in no way supported the concept of early use of low-yield nuclear weapons (Kreisher 2019), even though the NPR explicitly stated the weapon is being acquired to provide "a prompt response option" (US Defense Department 2018).

In the longer term, the NPR declared, the United States will also "pursue a nuclear-armed" submarine-launched cruise missile (SLCM-N) to "provide a needed nonstrategic regional presence, an assured response capability, and an Intermediate-Range Nuclear Forces (INF) Treaty-compliant response to Russia's continuing Treaty violation." The NPR specifically noted that, "If Russia returns to compliance with its arms control obligations, reduces its nonstrategic nuclear arsenal, and corrects its other destabilizing behaviors, the United States may reconsider the pursuit of a [submarine-launched cruise missile]." In pursuit of this new missile, the review stated that "we will immediately begin efforts to restore this capability by initiating a requirements study leading to an analysis of alternatives ... for the rapid development of a modern [submarine-launched cruise missile]." The report's authors believed that "US pursuit of a submarine-launched cruise missile may provide the necessary incentive for Russia to negotiate seriously a reduction of its nonstrategic nuclear weapons, just as the prior Western deployment of Intermediate-Range Nuclear Forces in Europe led to the 1987 INF Treaty" (US Defense Department 2018, 55).

The new nuclear "supplements" proposed by the 2018 NPR are needed, the authors said, to "provide a more diverse set of characteristics greatly enhancing our ability to tailor deterrence and assurance; expand the range of credible US options for responding to nuclear or non-nuclear strategic attack; and, enhance deterrence by signaling to potential adversaries that their concepts of coercive, limited nuclear escalation offer no exploitable advantage" (US Defense Department 2018, 55).

However, the US arsenal already includes nearly 1,000 gravity bombs and air-launched cruise missiles with low-yield warhead options (Kristensen 2017a). The NPR provided no evidence that existing capabilities are insufficient or documented that the yield of US nuclear weapons is a factor in whether Russia would decide to use nuclear weapons. The NPR authors simply claimed that the new capabilities are needed. The US Navy used to have a nuclear submarine-launched cruise missile (the TLAM/N) but retired it in 2011 because it was redundant and no longer needed. All other nonstrategic nuclear weapons – with the exception of gravity bombs for fighter-bombers – have also been retired because there was no longer any military need for them, despite Russia's larger nonstrategic nuclear weapons arsenal.

The suggestion that a US submarine-launched cruise missile could motivate Russia to return to compliance with the INF Treaty is flawed because Russia embarked upon its current violation of the treaty at a time when the TLAM/N was still in the US arsenal, and because the Trump administration since withdrew the United States from the INF Treaty. Moreover, US Strategic Command has already strengthened strategic bombers' support of NATO in response to Russia's more provocative and aggressive behavior (see above); 46 B-52 bombers are currently equipped with the air-launched cruise missile and both the B-52 and the new B-21 bomber will receive the new long-range standoff weapon, which will have essentially the same capabilities as the submarine-launched cruise missile proposed by the 2018 NPR.

Russia's decisions about the size and composition of its nonstrategic arsenal instead appear to be driven by the US military's superiority in conventional forces, not by the US nonstrategic nuclear arsenal or by the yield of a particular weapon. Instead, the pursuit of a new nuclear submarine-launched cruise missile to "provide a needed nonstrategic regional presence" in Europe and Asia could reinforce Russia's reliance on nonstrategic nuclear weapons. It could also potentially even trigger Chinese interest in such a capability as well – especially when combined with the parallel expansion of US long-range conventional strike capabilities including development of new conventional INF-range missiles. Moreover, development of a nuclear sea-launched cruise missile would violate the pledge the United States made in the 1992 Presidential Nuclear Initiative not to develop new types of nuclear submarine-launched cruise missiles (Koch 2012, 40).

One final argument against the submarine-launched cruise missile is that nuclear-capable vessels triggered frequent and serious political disputes during the Cold War when they visited foreign ports in countries that did not allow nuclear weapons on their territory. In the case of New Zealand, diplomatic relations have only recently – 30 years later – recovered from those disputes. Reconstitution of a nuclear submarine-launched cruise missile would reintroduce this foreign relations irritant and needlessly complicate relations with key allied countries in Europe and Northeast Asia.

It is possible that the Biden administration's NPR will cancel the SLCM-N, but the document had not been published when this article went to print.

The Trump administration significantly increased the nuclear weapons budget. According to an estimate published in May 2021 by the US Congressional Budget Office, modernizing and operating the US nuclear arsenal and the facilities that support it will cost around $634 billion for the period 2021–2030 (Congressional Budget Office 2021, 1). This is $140 billion more than

the Congressional Budget Office's 2019 estimate for the 2019–2028 period because modernization programs continue to ramp up, cost estimates are increasing, and the 2018 NPR called for new nuclear weapons (Congressional Budget Office 2019, 1). The nuclear modernization (and maintenance) program will continue well beyond 2039 and, based on the Congressional Budget Office's estimate, will cost $1.2 trillion over the next three decades. Notably, although the estimate accounts for inflation (Congressional Budget Office 2017), other estimates forecast that the total cost will be closer to $1.7 trillion (Arms Control Association 2017). Whatever the actual price tag will be, it is likely to increase over time, resulting in increased competition with conventional modernization programs planned for the same period. The NPR belittles concerns about affordability issues in the nuclear modernization program and instead labels it "an affordable priority," pointing out that the total cost is only a small portion of the overall defense budget (US Defense Department 2018, XI). There is little doubt, however, that limited resources, competing nuclear and conventional modernization programs, tax cuts, and the rapidly growing US budget deficit will present significant challenges for the nuclear modernization program.

In addition to the two new "supplement" weapons described above, the National Nuclear Security Administration (NNSA) and the Defense Department have proposed developing several other new nuclear warheads, including the W93 navy warhead. The NNSA's Stockpile Stewardship and Management Plan from December 2020 doubled the number of new nuclear warhead projects for the next 20 years (NNSA 2020b).

Nuclear planning, nuclear exercises

The changes in the Trump administration's NPR triggered new guidance from the White House and Defense Department that replaced the Obama administration's guidance from 2013 (Kristensen 2013a). The first of these was a new Nuclear Employment Guidance document signed by President Trump in April 2019, that in turn was implemented by the Nuclear Weapons Employment Planning and Posture Guidance signed by the Defense Secretary (US Defense Department 2020, 1). The changes in these documents were sufficient to trigger a change of the strategic war plan known as OPLAN 2012–12, the nuclear employment portion of what was previously known as the Single Integrated Operations Plan. The updated OPLAN 8010–12 entered into effect on April 30, 2019 (US Strategic Command 2019).

OPLAN 8010–12 consists of "a family of plans" directed against four adversaries: Russia, China, North Korea, and Iran. Known as "Strategic Deterrence and Force Employment," OPLAN 8010–12 first entered into effect in July 2012 in response to Operations Order Global Citadel signed by the defense secretary. The plan is flexible enough to absorb normal changes to the posture as they emerge, including those flowing from the NPR. Several updates have been made since 2012, but more substantial updates will trigger publication of what is known as a "change." The April 2019 change refocused the plan toward "great power competition," incorporated a new cyber plan, and reportedly blurred the line between nuclear and conventional attacks by "fully incorporat[ing] non-nuclear weapons as an equal player" (Arkin and Ambinder 2022a, 2022b).

OPLAN 8010–12 also "emphasizes escalation control designed to end hostilities and resolve the conflict at the lowest practicable level" by developing "readily executable and adaptively planned response options to de-escalate, defend against, or defeat hostile adversary actions" (US Strategic Command 2012). These passages are notable, not least of which because the Trump administration's NPR criticized Russia for an alleged willingness to use nuclear weapons in a similar manner, as part of a so-called escalate-to-deescalate strategy.

The 2020 Nuclear Employment Strategy, which reads more like an article than a strategy document, reiterates this objective: "If deterrence fails, the United States will strive to end any conflict at the lowest level of damage possible and on the best achievable terms for the United States, and its allies, and partners. One of the means of achieving this is to respond in a manner intended to restore deterrence. To this end, elements of US nuclear forces are intended to provide limited, flexible, and graduated response options. Such options demonstrate the resolve, and the restraint, necessary for changing an adversary's decision calculus regarding further escalation" (US Defense Department 2020, 2). This objective is not just directed at nuclear attacks, as the 2018 NPR called for "expanding" US nuclear options against "non-nuclear strategic attacks."

OPLAN 8010–12 is a whole-of-government plan that includes the full spectrum of national power to affect potential adversaries. This integration of nuclear and conventional kinetic and non-kinetic strategic capabilities into one overall plan is a significant change from the strategic war plan of the Cold War that was almost

Figure 1. A B-52H bomber is loaded with AGM-86B nuclear (unarmed) air-launched cruise missiles during exercise Prairie Vigilance at Minot AFB in August 2021. Image: USAF.

entirely nuclear. Former US Strategic Command commander Gen. John Hyten, now the Chairman of the Joint Chiefs of Staff, in 2017 explained the scope of modern strategic planning:

> "I'll just say that the plans that we have right now, one of the things that surprised me most when I took command on November 3 was the flexible options that are in all the plans today. So we actually have very flexible options in our plans. So if something bad happens in the world and there's a response and I'm on the phone with the secretary of defense and the president and the entire staff, which is the attorney general, secretary of state, and everybody, I actually have a series of very flexible options from conventional all the way up to large-scale nuke that I can advise the president on to give him options on what he would want to do.
>
> "So I'm very comfortable today with the flexibility of our response options. Whether the president of the United States and his team believes that that gives him enough flexibility is his call. So we'll look at that in the Nuclear Posture Review. But I've said publicly in the past that our plans now are very flexible.
>
> "And the reason I was surprised when I got to [Strategic Command] about the flexibility, is because the last time I executed or was involved in the execution of the nuclear plan was about 20 years ago, and there was no flexibility in the plan. It was big, it was huge, it was massively destructive, and that's all there. We now have conventional responses all the way up to the nuclear responses, and I think that's a very healthy thing (Hyten 2017)."

To practice and fine-tune these plans, the armed forces conducted several nuclear-related exercises in 2021 and early 2022. These included Strategic Command's Global Lightning exercises in March 2021 and January 2022, which is a command and control and battle staff exercise designed to assess joint operational readiness across all of Strategic Command's mission areas. To that end, a Global Lightning exercise typically links to several other exercises. In 2021, Global Lightning was integrated with US European Command and US Space Command, and involved the deployment of B-52 bombers from Barksdale and Minot Air Force Bases (US Strategic Command 2021a; Kristensen 2021a). In 2022, Global Lightning was integrated with US Indo-Pacific Command (US Strategic Command 2022a).

In August 2021, Air Force Global Strike Command conducted exercise Prairie Vigilance, a nuclear bomber exercise at Minot Air Force Base in North Dakota. This was the fourth iteration of this kind of exercise in 2021, which practiced nuclear cruise missile loading and rapid takeoff of B-52 bombers (Spencer 2021; see Figure 1).

Prairie Vigilance was the lead-up to Strategic Command's annual week-long Global Thunder exercise in November 2021. The exercise "provides training opportunities that exercise all US Strategic Command mission areas, with a specific focus on nuclear readiness" (US Strategic Command 2021b).

These developments coincide with steadily increasing US bomber operations in Europe since Russia's invasion of Ukraine in 2014. Before that, one or two bombers

would deploy for an exercise or airshow. But since then, the number of deployments and bombers has increased, and the mission changed. Very quickly after the Russian annexation of Crimea, Strategic Command increased the role of nuclear bombers in support of European Command (Breedlove 2015), which in 2016 put into effect a new standing war plan for the first time since the Cold War (Scapparotti 2017). Before 2018, the bomber mission was called the Bomber Assurance and Deterrence missions to show the flag, but now the bombers deploy as a Bomber Task Force that brings the full offensive capability to the forward base. Whereas the mission of Bomber Assurance and Deterrence was to train with allies and have a visible presence to deter Russia, the mission of the Bomber Task Force is to move a fully combat-ready bomber force into the European theater. "It's no longer just to go partner with our NATO allies or to go over and have a visible presence of American air power," according to the commander of the 2nd Bomb Wing. "That's part of it, but we are also there to drop weapons if called to do so" (Wrightsman 2019).

These changes are important indications of how US strategy has changed in response to deteriorating East-West relations and the new "great power competition" strategy promoted by the Trump administration. They also illustrate a growing integration of nuclear and conventional capabilities, as reflected in the new strategic war plan. The deployment of four B-52s to Royal Air Force Fairford in March 2019, for example, included two nuclear-capable aircraft and two that have been converted to conventional-only missions. NATO's official announcement of the exercise did not notice this feature but said the deployment "shows that the US nuclear umbrella protects Europe" (NATO 2019). The statement also said that the B-52 bombers "can carry both conventional and nuclear weapons" when, in fact, nearly half of them – 41 of 87 – cannot because they have been denuclearized under the New START treaty. The close integration of nuclear and conventional bombers into the same task force can have significant implications for crisis stability, misunderstandings, and the risk of nuclear escalation.

Additionally, as of 2019 US bombers are increasingly practicing an "agile combat employment" strategy, by which all bombers "hopscotch" to a larger number of widely dispersed smaller airfields – including airfields in Canada – in the event of a crisis. This exercise is intended to increase the number of aimpoints for a potential adversary seeking to destroy the US bomber force, thus increasing the force's survivability and raising the ante for an adversary to attempt such a strike (Arkin and Ambinder 2022a). Over the past year, the Strategic Air Command executed 127 Bomber Task Force missions (US Strategic Command 2022b, 14).

Land-based ballistic missiles

The US Air Force operates a force of 400 silo-based Minuteman III ICBMs split across three wings: the 90th Missile Wing at F. E. Warren Air Force Base in Colorado, Nebraska, and Wyoming; the 91st Missile Wing at Minot Air Force Base in North Dakota; and the 341st Missile Wing at Malmstrom Air Force Base in Montana. In addition to the 400 silos with missiles, another 50 silos are kept "warm" to load stored missiles if necessary. Each wing has three squadrons, each with 50 Minuteman III silos. They are collectively controlled by five launch control centers.

The 400 ICBMs as deployed carry one warhead each, either a 300-kiloton W87/Mk21 or a 335-kiloton W78/Mk12A. ICBMs equipped with the W78/Mk12A, however, could theoretically be uploaded to carry two or three independently targetable warheads each, for a total of 800 warheads available for the ICBM force. The US Air Force occasionally test-launches Minuteman III missiles with multiple unarmed re-entry vehicles to maintain and announce the capability to re-MIRV the Minuteman IIIs. On August 4, 2020, for example, a test-launch of a Minuteman III ICBM was equipped with three re-entry vehicles (US Strategic Command 2020). The test came only five days after the Trump administration's arms control envoy tweeted a photo of himself observing a snap exercise at Minot Air Force Base involving a Minuteman equipped with three re-entry vehicles (Billingslea 2020).

The Minuteman IIIs completed a multibillion-dollar, decade-long modernization program in 2015 to extend the service life of the missile to 2030. Although the United States did not officially deploy a new ICBM, the upgraded Minuteman IIIs "are basically new missiles except for the shell," according to Air Force personnel (Pampe 2012).

An ongoing Air Force modernization program involves upgrades to the Mk21 re-entry vehicles' arming, fuzing, and firing component – which validates the President's launch authorization and unlocks the firing system so that the bomb can detonate – at a cost of slightly over a billion dollars in total. The publicly stated purpose of this refurbishment is to extend the vehicles' service life, but the effort appears to also involve adding a "burst height compensation" to enhance the targeting effectiveness of the warheads

(Postol 2014). Priority is on replacement of the Mk21 fuze. A total of 693 fuze replacements were initially planned; however, the new fuzes will also reportedly be deployed on the Minuteman replacement missile, which means that the fuze modernization program is likely to expand significantly to accommodate those new missiles (Woolf 2020, 15–16). The effort complements a similar fuze upgrade underway to the Navy's W76-1/Mk4A warhead. The enhanced targeting capability might also allow for lowering the yield on future warhead designs.

It is possible to do a second life-extension of the Minuteman III. In March 2019, the Air Force's Deputy Chief of Staff for Strategic Deterrence and Nuclear Integration noted in his testimony to the House Subcommittee on Strategic Forces that there was one more opportunity to life-extend the missiles before the Minuteman III would have to be replaced (Clark 2019). However, the Air Force has decided against life-extension, instead opting to purchase a whole new generation of ICBMs.

In August 2017, the Air Force awarded $678 million worth of contracts to Boeing and Northrop Grumman to develop trade studies for the next-generation ICBM that is currently known as the Ground-Based Strategic Deterrent (Erwin 2018). In October 2019, the Program Manager for Ground-Based Strategic Deterrent noted that the official name for the missile would be selected within 12 months; however, over two years later an official name has still not yet been announced (Bartolomei 2019). On July 16, 2019, the Air Force issued a formal "request for proposals" for the engineering and manufacturing development phase of the Ground-Based Strategic Deterrent program, which includes five production lot options to produce and deploy the system (Bryant 2019).

As the two companies under contract for the Ground-Based Strategic Deterrent's technology maturation and risk reduction phase, Boeing and Northrop Grumman were both expected to bid for the engineering and manufacturing development contract. However, only a week after the request for proposals was issued, Boeing surprisingly walked away from the competition, stating that "the current acquisition approach does not provide a level playing field for fair competition" (Weisgerber 2019). The dispute centers on Northrop Grumman's 2018 acquisition of Orbital ATK, which is one of only two US-based companies that produces solid rocket motors and launch vehicles. Under the terms of the acquisition, Northrop Grumman is required to "make its solid rocket motors and related services available on a non-discriminatory basis to all competitors for missile contracts" (Federal Trade Commission 2018). However, Boeing has expressed concern that Northrop Grumman would not comply with that order. This put Northrop Grumman at a favorable position in the bidding process over Boeing, which does not produce those systems in-house. Boeing stated an intention to not submit a bid for the engineering and manufacturing development contract. Nonetheless, it conducted a substantial lobbying campaign throughout the summer of 2019 in an effort to convince Congress and the Air Force to force Northrop Grumman into submitting a joint "best-of-industry" bid with Boeing (Mehta 2019). However, Northrop Grumman declined Boeing's offer and the Air Force did not intervene to force a joint bid. The Air Force subsequently terminated the remainder of Boeing's technological maturation and risk reduction contract in October 2019 by refusing to allocate any further funding to the contract. This effectively ended Boeing's involvement with the Ground-Based Strategic Deterrent program (Insinna 2019).

The request for proposal deadline for the engineering and manufacturing development contract was December 13, 2019. By that date, the Air Force received only a single bid for the contract, and on September 8, 2020, the Air Force officially awarded the $13.3 billion engineering and manufacturing development contract to Northrop Grumman. The nationwide team will include Aerojet Rocketdyne, General Dynamics, Collins Aerospace, Lockheed Martin, Textron Systems, HDT Global, Bechtel, Kratos Defense and Security Solutions, Clark Construction, L3Harris, and Honeywell (Northrop Grumman 2020). Aerojet Rocketdyne will produce the system's solid-fuel rocket motors in conjunction with newly acquired Orbital ATK, which is now called Northrop Grumman Innovation Systems.

According to the Air Force's latest milestone requirements, the Air Force must deploy 20 new Ground-Based Strategic Deterrent missiles with legacy re-entry vehicles and warheads in order to achieve initial operating capability, scheduled in fiscal year 2029 (Sirota 2020). The plan is to buy 659 missiles – 400 of which would be deployed, while the remainder will be used for test launches and as spares – at a price between $93.1 billion and $95.8 billion, increased from a preliminary $85 billion Pentagon estimate in 2016 (Capaccio 2020). These amounts do not include the costs for the new Ground-Based Strategic Deterrent warhead – the W87-1 – which is projected to cost up to $14.8 billion (Government Accountability Office 2020). The Air Force says the Ground-Based Strategic Deterrent will meet existing user requirements but have the adaptability and flexibility to be upgraded through 2075 (US Air Force 2016). The new missile is expected to have a greater range than the Minuteman III. Still, it is unlikely that it will have enough range to target countries like China, North Korea, and Iran without

overflying Russia. In June 2021, program officials announced that the first Ground-Based Strategic Deterrent prototype would conduct its first flight by the end of 2023 (Bartolomei 2021).

The Ground-Based Strategic Deterrent will be capable of carrying single or multiple warheads. The Air Force initially planned to equip the Ground-Based Strategic Deterrent with life-extended versions of the existing W78 and W87 warheads. The modified W78 was known as Interoperable Warhead 1. But in 2018, the Air Force and NNSA canceled the W78 upgrade and instead proposed a W78 Replacement Program known as the W87-1. The new warhead will use a W87-like plutonium pit, "using a well-tested IHE [Insensitive High Explosive] primary design" (Energy Department 2018b). The new warhead will be incorporated into a modified version of the Mk21 re-entry vehicle and be designated as the W87-1/Mk4A. In order to produce the W87-1 in time to meet the Ground-Based Strategic Deterrent's planned deployment schedule, the NNSA has set an extremely ambitious production schedule that relies upon its ability to produce at least 80 plutonium pits per year by 2030. However, due to the agency's consistent inability to meet project deadlines and its lack of a latent large-scale plutonium production capability, the 80-pit requirement was always unlikely to be achieved (Government Accountability Office 2020; Institute for Defense Analyses 2019). In June 2021, the Acting Administrator of the NNSA announced to Congress what external analysts had long predicted – that the security administration's goal of producing up to 80 pits by 2030 would not be possible (Demarest 2021). This was further confirmed by the NNSA in early 2022 (Demarest 2022). This could mean that despite completing its March 2021 requirements review for the W87-1 – a key milestone that allows the program to progress into the next stage of its development – it is likely that the program will face delays and that new delivery systems will be initially deployed with legacy warheads (Sirota 2021; Department of the Air Force 2020).

In October 2019, Lockheed Martin was awarded a -$138 million contract to integrate the Mk21 re-entry vehicle into the Ground-Based Strategic Deterrent, beating out rivals Boeing, Raytheon, Northrop Grumman, and Orbital ATK (which Northrop Grumman now owns and has been renamed to Northrop Grumman Innovation Systems) (Lockheed Martin 2019). Because the W87-1/Mk21A will be bulkier than the current W78/Mk12A, the Ground-Based Strategic Deterrent payload section would have to be wider to accommodate multiple warheads. Also, Northrop Grumman's Ground-Based Strategic Deterrent illustration shows a missile that is different than the existing Minuteman III, with a wider upper body and payload section (Kristensen 2019b).

The Air Force faces a tight construction schedule for the deployment of the Ground-Based Strategic Deterrent. Each launch facility is expected to take seven months to upgrade, while each missile alert

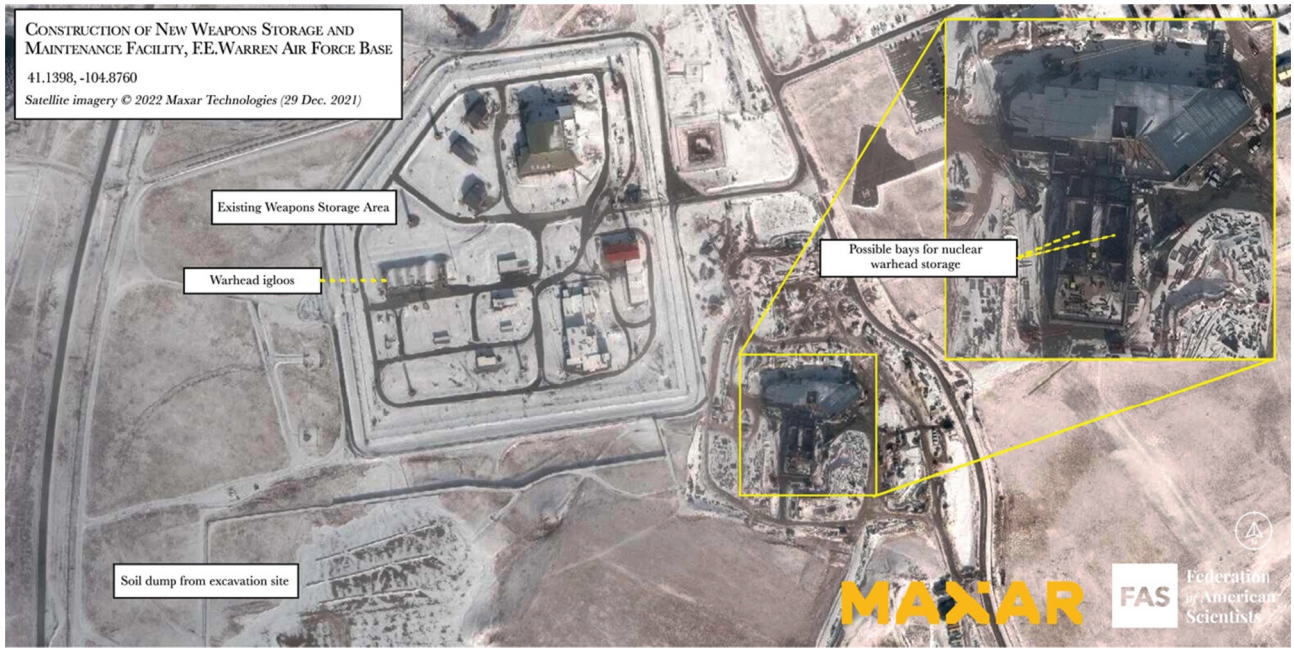

Figure 2. A new underground nuclear weapons storage facility is under construction at F.E. Warren AFB for storage of W78 and W87 warheads for Minuteman III ICBMs. Image: © 2022 Maxar Technologies.

facility will take approximately 12 months. The Air Force intends to upgrade all 150 launch facilities and eight of 15 missile alert facilities for each of the three ICBM bases; the remaining seven missile alert facilities at each base will be dismantled (US Air Force 2020a). Since each missile alert facility is currently responsible for a group of 10 launch facilities, this reduction could indicate that each missile alert facility could be responsible for up to 18 or 19 launch facilities once the Ground-Based Strategic Deterrent becomes operational. This could have implications for the future vulnerability of the Ground-Based Strategic Deterrent's command-and-control system (Korda 2020). Once these upgrades begin, potentially as early as 2023, the Air Force must finish converting one launch facility per week for nine years in order to complete deployment by 2036 (Mehta 2020). It is expected that construction and deployment will begin at F. E. Warren between 2023 and 2031, followed by Malmstrom between 2025 and 2033, and finally Minot between 2027 and 2036.

As the Ground-Based Strategic Deterrent gets deployed, the Minuteman IIIs will be removed from their silos and temporarily stored at their respective host bases – either F. E. Warren, Malmstrom, or Minot – before being transported to Hill Air Force Base, the Utah Test and Training Range, or Camp Navajo. The rocket motors will eventually be destroyed at the Utah Test and Training Range, while non-motor components will ultimately be decommissioned at Hill Air Force Base. To that end, five new storage igloos and 11 new storage igloos will be constructed at Hill Air Force Base and Utah Test and Training Range, respectively (US Air Force 2020a). New training, storage, and maintenance facilities will also be constructed at the three ICBM bases, which will also receive upgrades to their Weapons Storage Areas. The first base to receive this upgrade is F. E. Warren, where a groundbreaking ceremony for the new Weapons Storage and Maintenance Facility (also called the Weapons Generation Facility) was held in May 2019. Substantial construction began in spring 2020 and is scheduled to be completed in September 2022 (Kristensen 2020b; US Air Force 2019d). Commercial satellite imagery indicates that construction has made considerable progress as of March 2022 (see Figure 2).

In May 2021, the US Congressional Budget Office estimated that the cost of acquiring and maintaining the Ground-Based Strategic Deterrent would total approximately $82 billion over the 10-year period between 2021–2030 – approximately $20 billion more than the Congressional Budget Office had previously estimated for the 2019–2028 period (Congressional Budget Office 2021, 2019).

The Air Force conducts several Minuteman III flight-tests each year. The first test of 2021 took place on February 23rd, when a team of airmen derived from all three ICBM bases launched a Minuteman III from Vandenberg Air Force Base to the Reagan Test Site on Kwajalein Atoll in the Western Pacific (Defense Visual Information Distribution Service 2021).

The second planned test launch of 2021 was aborted immediately prior to launch on May 5th – an extremely rare incident. In a statement, the Air Force Global Strike Command spokesperson noted that "During terminal countdown, the missile computer detected a fault in the sequence of checks it does prior to launching. Upon detection of this fault, it shut itself down" (Cohen 2021).

The final test of 2021 took place on August 11, which "involved a Hi Fidelity Joint Test Assembly re-entry vehicle that detonated conventional (i.e. non-nuclear) explosives prior to hitting the surface of the water" (US Air Force 2021a).

The first planned Minuteman III test of 2022 was postponed on March 2nd due to the Russian invasion of Ukraine and associated heightened nuclear tensions. A Pentagon spokesperson stated that this postponement was intended "to demonstrate that we have no intention of engaging in any actions that can be misunderstood or misconstrued" (Garamone 2022).

Nuclear-powered ballistic missile submarines

The US Navy operates a fleet of 14 Ohio-class ballistic missile submarines, of which eight operate in the Pacific from their base near Bangor, Washington, and six operate in the Atlantic from their base at Kings Bay, Georgia. Normally, 12 of the 14 submarines are considered operational, with the remaining two boats in a refueling overhaul at any given time. But because operational submarines undergo minor repairs at times, the actual number at sea at any given time is closer to eight or 10. Four or five of those are thought to be on "hard alert" in their designated patrol areas, while another four or five boats could be brought to alert status in hours or days.

Each submarine can carry up to 20 Trident II D5 submarine-launched ballistic missiles (SLBMs), a number reduced from 24 to meet the limits of New START. Since 2017, the Navy has been replacing the original Trident II D5 with a life-extended and upgraded version known as Trident II D5LE (LE stands for "life-extended"). The D5LE, which has a range of

more than 12,000 km (7,456 miles), is equipped with the new Mk6 guidance system designed to "provide flexibility to support new missions" and make the missile "more accurate," according to the Navy and Draper Laboratory (Naval Surface Warfare Center 2008; Draper Laboratory 2006). The D5LE upgrade will continue until all boats have been upgraded and will also replace existing Trident SLBMs on British ballistic missile submarines. The D5LE will also arm the new US Columbia-class and British Dreadnought-class ballistic missile submarines when they enter service.

Instead of building a new ballistic missile, like the Air Force wants to do with the Ground-Based Strategic Deterrent, the Navy plans to do a second life-extension of the Trident II D5 to ensure it can operate through 2084 (Eckstein 2019). In 2021, the Director of the Navy's Strategic Systems Program testified to Congress that the D5LE2, as the second life-extended missile is known, is scheduled to enter service on the ninth Columbia-class SSBN, following which it will be back-fitted to the remaining eight boats (Wolfe 2021a). The Navy also announced in 2021 that it would acquire an additional 108 Trident missiles to be used for deployment and testing (Wolfe 2021b).

Each Trident SLBM can carry up to eight nuclear warheads, but they normally carry an average of four or five warheads, for an average load-out of approximately 90 warheads per submarine. The payload of the different missiles on a submarine are thought to vary significantly to provide maximum targeting flexibility, but all deployed submarines are thought to carry the same combination. Normally, around 950 warheads are deployed on the operational ballistic missile submarines, although the number can be lower due to maintenance of individual submarines. The New START data from September 2021, however, indicated there were 944 warheads deployed on 221 SLBM launchers (State Department 2021b). Overall, SSBN-based warheads account for approximately 70 percent of all warheads attributed to the United States' deployed strategic launchers under New START.

Three warhead types are deployed on SLBMs: the 90-kiloton enhanced W76-1, the 8-kiloton W76-2, and the 455-kiloton W88. The W76-1 is a refurbished version of the W76-0, which is being retired, apparently with slightly lower yield but with enhanced safety features added. The NNSA completed production of the W76-1 in January 2019, a massive decade-long production of an estimated 1,600 warheads (Energy Department 2019a). The Mk4A re-entry body that carries the W76-1 is equipped with a new arming, fuzing, and firing unit with better targeting efficiency than the old Mk4/W76 system (Kristensen, McKinzie, and Postol 2017).

The other SLBM warhead, the higher-yield W88, is currently undergoing a life-extension program that addresses nuclear safety concerns and will ultimately support future life-extension options. The first production unit for the W88 Alt 370 was completed on July 1, 2021 (NNSA 2021a).

In the final weeks of 2019, the Navy deployed a low-yield version of the W76-1 known as W76-2 on the *USS Tennessee* (SSBN-734). The W76-2 only uses the warhead fission primary to produce a yield of about 8 kilotons. The First Production Unit of the W76-2 was completed at the Pantex Plant on February 22, 2019 and reached initial operational capability some time before the end of the fiscal year on September 30, 2019 (NNSA 2019). It is unknown exactly how many W76-2 warheads were produced; however, the NPR says it's a "small number" (US Defense Department 2018, 54). We estimate that no more than 25 were ultimately produced, and that one or two of the 20 missiles on each SSBN is armed with one or two W76-2 warheads, while the remainder of the SLBMs will be filled with either the 90-kiloton W76-1 or the 455-kiloton W88 (Arkin and Kristensen 2020).

The United States is also planning to build a new SLBM warhead – the W93 – which will be housed in the Navy's proposed Mk7 aeroshell (re-entry body). The W93 appears intended to initially supplement, rather than replace, the W76-1 and W88. A second new warhead is planned to replace those warheads.

The US sea-based nuclear weapons program also provides substantial support to the British nuclear deterrent. The missiles carried on the Royal Navy ballistic missile submarines are from the same pool of missiles carried on US ballistic missile submarines. The warhead uses the Mk4A re-entry body and is thought be a slightly modified version of the W76-1 (Kristensen 2011b); the British government calls it the Trident Holbrook (UK Ministry of Defence 2015). The Royal Navy also plans to use the new Mk7 for the replacement warhead it plans to deploy on its new Dreadnought submarines in the future. Despite a significant lobbying effort on the part of the United Kingdom, including an unprecedented letter to the US Congress from the UK Minister of Defense asking it to support the W93 warhead, the program's status has not yet been settled (Borger 2020).

Since the first deterrent patrol in 1960, US ballistic missile submarines have conducted approximately 4,200 deterrent patrols at sea. During the past 15 years,

operations have changed significantly, with the annual number of deterrent patrols having declined by more than half, from 64 patrols in 1999 to 30 to 36 annual patrols in recent years. Most submarines now conduct what are called "modified alerts," which mix deterrent patrol with exercises and occasional port visits (Kristensen 2013b). While most ballistic missile submarine patrols last around 77 days, they can be shorter or, occasionally, last significantly longer. In June 2014, for example, the Pennsylvania (SSBN-735) returned to its Kitsap Naval Submarine Base in Washington after a 140-day deterrent patrol, the longest patrol ever by an Ohio-class ballistic missile submarine. In the Cold War years, the overwhelming majority of deterrent patrols took place in the Atlantic Ocean. In contrast, more than 60 percent of deterrent patrols today normally take place in the Pacific, reflecting increased nuclear war planning against China and North Korea (Kristensen 2018).

Ballistic missile submarines normally do not visit foreign ports during patrols, but there are exceptions. Over a four-year period in the late 1970s and early 1980s, US submarines routinely conducted port visits to South Korea (Kristensen 2011a). Occasional visits to Europe, the Caribbean, and Pacific ports continued during the 1980s and 1990s. After Russia's invasion of Ukraine in 2014, the Navy started to conduct one or two foreign port visits per year. A US Navy visit to Scotland in 2015 appeared to be a warning to Russia and was described as a plan to make ballistic missile submarines more visible (Melia 2015). A highly publicized visit to Guam in 2016 – the first visit to the Island by a ballistic missile submarine since 1988 – was a clear warning to North Korea. Port visits have continued every year since, except in 2020, to locations including Scotland, Alaska, Guam, and Gibraltar.

Design of the next generation of ballistic missile submarines, known as the Columbia-class, is well under way. This new class is scheduled to begin replacing the current Ohio-class ballistic missile submarines in the late 2020s. The Columbia-class will be 2,000 tons heavier than the Ohio-class and will be equipped with 16 missile tubes rather than 20. The Columbia program, which is expected to account for approximately one-fifth of the Navy's entire shipbuilding program from the mid-2020s to the mid-2030s, is projected to cost $109.8 billion (Congressional Research Service 2022, 8). The lead boat in a new class is generally budgeted at a significantly higher amount than the rest of the boats, as the Navy has a longstanding practice to incorporate the entire fleet's design detail and non-recurring engineering costs into the cost of the lead boat. As a result, the Navy's fiscal 2022 budget submission estimates the procurement cost of the first Columbia-class SSBN – the *USS Columbia* (SSBN-826) – at approximately $15 billion, followed by $9.3 billion for the second boat (Congressional Research Service 2022, 9). A $5.1 billion development contract was awarded to General Dynamics Electric Boat in September 2017, and construction of the first boat began on October 1, 2020 – the first day of fiscal 2021. General Dynamics expects to receive $75 billion in revenue over the life span of the Columbia-class project (Medici 2017). Certain elements of construction may be delayed due to the ongoing COVID-19 pandemic, as the Columbia program officer noted in June 2020 that missile tube production had already been delayed by "about a couple of months" due to the pandemic (Eckstein 2020). According to the Congressional Research Service, "Until such time that the Navy can find ways to generate additional margin inside the program's schedule, the program appears to be in a situation where many things need to go right, and few things can go wrong, between now and 2031 for the lead boat to be ready for its first patrol in 2031" (Congressional Research Service 2022, 15).

The Columbia-class submarines are expected to be significantly quieter than the current Ohio-class fleet. This is because a new electric-drive propulsion train will turn each boat's propeller with an electric motor instead of louder, mechanical gears. Additionally, the components of an electric-drive propulsion train can be distributed around the boat, increasing the system's resilience and lowering the chances that a single weapon could disable the entire drive system (Congressional Research Service 2000, 20). The Navy has never built a nuclear-powered submarine with electric-drive propulsion before, which could create technical delays for a program that is already on a very tight production schedule (Congressional Research Service 2022, 19).

In October 2019, the Columbia program manager noted in a presentation that final ship arrangements for the new class of submarines had been completed on September 6, apparently a year ahead of schedule (Bartolomei 2019). The Navy's revised schedule now indicates that the Ohio-class boats will begin going offline in fiscal 2027, around the same time that the first Columbia-class boat is scheduled to be delivered in October 2027. Sea trials are expected to last approximately three years, and the first Columbia deterrence patrol is scheduled for 2031 (Congressional Research Service 2022, 8). The Columbia deliveries will coincide with the Ohio-class boats being taken out of service, and the Navy projects that they will go from 14 boats to 13 in 2027, 12 in 2029, 11 in 2030, and 10 in 2037, before eventually climbing back to 11 in 2041 and the full

complement of 12 boats in 2042 (US Navy 2019; Rucker 2019). The lead boat of the new Columbia-class submarine fleet will be designated the *USS Columbia* (SSBN-826), and the second boat will be designated the *USS Wisconsin* (SSBN-827). The rest of the Columbia-class submarine fleet has not yet been named (US Navy 2020).

Compared with the previous year's two test launches, six Trident II D5LEs were test-launched in 2021. Four launches were conducted in February 2021 as part of a commander's evaluation test, while two more were launched from the *USS Wyoming* (SSBN-742) in September 2021 as part of a demonstration and shakedown operation (DASO-30) designed to test both the system and the crew's readiness for operational deployment (US Navy 2021). The most recent missile launch marked the 184th successful test launch of the Trident II system since its introduction into the US arsenal in 1989 (US Navy 2021).

Demonstration and shakedown operations are conducted after an ballistic missile submarine completes its engineering refueling overhaul – a multi-year operation that takes place around the 20-year point for each boat. The overhaul consists of extensive structural repairs and the refueling of the boat's nuclear reactor. These efforts resulted in a 20-year life-extension for each boomer. The Navy first completed the USS Ohio's (SSBN-726) engineering refueling overhaul in December 2005, and has since completed 16 additional overhauls, completing the *USS Wyoming*'s (SSBN-742) engineering refueling overhaul in October 2020 (US Defense Department Inspector General 2018; Naval Sea Systems Command 2020). The final ballistic missile submarine to undergo an engineering refueling overhaul is the *USS Louisiana* (SSBN-743), which began the overhaul process in August 2019 and is expected to be completed in the fall of 2022 (Naval Sea Systems Command 2021). The Columbia-class SSBNs will not require nuclear refueling; as a result, their midlife maintenance operations will take significantly less time than their Ohio-class counterparts (Congressional Research Service 2022, 5).

Strategic bombers

The US Air Force currently operates a fleet of 20 B-2A bombers (all of which are nuclear-capable) and 87 B-52 H bombers (46 of which are nuclear-capable). A third strategic bomber, the B-1B, is not nuclear-capable. Of these bombers, we estimate that approximately 60 (18 B-2As and 42 B-52 Hs) are assigned nuclear missions under US nuclear war plans, although the number of fully operational bombers at any given time is lower. The New START data from September 2021, for example, only counted 45 deployed nuclear bombers (11 B-2As and 34 B-52 Hs) (State Department 2021b). The bombers are organized into nine bomb squadrons in five bomb wings at three bases: Minot Air Force Base in North Dakota, Barksdale Air Force Base in Louisiana, and Whiteman Air Force Base in Missouri. The new B-21 bomber program will result in an increase in the number of nuclear bomber bases.

Each B-2 can carry up to 16 nuclear bombs (the B61-7, B61-11, and B83-1 gravity bombs), and each B-52 H can carry up to 20 air-launched cruise missiles (the AGM-86B). B-52 H bombers are no longer assigned gravity bombs (Kristensen 2017b). An estimated 788 nuclear weapons, including approximately 500 air-launched cruise missiles, are assigned to the bombers, but only about 300 weapons are thought to be deployed at bomber bases. The estimated remaining 488 bomber weapons are thought to be in central storage at the large Kirtland Underground Munitions Maintenance and Storage Complex outside Albuquerque, New Mexico.

The United States is modernizing its nuclear bomber force by upgrading nuclear command-and-control capabilities on existing bombers, developing improved nuclear weapons (the B61-12 and the long-range standoff missile), and designing a new heavy bomber, the B-21 Raider.

Upgrades to the nuclear command-and-control systems that the bombers use to plan and conduct nuclear strikes include the Global Aircrew Strategic Network Terminal. This is a new high-altitude electromagnetic pulse-hardened network of fixed and mobile nuclear command-and-control terminals. This network provides wing command posts, task forces, munitions support squadrons, and mobile support teams with survivable ground-based communications to receive launch orders and disseminate them to bomber, tanker, and reconnaissance air crews. First delivery of the global aircrew strategic network terminals, which the Air Force describes as "the largest upgrade to its nuclear command, control and communication systems in more than 30 years," was expected in May 2020. However, it appears that this was delayed until Barksdale Air Force Base became the first base to receive the system in January 2022 (US Air Force 2022).

Another command-and-control upgrade involves a program known as Family of Advanced Beyond Line-of-Sight Terminals, which replaces existing terminals designed to communicate with the MILSTAR satellite constellation. These new, extremely high frequency terminals are designed to communicate with several satellite constellations, including advanced extremely high frequency satellites. The 37 ground stations and

nearly 50 airborne terminals of the Family of Advanced Beyond Line-of-Sight Terminals will provide protected high-data rate communication for nuclear and conventional forces, including for what is officially called "presidential national voice conferencing." According to the Air Force (US Air Force 2019b), "[The Family of Advanced Beyond Line-of-Sight Terminals] will provide this new, highly secure, state-of-the-art capability for [Defense Department] platforms to include strategic platforms and airborne/ground command posts via MILSTAR, [advanced extremely high frequency], and enhanced polar system satellites. [The Family of Advanced Beyond Line-of-Sight Terminals] will also support the critical command and control . . . of the MILSTAR, [advanced extremely high frequency], and enhanced polar system satellite constellations."

The heavy bombers are also being upgraded with improved nuclear weapons. This effort includes development of the first guided, standoff nuclear gravity bomb, known as the B61-12, which is intended to replace all existing gravity bombs. The bomb will use a modified version of the warhead used in the current B61-4 gravity bomb. B61-12 integration drop tests have already been conducted from the B-2 bomber (the B61-12 may also be integrated onto US-and allied-operated tactical aircraft, including the F-15E, the F-16C/D, the F-16MLU, and the PA-200 Tornado). Approximately 480 B61-12 bombs, which appear to have limited earth-penetration capability, are expected to cost a total of roughly $10 billion (Kristensen and McKinzie 2016). The first production unit was initially scheduled for March 2020; however, in September 2019 a NNSA official confirmed that both the B61-12 and the upgraded W88 warhead for the Trident II SLBM would likely face delays during production due to concerns over the longevity of its commercial off-the-shelf subcomponents (Gould and Mehta 2019). The First Production Unit prototype of the B61-12 was completed on August 25, 2020 at the Pantex Plant (NNSA 2020a). The first real First Production Unit was only completed in November 2021, and full-scale production is now scheduled for May 2022 (NNSA 2021b).

The Air Force is also developing a new nuclear air-launched cruise missile known as the long-range standoff missile. It will replace the AGM-86B air-launched cruise missile in 2030 and carry the W80-4 warhead, a modified version of the W80-1 used in the current air-launched cruise missile. In February 2019, the Nuclear Weapons Council authorized the development engineering phase (Phase 6.3) for the W80-4. The production engineering stage (Phase 6.4) is planned for December 2021 (Energy Department 2019b). A solicitation invitation to defense contractors in 2015 listed three potential options for the long-range standoff engine: First, a derivative subsonic engine that improves on current engine technology by up to 5 percent; second, an advanced subsonic engine that improves on current technology by 15 percent to 20 percent; and third, a supersonic engine (US Air Force 2015). In August 2017, the Air Force awarded 5-year contracts of $900 million each to Lockheed Martin and Raytheon to develop design options for the missile. After reviewing the designs, the Air Force, in December 2019, cleared the two companies to continue development of the missile (Sirota 2019). The Air Force originally planned to down-select to a single contractor in fiscal 2022 during the awarding of the engineering and manufacturing development contract; however, in April 2020, the Air Force selected Raytheon Technologies as the prime contractor for the long-range standoff (US Air Force 2020b). This was a relatively surprising move, as selecting a single-source contractor at this early stage could ultimately result in higher program costs. In July 2021, Raytheon Technologies was awarded up to $2 billion to proceed with the engineering and manufacturing development stage of the long-range standoff, in order to prepare for full-rate production beginning in 2027 (Insinna 2021).

In March 2019, the Air Force awarded Boeing a -$250 million contract to integrate the future long-range standoff capability onto the B-52 Hs, a process that is expected to be completed by the beginning of 2025 (Hughes 2019). Development and production are projected to reach at least $4.6 billion for the missile (US Air Force 2019a) with another $10 billion for the warhead (Energy Department 2018a).

The missile itself is expected to be entirely new, with significantly improved military capabilities compared with the air-launched cruise missile, including longer range, greater accuracy, and enhanced stealth (Young 2016). This violates the 2010 White House pledge (White House 2010) that the "United States will not . . . pursue . . . new capabilities for nuclear weapons," though the NPR from 2018 did away with such constraints.

Supporters of the long-range standoff argue that a nuclear cruise missile is needed to enable bombers to strike targets from well outside the range of the modern and future air-defense systems of potential adversaries. Proponents also argue that these missiles are needed to provide US leaders with flexible strike options in limited regional scenarios. However, critics argue that conventional cruise missiles, such as the extended-range version of the Joint Air-to-Surface Standoff Missile, can currently provide standoff strike capability, and that other nuclear weapons would be sufficient to hold the targets at risk. In fact,

the conventional extended-range joint air-to-surface standoff missile is now an integral part of Strategic Command's annual strategic exercises.

Unlike the current air-launched cruise missile, which is only carried by the B-52 H bomber, the long-range standoff missile will be integrated on both the B-52 H and new B-21 bombers (Kristensen 2013c). Warhead production is scheduled from 2025 through 2031. The Air Force plans to buy 1,000 missiles (Reif 2015), but there will only be enough warheads for about half of those. The excess missiles are intended to be used as spares and for test flights over the course of the weapon's 30-year service life. Moreover, several hundred of the existing air-launched cruise missiles were converted to conventional missiles (AGM-86C/D) and the US Air Force Global Strike Command has previously indicated that it intends to develop a conventional version of the long-range standoff (Wilson 2015).

But given the deployment of several new long-range conventional cruise missiles and the development of even more advanced versions, it remains to be seen if the Air Force can persuade Congress to also pay for a conventional version of the long-range standoff. Indeed, the Air Force has replaced the AGM-86C/D conventional air-launched cruise missile with the extended-range conventional Joint Air-to-Surface Standoff Missile. If Congress will not pay for conventional long-range standoffs, it can probably be assumed that the plan to buy 1,000 missiles can be reduced by several hundred.

Northrop Grumman continues to develop the new B-21 Raider next-generation heavy bomber, as the preliminary design review received approval in early 2017 and the first test vehicle is currently in production. The B-21 is scheduled to make its first flight no earlier than 2022 from its production facility in Palmdale, California, to Edwards Air Force Base (Wolfe 2020). The B-21 is expected to enter service in the mid-2020s to gradually replace the B-1B and B-2 bombers during the 2030s, and it is expected that the Air Force will procure at least 145 of the new bombers at an estimated cost of $550 million per plane to increase the total bomber force from 175 to 220 aircraft (Tirpak 2020).

The Air Force announced in March 2019 that the B-21 bombers will first be deployed at Ellsworth Air Force Base (South Dakota), followed by Whiteman Air Force Base (Missouri) and Dyess Air Force Base (Texas) "as they become available" (US Air Force 2019c). The upgrade of the non-nuclear B-1 bases to the nuclear B-21 bomber will increase the number of bomber bases with nuclear weapons storage facilities from two bases today (Minot AFB and Whiteman AFB) to five bases by the 2030s (Barksdale AFB will also regain nuclear storage capability) (Kristensen 2020c). Further details about the B-21 program, including updated cost estimates, are still shrouded in secrecy; however, like all previous bomber programs, the costs will most likely increase.

The B-21 is very similar in design to the B-2 but is expected to be slightly smaller and have a reduced weapons capability. The B-21 will be capable of delivering both the B61-12 guided nuclear gravity bomb and the long-range standoff, as well as a wide range of non-nuclear weapons, including the Joint Air-to-Surface Standoff cruise missile.

In early 2022, the Air Force announced that six B-21 bombers were currently in production, and the first assembled bomber was taken to conduct its calibration tests in early March 2022 (Tirpak 2022). This aircraft will be the first B-21 to make a maiden flight, which is expected in mid-2022 from its manufacturing and assembly facility to Edwards Air Force Base in California (Tirpak 2022).

Nonstrategic nuclear weapons

The United States has one type of nonstrategic nuclear weapon in its stockpile: the B61 gravity bomb. The weapon exists in two modifications: the B61-3 and the B61-4. A third version, the B61-10, was retired in September 2016. Approximately 200 tactical B61 bombs of all versions remain in the stockpile. About 100 of these (versions −3 and −4) are thought to be deployed at six bases in five European countries: Aviano and Ghedi in Italy; Büchel in Germany; Incirlik in Turkey; Kleine Brogel in Belgium; and Volkel in the Netherlands. This number has declined since 2009 partly due to reduction of operational storage capacity at Aviano and Incirlik (Kristensen 2015, 2019c). The remaining 100 B61s stored in the United States are for backup and potential use by US fighter-bombers in support of allies outside Europe, including northeast Asia. This includes F-15Es from the 391st Fighter Squadron of the 366th Fighter Wing at Mountain Home in Idaho (Charkhuff 2021).

The Belgian, Dutch, German, and Italian air forces are assigned nuclear strike missions with US nuclear weapons. Under normal circumstances, the nuclear weapons are kept under the control of US Air Force personnel; their use in war must be authorized by the US president. The Belgian and Dutch air forces currently use the F-16 aircraft for the nuclear missions, although both countries are in the process of obtaining the F-35A to eventually replace their F-16s. The Italian Air Force

uses the PA-200 Tornado for the nuclear mission but is in the process of acquiring the F-35A. Like the Tornados, the nuclear F-35As will be based at Ghedi Air Base, which is currently being upgraded. Germany also uses the PA-200 Tornado for the nuclear mission; however, it is planning to retire its Tornados by 2030, and would require a new dual-capable aircraft if it intended to remain part of NATO's nuclear sharing mission. The new German coalition government announced in November 2021 that it intended to do so, and it is rumored that the German government will issue a letter of request to purchase the Boeing F/A-18E/F Super Hornet in early 2022 to replace its Tornado aircraft (Siebold and Wacket 2021; Jennings 2021). Yet the F-35A is apparently still a candidate (Reuters 2022).

At least until 2010, Turkey was still using F-16s for the nuclear mission, although it is possible that the mission has since been mothballed. In 2019, the Trump administration also halted delivery of F-35As to Turkey – some of which were intended to take over the nuclear mission – because of its plans to acquire the Russian S-400 air-defense system (DeYoung, Fahim, and Demirjian 2019). Legislators and analysts raised concerned about the security of the nuclear weapons at the Incirlik base during the failed coup attempt in Turkey in July 2016; the chairman of the Senate Foreign Relations Subcommittee for Europe stated in September 2020 that "our presence, quite honestly, in Turkey is certainly threatened," and further noted that "we don't know what's going to happen to Incirlik" (Gehrke 2020). Despite rumors in late 2017 that the weapons had been "quietly removed" (Hammond 2017), the New York Times reported in 2019 that US officials had reviewed emergency nuclear weapons evacuation plans for Incirlik, indicating that that there were still weapons present at the base (Sanger 2019). The numbers appear to have been reduced, however, from up to 50 to approximately 20. If the United States decided to withdraw the remaining nuclear weapons from Incirlik, it could probably do so with a single C-17 transport aircraft from the 4th Airlift Squadron at Joint Base Lewis-McChord in Washington – the only unit in the Air Force that is qualified to airlift nuclear weapons.

NATO States that do not host nuclear weapons can still participate in the nuclear mission as part of conventional supporting operations, known as Support Nuclear Operations With Conventional Air Tactics – or SNOWCAT.

Figure 3. A B61-12 guided nuclear bomb is dropped from an F-35A. The B61-12 will enter full-scale production in May 2022 and probably begin deploying to bases in Europe in 2023. Image: USAF.

NATO is working on a broad modernization of the nuclear posture in Europe that involves upgrading bombs, aircraft, and the weapons storage system. The B61-12 is estimated to be 12 feet long, weighing approximately 825 pounds, and is designed to be air-launched in either ballistic or gravity drop modes (Baker 2020). The B61-12 will use the nuclear explosive package of the B61-4, which has a maximum yield of approximately 50 kilotons and several lower-yield options. However, it will be equipped with a guided tail kit to increase accuracy and standoff capability, which will allow strike planners to select lower yields for existing targets to reduce collateral damage. The increased accuracy will give the tactical bombs in Europe the same military capability as strategic bombs used by the bombers in the United States. Although the B61-12 has not been designed as a designated earth-penetrator, it does appear to have some limited earth-penetration capability. This increases its ability to hold at risk underground targets (Kristensen and McKinzie 2016). Until their new aircraft are ready, Italy and Germany will continue to fly the PA-200, which, due to its age and legacy systems, will not be able to utilize the B61-12s new guided tail kit function. Instead, it will deliver the bomb as a "dumb" bomb akin to the current B61-3s and B61-4s.

In March 2020, the F-15E became the first aircraft to be certified to operate the B61-12, after completing the last in a series of six compatibility tests at Nellis Air Force Base and the Tonopah Test Range (Baker 2020). In addition to the F-15E, integration of the B61-12 on B-2, F-16, and PA-200 aircraft is well under way. In October 2021, the F-35A completed two drop tests of the B61-12 Joint Test Assembly (see Figure 3), thus completing the final stage of its nuclear design certification process (US Air Force 2021b). The B61-12 will begin full-scale production in May 2022, certification with the F-35A before January 2023, followed by training of the nuclear fighter-wings in Europe later in 2023 (Defense Visual Information Distribution Service 2022). Once deployment to Europe begins, possibly in 2023, the B61-3/4 bombs currently deployed in Europe will be returned to the United States.

NATO is life-extending the weapons storage security system, which involves upgrading command and control, as well as security, at the six active bases (Aviano, Büchel, Ghedi, Kleine Brogel, Incirlik, and Volkel) and one training base (Ramstein). Specifically, these upgrades include the installation of double-fence security perimeters, modernizing the weapon storage and security systems and the alarm communication and display systems, and the operation of new secure transportation and maintenance system trucks (Kristensen 2021b). Security upgrades now appear to have been completed at Aviano and Incirlik and are underway at Ghedi.

In addition to the modernization of weapons, aircraft, and bases, NATO also appears to be increasing the profile of the dual-capable aircraft posture. In June 2020, for example, the 31st Fighter Wing at Aviano Air Base conducted the first "elephant walk" ever to display all aircraft in a single visual show of force of its capability to "deter and defeat any adversary who threatens US or NATO interests" (US Air Force 2020c). NATO's annual Steadfast Noon nuclear force exercise also includes participation from a large number of NATO members every year. In 2021, the exercise involved the participation of 14 countries – including Dutch and Belgian F-16s, and German and Italian Tornados – over southern Europe (NATO 2021).

Having reached 50 ratifications in October 2020, the Treaty on the Prohibition of Nuclear Weapons officially entered into force on January 22, 2021. It is unclear whether the treaty will have an effect on the status of NATO's nuclear posture over the coming years – and specifically on the forward-deployment of US nuclear weapons on European NATO territory. However, public opinion in Belgium, Germany, Italy, and the Netherlands is firmly opposed to hosting US nuclear weapons (International Campaign to Abolish Nuclear Weapons (ICAN) 2018). To that end, some host country parliaments have already taken actions that challenge the future of US nuclear weapons on their soil; in January 2020, a motion to "draw up, as soon as possible, a roadmap aiming at the withdrawal of nuclear weapons on Belgian territory" was narrowly defeated by a vote of 74–66 in the Belgian parliament (Galindo 2020). It is possible that similar resolutions could be debated and voted upon in other nuclear hosting nations over the coming years. This explains why the United States tried in vain to persuade other countries to withdraw their ratifications, only a week before the Treaty on the Prohibition of Nuclear Weapons reached 50 ratifications (Lederer 2020).

The 2018 NPR recommended rapid development of a nuclear nonstrategic submarine-launched cruise missile to recreate a capability to deploy such a weapon in support of NATO (and Pacific) allies. A previous cruise missile was retired in 2011. The new weapon would likely be intended for deployment on attack submarines. The analysis of alternatives for the nuclear nonstrategic submarine-launched cruise missile was scheduled to be completed in 2021, with development of the missile

beginning in 2022. However, it remains unclear whether the Navy has met these deadlines (Wolfe 2021b). It also remains unclear whether the Biden administration will continue the project.

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