The Hague Centre for Strategic Studies

Shifting sands of strategic stability

Towards a new arms control agenda

Paul van Hooft, Lotje Boswinkel and Tim Sweijs

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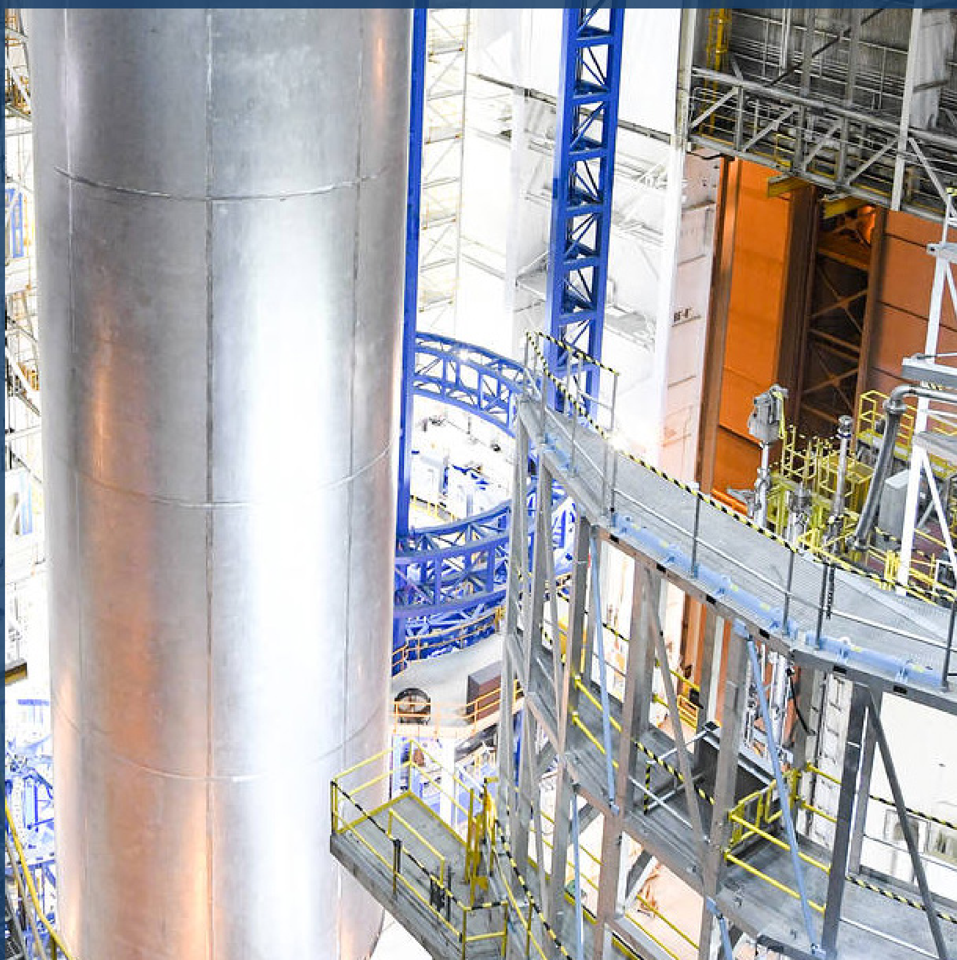

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Executive Summary

The reemergence of geopolitical competition, the advent of nuclear multipolarity, and multiple emerging technologies, are reshaping incentives to search for a first strike advantage as well as prompting more reckless behavior of actors during a crisis

Increased geopolitical competition, nuclear multipolarity, and emerging technologies are steadily undermining strategic stability as well as the existing arms control and non-proliferation regime architecture. The 1980s and 1990s were a high-water point in terms of the normative and legal institutionalization of arms control and non-proliferation regimes, including, but not limited to, the Intermediate-Range Nuclear Forces (INF) Treaty, the Strategic Arms Reductions Treaty (START) and the Strategic Offensive Reductions Treaty (SORT), the Missile Technology Control Regime (MTCR), the Open Skies Treaty (OST), the Vienna Document (VD), and the Wassenaar Arrangement. We are seeing a disintegration of these regimes.

This report first offers an in-depth analysis of how both geopolitical and technological developments affect strategic stability. It then looks at the arms control, non-proliferation and deterrence policy measures that states have at their disposal to contain and prevent the *production*, *proliferation*, *deployment* and *employment* (PPDE) of weapon technologies that threaten strategic stability, to provide new solutions for a new generation of durable arrangements. While arms control and non-proliferation efforts are aimed at countering the production, the proliferation and the deployment of such capabilities, deterrence seeks to prevent their actual employment. Rather than singling out one weapon technology or one specific arms control regime, it introduces a new analytical framework that assesses the feasibility of policy measures to control weapon technologies along the PPDE-chain. Applying this framework to ten emerging weapon technologies, the report identifies specific policy measures to curtail the risks associated with each of them. The overview of measures offers European and Dutch policymakers a blueprint for a broader integrated arms control agenda, and facilitates careful consideration of the appropriate balance of policy mixes along the PPDE-chain included therein. On that basis the report offers a set of policy recommendations to policymakers to bolster strategic stability.

Strategic stability

Geopolitical competition, nuclear multipolarity, and emerging technologies affect both aspects of strategic stability: deterrence stability and crisis stability. Nuclear deterrence aims to raise the costs of aggression to unacceptable levels. Its credibility depends on ensuring that a state will always have a secure second strike capability to inflict catastrophic damage on its opponent even after a first strike by the adversary. Deterrence stability can then be defined as a situation in which both adversaries remain confident of their capability to conduct a retaliatory second strike. If neither party believes they nor their adversary can gain an advantage by attacking first, neither has an incentive to engage in quantitative or qualitative arms racing over extended periods of time. Crisis stability, in turn, can be defined as a situation in which actors believe their ability to retaliate remains intact even if they do not immediately respond to aggression. When they do not believe this, use-it-or-lose-it dynamics emerge. Crisis stability lies close to *escalation control*, or the ability to prevent conventional or limited nuclear use to escalate uncontrollably into a catastrophic conflagration. Unlike the former, the time horizon is very short for crisis stability. The reemergence of geopolitical competition, the advent of nuclear multipolarity, and multiple emerging technologies, are reshaping incentives to search for a first strike advantage as well as prompting more reckless behavior of actors during a crisis (see Table 1).

Table 1. Effects of increased competition and multipolarity on deterrent and crisis stability

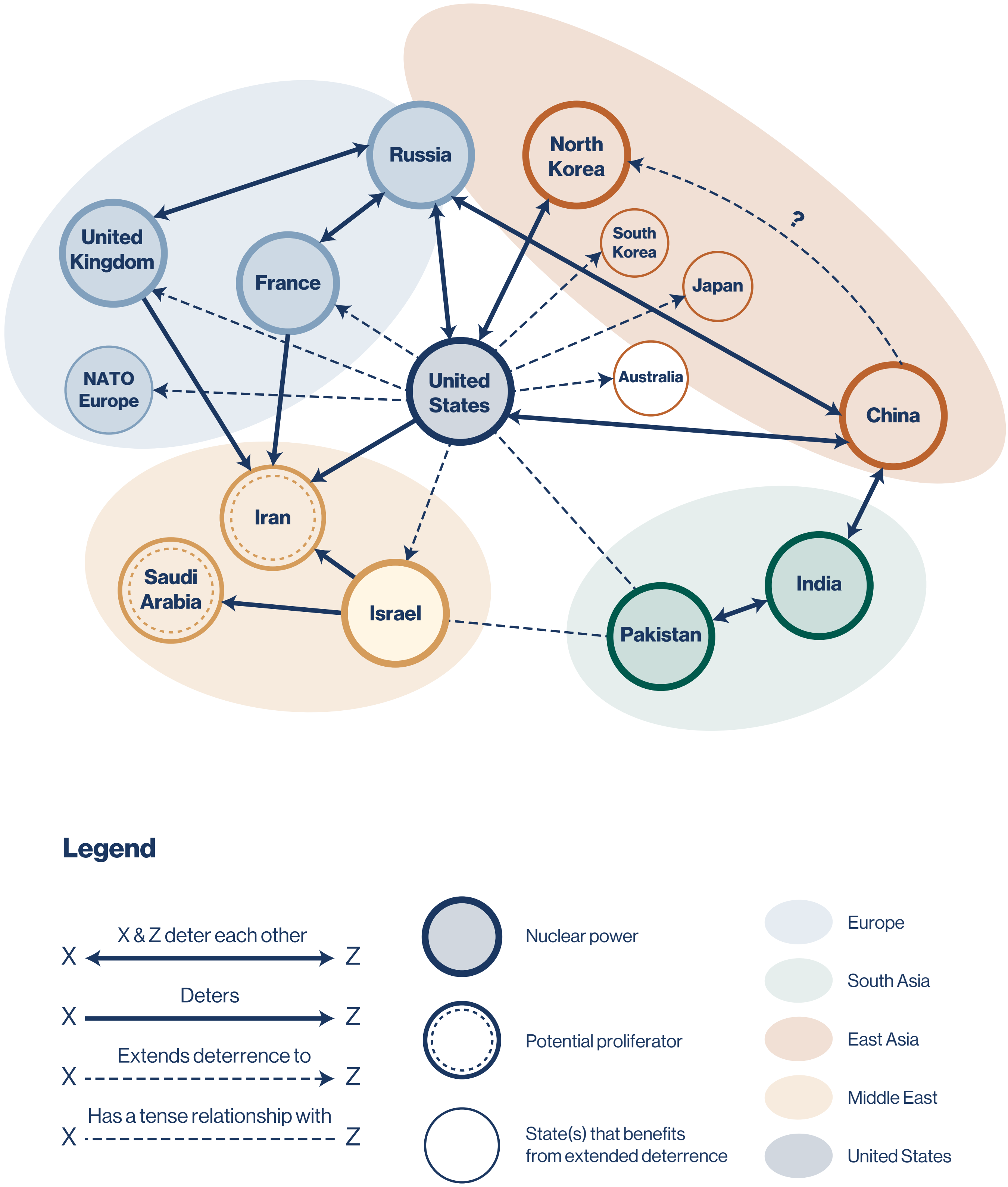
	Deterrence Stability	Crisis Stability
Competition	The intensification of conventional and nuclear competition diminishes the confidence in a secure second strike.	Misunderstandings during a crisis are likely to increase due to the unpredictability of purpose of policies and stark outcome differences.
Multipolarity	The complexity of long-term strategic calculus increases, given the growing number of nuclear actors and access to technology.	The lack of deeply institutionalized ties among powers increases uncertainty and the likelihood of errors in judgement.

Geopolitical trends

Intensified competition between great powers and new regional powers, interacting with the addition of new nuclear powers since the end of the Cold War, has led to a second nuclear age that is no longer characterized by the bilateral relationship between the United States and the Soviet Union. During the Cold War, the two superpowers held large and dispersed nuclear arsenals that were, for all intents and purposes, impossible to eliminate in a first strike. Arms control efforts between the two eventually became deeply institutionalized.

At the center of the current nuclear age, however, is the triangular relationship between the United States, Russia, and China. Interacting with this core of great powers, are the UK, France, and Israel, as well as three states that have acquired nuclear weapons after the Cold War: Pakistan, India, and North Korea. As the extra-regional hegemonic power in Europa, Asia and the Middle East, the United States occupies a uniquely central position in the dyads. Its nuclear rivals aim to deter the US from involvement in regional issues, whether through nuclear or conventional means. The competitive pressures therefore exist at the regional level and secondarily on the global level (see Figure 1).

Figure 1. Interacting nuclear dyads and strategic relationships



Emerging technologies

The development and weaponization of new and existing technologies, in turn, is largely driven by the new geopolitical competition. The report looks at ten weapon technologies for strategic stability through their impact on deterrence and on crisis stability: 1) hypersonic missiles; 2) anti-satellite weapons; 3) directed-energy weapons; 4; dual-capable missiles; 5) missile defense systems; 6) offensive cyber capabilities; 7) lethal autonomous weapon systems; 8) remote sensing, 9) artificial intelligence; and 10) dual-capable C3I systems. Each has different effects on deterrent and crisis stability.

The nuclear revolution is not absolute and nuclear stalemate is reversible

First, the means to achieve a competitive advantage have increased. Emerging technologies could re-open the door of arms racing for first strike advantages and secure second strikes (see Table 2). The nuclear revolution is not absolute and nuclear stalemate is reversible. The sophistication of precision-guided weapons through sensing, data fusion, and machine speed responses provides military planners with nuclear as well as conventional counter-force options, as these advanced conventional weapons can fulfill some of the same tasks as nuclear weapons due to increased precision. In combination with the revolution or evolution of missile technology that hypersonic cruise missiles and glide vehicles represent – with their abilities to fly at speeds above Mach-5, fly low, and maneuver in order to evade timely detection and interception – the decision-making windows for policymakers are shrinking. While part of the answer may lie in more effective air and missile defense, aided by the defender's own artificial intelligence and autonomous sensing, such measures themselves may also lead states to pursue next generation offensive capabilities. Together this may further a general use-it-or-lose-it sense. It is also more difficult than during the Cold War to erect clear barriers between strategic weapons and advanced conventional weapons. The same Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance (C4ISR) systems that enable effective conventional precision-strike overlap with those used for nuclear weapons. Disabling the C4ISR infrastructure that underpins an adversary's Anti-Access Area Denial (A2/AD) may be essential within a conventional conflict but may be indistinguishable from the first stage of a nuclear first strike. The risk that a conventional conflict inadvertently escalates further destabilizes European and Asian security. Complicating matters further is that many of the technologies driving the new instability are dual-use in nature. Unlike the Cold War era, most of today's innovation may in fact be taking place in the commercial sector. This poses a challenge to non-proliferation agreements, such as the Wassenaar Arrangement and the MTCR. New arms control agreements that deal with these technological changes will consequently need to take into account this more multi-faceted view of technology and the evolved configuration of the political landscape – similar to how the 1996 Wassenaar Arrangement superseded the Cold War's era Coordinating Committee for Multilateral Export Controls launched in 1949.

Table 2. Emerging technologies and strategic stability

Emerging Technology	Deterrence Stability	Crisis Stability
Hypersonic missiles	Compressed timelines increase suitability for conventional or nuclear first strike.	Compressed timelines may create misperception and miscommunication.
		A failure to discriminate between conventional and nuclear warhead during flight could lead to errors of judgement.
Anti-satellite weapons	Disruption of sensing and command and communication can become an opening stage of first strike.	Errors of judgements may occur due to uncertainty about whether attack is directed at conventional or nuclear infrastructure.
Directed energy weapons	Potential use in missile defense and as ASAT undermines confidence in second strike capabilities.	Errors of judgment may occur as a consequence of speed of delivery and low detectability.
Dual-capable C3I and missiles	Dual-capable systems create the opportunity to conduct conventional first strikes on adversary's nuclear arsenal without nuclear weapons.	Risk of inadvertent escalation increases due to inability to distinguish between opening stages of nuclear or conventional attack.
Missile defense	Missile defense decreases adversary's confidence in its second strike.	Need for speed increases potential for technical and human errors of judgement.
	Defenses may incentivize the adoption of launch-under-attack posture.	
Offensive cyber capabilities	Cyber capabilities create new opportunities for non-kinetic left-of-launch attacks on first strike.	Errors of judgment may arise from discrimination problem in cyber intrusion between surveillance and attack.
	Capabilities allow for the manipulation of data to influence, disrupt, or decapitate command and control.	
Lethal autonomous weapons	Attacks on nuclear weapon delivery systems, command and control systems, and sensitive infrastructure components can overwhelm an adversary.	Limited human involvement and the speed of LAWS could increase unintended escalation.
Remote sensing	AI-enabled detection of concealed and mobile nuclear launch-platforms undermines second-strike capabilities.	Attacks on satellites could be mistaken for attacks on the nuclear infrastructure.
Artificial intelligence	Improvements in data analysis and speed can create first strike capabilities.	Compressed timeframes and potential biases in machine learning could lead to errors of judgement.

Second, the opportunities to pursue a competitive advantage have grown, and European policymakers will need to deal with the implications of emerging nuclear and conventional precision-strike multipolarity. The emergence of China as a challenger to American power in Asia alongside a revanchist Russia has created a three-way interaction with consequences for deterrence within Europe as well as for arms control. Russia has looked to its large and varied arsenal of nuclear weapons to compensate for its declining status. Moreover, Russian military strategy includes plans to use this arsenal for leverage in concrete scenarios in northeastern Europe. Simultaneously, the intensifying Sino-American competition has spurred China to innovate a series of conventional missile capabilities – generally referred to, together with its set of sensing and Command and Control assets, as A2/AD capabilities – that aim to raise the costs for US power projection in the Western Pacific. Moreover, as China makes advances in missile technology, it is likely that smaller and medium powers within Asia and elsewhere will seek to acquire their own conventional precision-strike capabilities. While these states long had the motive, now they have the opportunity to act on it. In a multipolar world they will be able to purchase such capabilities from China and Russia, or emulate their successes through their own indigenous efforts. These developments have various consequences for Europe. In part, the United States withdrew from the INF with Russia to free itself to develop short and middle range missiles for the Western Pacific. The US National Defense Strategy already underlined that the United States will only plan for one major regional war at a time, relying on deterrence in the second region. It is apparent from the 2018 Nuclear Posture Review (NPR) that US officials perceive deterrence gaps in the European theater. In fact, US officials implicitly acknowledge that the linkage between American conventional deterrence through a physical presence in Europe has been weakened, because the NPR increased the role of low-yield nuclear weapons as a substitute for conventional forces in the European theater. Durable arms control efforts in the emerging multipolar world must therefore evolve from the arrangements that were based on the bipolar Cold War context and adapt to the circumstances of today.

Unsurprisingly, Europe has a more limited role in a geopolitical environment that centers around a trilateral American-Russian-Chinese nuclear relationship. However, European states could address the conventional imbalance between NATO Europe and Russia. This imbalance in NATO's northeast adds escalatory pressure to the US to fill the deterrence gaps in the escalation ladder through greater flexibility in its nuclear arsenal and investments in advanced conventional weapons. In the realm of strategic stability, a distinction can be made between deterrence by punishment and deterrence by denial. Nuclear weapons are nearly exclusively used for deterrence by punishment. An avenue to prevent the re-nuclearization of European security is therefore to strengthen Europe's capability for conventional deterrence by denial. Similar to the success of Cold War arms control and non-proliferation efforts, acquiring such capabilities would also improve the negotiation position of European states to pursue new agreements with Russia. Most European states are not yet directly involved in the arms competition, with the partial exceptions of the UK and France. But the interlocking competitions will involve them eventually, and Europe is certainly central to the nuclear competition between the US and Russia. More importantly, Europeans are closely involved with the development of the plethora of dual-use technologies that are driving the technological dynamics of strategic instability. Consequently, Europeans must take their responsibility, for strengthening strategic stability, both through arms control and counter proliferation (see below) and through greater investments in deterrence. The consequences of inaction are high.

Assessments along the production-proliferation-deployment-employment chain

This report therefore assesses which arms control, non-proliferation an deterrence approaches are best suited for the various technological developments. It examines the stages through which an emerging (or existing) weapon technology is being developed and brought into use. Each of these stages has a different logic. *Production* encompasses possession of the technological knowledge, basic skills, and access to materials to indigenously produce a weapon technology. *Proliferation* includes the ability to acquire technologies and materials from other states or non-state actors. *Deployment* refers to what other hard constraints, such as platform technologies or access to specific locations, would allow the weapon technology to be put to use. *Employment* covers all the soft constraints such as organizational aptitude and fitness to effectively use the technology.

Along this production-proliferation-deployment-employment chain, the ten emerging technologies are evaluated using a rigorous assessment framework on the basis of desk research, expert interviews and iterative discussions within the project team followed by an independent review of a subject matter expert (see Table 3 and Figure 4 for a visual representation). Using the assessment framework, each technology is scored low, medium or high, indicating the ease, feasibility or likelihood of its production, proliferation, deployment and employment.

Table 3. Assessments for all weapon technologies and stages

	Production	Proliferation	Deployment	Employment
Hypersonic missiles	Low	Low	Medium	High
ASATs	Low	Medium	Medium	Low
DEWs	Low	Medium	Low	Low
Dual-capable missiles	Medium	Medium	Medium	Medium
Missile defense	Low	Low	Low	High
Cyber	Medium	High	Low	Medium
LAWS	Low	Medium	Medium	Low
Remote sensing	Medium	Medium	Medium	High
AI	Low	Medium	Medium	Low
Dual-capable C3I	High	Medium	High	High

The assessment of technologies along the PPDE-chain offers a number of insights. First, the production of most emerging technologies is still highly complex and will thus be restricted to major military powers. Crucially, only those applications of relevance to strategic stability are considered: cyber attacks on critical national infrastructure or high-value military infrastructures for sustained periods of time and antisatellite weapons taking out nuclear communication assets are therefore considered; simple LAWS or anti-drone laser systems are not. With the exception of hypersonic missiles and missile technology, the proliferation of all discussed technologies scores at least medium if not high: emerging technologies' dual-use nature is most often to blame for this. Offensive cyber capabilities spread most rapidly, as the technology is not merely dual-use but even omni-use, in addition to being largely intangible. When it comes to deployment, the majority of technologies require fairly or very sophisticated infrastructures, weapon platforms and enablers, with at times modification of existing technologies possible. Only the deployment of dual-capable C3I is supposedly straightforward, even if strictly limited to nuclear powers. Finally, the assessment reveals that more "traditional" technologies such as offensive and defensive missile capabilities are most easily employable. For more novel ones, various organizational, doctrinal and normative constraints often hinder their use. In a next step, the assessments help identify the stages where arms control, non-proliferation and deterrence measures can be most effectively targeted.

More "traditional" technologies such as offensive and defensive missile capabilities are most easily employable

Figure 2. Technology assessments along the PPDE-chain

Solutions

Emerging technologies lend themselves to a wide variety of both time-tested and newer arms control, non-proliferation, and deterrence measures along the PPDE chain. Compared to the past, today the focus of arms control lies less on arsenal size reductions. Our analysis shows that in this emerging landscape the emphasis of arms control is shifting from controlling primary production inputs to limiting their military applicability and proliferation. Because emerging technologies are often of dual-use nature and intangible or miniaturized, traditional export control tools are increasingly difficult to design, implement and verify. As a result, dual-use export control lists need to be highly specific and tailored; and because of the extremely fast-paced environment, continuously revised and updated. For some technologies, such as cyber, AI and LAWS, limiting the proliferation of expertise could be promising. Furthermore, traditional quantitative measures that were salient in previous times (INF, START, ABM) have become less relevant for newer technologies. This is partly political: multipolarity lends itself less to a quantity-based approach because different geopolitical dynamics ask for different arms control solutions. But the intangible nature of several of the emerging technologies makes capping deployment also technically complex, if not impossible. Finally, it appears that confidence-building measures constitute a considerable part of the toolbox at hand. In times of increased international competition and eroding trust, working towards arms control and achieving the intended effects of confidence-building measures will prove challenging. States are naturally inclined to seek comparative advantages, a tendency which is further exacerbated by notions such as an AI winner-takes-all market and fears of a hypersonic missile gap.

A closer look at the blueprint for a new arms control, non-proliferation and deterrence agenda (see Table 4) suggests four robust and general avenues for European and Dutch policymakers to focus their efforts on. Each of these encompasses the longer and much more detailed list of solutions presented in Table 4.

1. Curbing production and proliferation: update, coordinate, collaborate

The first type of solutions should be aimed at curbing production and proliferation. Traditional export control regimes are challenged but still relevant. In their role as major producers and consumers of high-end technology, the EU, and the Netherlands particularly, have much greater leverage in setting the standards for dual-use technologies. Constantly reviewing and revising specific and tailored export lists is key, even if they are hard to implement and verify, and technological developments fast outpace regulation efforts. Involving the private sector in creating and evaluating export regulations is crucial to ensure support and ease of implementation. Private sector activities rather than products can also be specifically targeted through know-your-vendor laws. The proliferation of knowledge and expertise can be countered by contract obligations. More traditional measures such as pre-launch notifications for tests or stricter regulation for testing could help curb the production of tangible, more traditional technologies such as hypersonic missiles, ASATs, DEWs and missile defense.

2. Reducing risk through technical and political means: specify, verify, declare

The second type of solutions should focus on risk reduction: when the deployment of technologies cannot be curbed, the risks associated with deployment and use should be controlled to prevent inadvertent escalation. Risk reduction can be achieved both through technical and political means. Cross-checking is crucial when dealing with automation, but necessary more generally in an age of mis- and disinformation. Confidence-building measures include political hotlines, technical cross-verification measures, and optimal situational awareness capabilities, preferably shared. Unilateral declaratory statements may further enhance trust or increase risk-awareness.

3. Developing norms and rules: shape, regulate, demonstrate

The stakes in strategic stability are high for everyone

The third set of measures should target regulation of the production, deployment and use of technologies by setting norms and rules. Developing and implementing frameworks through which self-restraint is exercised is a good start; efforts to share such rules and norms internationally should follow suit. Europe could play the role of a mediator between the US and Russia, and between the US and China. Particularly with China, Europe could help with the socialization of the norms built up during the Cold War through Track 1.0 and Track 2.0 dialogues. Currently, standards that are being developed include frameworks that ensure human control over AI-enabled systems. Discussions here should not be limited to democratic states only. Even if underlying motivations differ, the incentive to maintain certain degrees of human control is shared more widely if it comes down to preventing nuclear escalation. Furthermore, regulation tools should be co-developed and shared with (and, if needed, imposed on) private sector actors. Industry codes of conduct and security-over-efficiency rules are among the tools at hand.

4. Strengthening integrated deterrence: communicate, attribute, reciprocate

Finally, deterrence remains an important policy pillar in support of strategic stability. While not commonly discussed in tandem with arms control and non-proliferation, integrated deterrence postures may complement these measures aimed at risk reduction. It is noticeable that deterrence by denial is becoming increasingly difficult for emerging technologies. Given the expansion of domains and instruments, deterrence is likely to be more cross domain in nature than in the past, which requires robust, integrated deterrence postures. New technologies are faster and more efficient, to the detriment of traditional defensive measures such as hardening. And while defense against cyber operations can be enhanced, bullet-proof software is unlikely. Transparency and attribution is key, especially when it comes to more secretive technologies such as cyber. As a result, one can either foresee a shift to deterrence by punishment[1] or newer forms such as deterrence through entanglement (even if risky) and cumulative deterrence complemented with efforts to build norms in a more integrated fashion in the realm of new technologies.

The current climate of increasing geopolitical competition between great powers and regional powers further undermines collective action. Fortunately, it can be concluded that the arms control agenda expands, combining time-tested measures with novel ones. Finding ways to develop an arms control and counterproliferation agenda in times of low trust will thus be one of the major challenges ahead. But efforts are by no means futile. The stakes in strategic stability are high for everyone. It is only through negotiation and communication that states can hope to prevent the breakdown of strategic stability and avoid disaster.

1 See, for example, the discussion on asymmetric deterrence in: Rob de Wijk, "The Role of Deterrence in a New European Strategic Environment," *SIRIUS-Zeitschrift Für Strategische Analysen* 2, no. 1 (2018).

Table 4. Arms control policy agenda

	Production	Proliferation	Deployment	Employment
Hypersonic missiles	• Expand the HCoC to including pre-launch notification obligations for hypersonic missile tests	• Expand coverage of existing export regimes, notably MTCR and UNSCR 1540	• Limit sites where nuclear-tipped (hypersonic) missiles may be deployed.	• Promote data exchanges including advance test notifications • Restrain sea-based tests • Separate launch locations as well as nuclear and conventional assets • Publicly specify that hypersonic missiles will be conventionally-tipped only and used against conventional targets only • Explore both punishment- and denial-based deterrence options
Anti-satellite weapons (ASATs)	• Clear inconsistencies in the OST and further control ASAT tests • Promote pre-launch notifications for ASATs tests under existing regimes such as the HCoC	• Expand coverage and increase verification of existing export regimes, such as MTCR and UNSCR 1540	• Clear inconsistencies in the OST and (further) limit the deployment of ASATs • Place limits on the proximity of space objects • Enhance verification through broadcasting obligations and potentially shared SSA capabilities	• Work towards an international code of conduct for space, building on existing efforts such as the UK-sponsored UN resolution A/RES/75/36 • Implement national and international space situational awareness systems to monitor and enforce space activities • Explicitly include the risks associated with ASATs in bilateral and multilateral strategic dialogues concerning nuclear weapons • Examine the possibilities and constraints associated with space deterrence
Directed-energy weapons	• Clear inconsistencies in the OST and further regulate the testing of space-based DEWs • Step up verification, potentially through shared situational awareness capabilities	• Refine and reinforce existing arms control regimes including the Arms Trade Treaty and the Wassenaar Arrangement	• Start the discussion of international rules limiting the number of DEWs that can be deployed through formal gov-to-gov talks (track 1) and expert-to-expert (track 2) meetings	• Establish a working group of legal experts to reflect on the legal implications of collateral damage of DEW • Include the use of DEWs in the efforts to set norms for behavior in space
Dual-capable Missiles		• Reinforce the implementation and verification of MTCR	• Limit the deployment of nuclear-tipped missiles, e.g. by banning nuclear weapons from sites	• Publicly commit to no-first-use • Work internationally to create pre-launch notification protocols
Missile defense			• Reflect on the utility of missile defense as a bargaining chip to facilitate further arms control discussions, also including offensive weapons	• Ensure and communicate that defensive systems are not intended to undermine second strike capabilities • Clearly separate strategic from regional missile defense efforts • Consider regional rather than global solutions tailored to specific regional strategic constraints • Determine and limit the minimally required nuclear arsenal size to ensure a second strike capability vis-à-vis adversaries' strategic missile defense postures
Offensive cyber capabilities	• Invest in AI-enabled coding to limit opportunities for zero-day exploits • Impose stricter regulations for software developers to prioritise security over efficiency • Identify and fix potential zero-day exploits by bolstering cooperation with hackers	• Continuously review and update EU export control rules • Introduce "know your vendor laws" to the access-as-a-service industry • Impose stricter regulations on cyber specialists offering their services to work for foreign governments		• Build notification procedures and crisis deconfliction mechanisms • Build on efforts to set norms in cyberspace, including by the UN Group of Governmental Efforts and the Paris Call for Trust and Security in Cyberspace • Add weapons of mass disruption to existing regulatory frameworks • Enhance cyber situational awareness to increase transparency in the cyber domain • Develop attribution frameworks (digital forensic, legal, political) to facilitate timely attribution and support deterrence • Develop cyber deterrence (capability, communication, political will) posture

Table 4. Arms control policy agenda (continued)

	Production	Proliferation	Deployment	Employment
LAWS	• Ensure high-level ethical standards in the production phase and promote morally responsible engineering through the introduction of industry codes of conduct • Work with multistakeholder working groups to ensure implementability and support • Continue international dialogue, such as initiated by the CCW Group of Governmental Experts, to agree and commonly adopt system-tailored rules ensuring meaningful human control • Promote legal compliance, e.g., through formalizing Article 36 in domestic procedures	• Continuously revise and adjust existing export control lists, including the Wassenaar Arrangement, the MTCR and EU dual-use regulations • Strictly control the export of semiconductor equipment while implementing tailored end-use and end-user controls on chips only • Explore options to limit the proliferation of expertise, e.g., imposing contract obligations	• Foster international dialogue on LAWS deployment, especially among US, Russia, and China • Provide training to military personnel on the ethical issues related to the deployment of LAWS	• Share best practices and develop context-specific human control standards • Apply tort law by subjecting LAWS to strict liability regimes that allow to hold a defendant accountable even without evidence of clear fault • Assign a legal personhood to LAWS to grant compensation to parties injured by an autonomous system • Promote trust by declaring the ways in which LAWS could be used • Examine the possibilities and constraints associated with deterring adversaries from deploying LAWS
Remote sensing		• Continue to implement, verify and update export control regimes applicable to remote sensing		• Increase the resilience of systems whose survivability may be undermined by remote sensing
AI	• Ensure high-level ethical standards in the production phase and promote morally responsible engineering through the introduction of industry codes of conduct • Continue international dialogue, such as initiated by the CCW Group of Governmental Experts, to agree and commonly adopt system-tailored rules ensuring meaningful human control • Promote legal compliance, e.g., through formalizing Article 36 in domestic procedures	• Continuously review and update tailored dual-use export control lists that include AI software, algorithms and datasets • Strictly control the export of semiconductor equipment while implementing tailored end-use and end-user controls on chips only • Explore options to limit the proliferation of expertise, e.g., imposing contract obligations	• Share best practices and develop context-specific human control standards • Establish regulations limiting the deployment of AI-enabled systems involved in warfighting only to highly tested and proven technologies under strict ethical regulations • Keep humans *in the loop* and require strict operator trainings; • Specify the conditions under which a human *on the loop* and *out of the loop* is legitimate and illegitimate • Implement cross-checking requirements • Boost system resilience through bolstering cyber security • Separate early warning from command and control	• Share best practices and develop context-specific human control standards • Promote the use of goal functions that cannot be changed by the AI-enabled system to ensure compliance with ethical, legal and military guidelines • Introduce the use of ethical governors to verify the legality of AI-driven actions (and potentially block them) • Openly communicate national regulatory frameworks, strategies and policies • Lower alert levels of AI enabled weapon systems in order to reduce inadvertent escalation (e.g., a battlefield equivalent of the "flash crash")
Dual-capable 3CI				• Establish confidence-building measures such as hotlines between key nuclear adversaries • Publicly highlight the escalatory risks associated with C3I entanglement • Publicly commit to not targeting one another's C3I capabilities • Strengthen deterrence by punishment posture by clearly communicating the consequences of attack on C3I capabilities

Introduction

What can be done about arms control and non-proliferation in a rapidly evolving international environment? Increased geopolitical competition on the one hand, and emerging technologies on the other, are steadily undermining strategic stability.

The 1980s and 1990s were a high-water point in terms of the normative and legal institutionalization of arms control and non-proliferation regimes, including, but certainly not limited to, the Intermediate-Range Nuclear Forces (INF) Treaty, the Strategic Arms Reductions Treaty (START) and the Strategic Offensive Reductions Treaty (SORT), the Missile Technology Control Regime (MTCR), the Open Skies Treaty (OST), the Vienna Document (VD), and the Wassenaar Arrangement. The durability of arms control and non-proliferation efforts encapsulated in these regimes is now under pressure. Current geopolitical and military-technological developments are drastically undermining strategic stability and the basis for existing arms control arrangements. The means, motives, and opportunities for competitive advantages have changed for most of the nuclear-armed states in two major ways.

The decision-making windows for policymakers are shrinking

First, the means to achieve a competitive advantage have increased, as emerging or new military technologies such as artificial intelligence and autonomous systems – and their additions to the speed of decision-making and the possibilities of sensing for precision attack – amplify the potential of existing missile technologies. Both offensive and defensive systems are incorporating these advances to bypass dependency on slower human responses. In combination with the revolution or evolution of missile technology that hypersonic cruise missiles and glide vehicles represent – with their abilities to fly at speeds above Mach-5, fly low, and maneuver in order to evade timely detection and interception – the decision-making windows for policymakers are shrinking. While part of the answer may lie in more effective air and missile defense, aided by the defender's own artificial intelligence and autonomous sensing, such measures themselves may also lead states to pursue next generation offensive capabilities. Together this may further a general sense to use it or lose it. It is also more difficult than during the Cold War to erect clear barriers between strategic weapons and advanced conventional weapons. The same Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance (C4ISR) systems that enable effective conventional precision-strike overlap with those used for the nuclear weapons. Disabling the C4ISR infrastructure that underpins an adversary's Anti-Access Area Denial (A2/AD) may be essential within a conventional conflict but also may be indistinguishable from the first stage of a nuclear first strike. The risk that a conventional conflict inadvertently escalates further destabilizes European and Asian security. Complicating matters further is that many of the technologies driving the new instability are dual-use in nature, and, unlike the Cold War era, most of the innovation may in fact be taking place in the commercial sector. This poses a challenge to non-proliferation agreements such as the Wassenaar Arrangement and the MTCR. New arms control agreements that deal with these technological changes will consequently need to take into account this more multi-faceted view of technology and the evolved configuration of the political landscape – similar to how the 1996 Wassenaar Arrangement superseded the Cold War's era Coordinating Committee for Multilateral Export Controls launched in 1949.

Second, the opportunities to pursue a competitive advantage have grown, and European policymakers will need to deal with the implications of emerging nuclear and conventional precision-strike multipolarity. The emergence of China as a challenger to American power in Asia alongside a revanchist Russia has created a three-way interaction with consequences for deterrence within Europe as well as for arms control. Russia has looked to its large and varied arsenal of nuclear weapons to compensate for its declining status. Moreover, Russian military strategy includes plans to use this arsenal for leverage in concrete scenarios in north-eastern Europe. Simultaneously, the intensifying Sino-American competition has spurred China to innovate a series of conventional missile capabilities – generally referred to, together with its set of sensing and Command and Control assets, as A2/AD capabilities – that aim to raise the costs for US power projection in the Western Pacific. Moreover, as China makes advances in missile technology, it is likely that smaller and medium powers within Asia and elsewhere will seek to acquire their own conventional precision-strike capabilities. While these states long had the motive, now they have the opportunity to act on it. In a multipolar world, they will be able to purchase such capabilities from China and Russia, or emulate their successes through their own indigenous efforts. These developments have various consequences for Europe. In part, the United States withdrew from the INF with Russia to free itself to develop short and middle range missiles for the Western Pacific. The US National Defense Strategy already underlined that the United States will only plan for one major regional war at a time, relying on deterrence in the second region. It is apparent from the 2018 Nuclear Posture Review (NPR) that US officials perceive deterrence gaps in the European theater. In fact, US officials implicitly acknowledge that the linkage between American conventional deterrence through a physical presence in Europe has been weakened, because the NPR increased the role of low-yield nuclear weapons as a substitute for conventional forces in the European theater.[2] Durable arms control efforts in the emerging multipolar world must therefore evolve from the arrangements that were based on the bipolar Cold War context and adapt to the circumstances of today.

While these states long had the motive, now they have the opportunity to act on it

While non-proliferation and arms control efforts are aimed at countering the *production*, *proliferation* and *deployment* of such capabilities, deterrence is aimed at preventing their *actual employment*. In the realm of strategic stability, a distinction can be made between deterrence by punishment (raising costs of aggression by punishment after the fact) and deterrence by denial (raising costs during aggression).[3] Nuclear weapons are nearly exclusively used for deterrence by punishment. An avenue to prevent the re-nuclearization of European security is to strengthen Europe's capability for conventional deterrence by denial. In combination with a comprehensive effort to contain and curb proliferation of nuclear weapons as well as critical delivery vehicles, conventional deterrence could offer an avenue to keep a lid on the Pandora's Box of re-nuclearization of European security by the United States, Russia, or others in the 2021-2035 period. Similar to the success of Cold War arms control and non-proliferation efforts, acquiring such capabilities would also improve the negotiation position of European states to pursue new agreements with Russia.

In light of these geopolitical and military-technological developments, this report considers how existing arms control regimes be adapted and new ones designed in close alignment with the calibration of deterrence postures in order to uphold strategic stability. As in the past, non-proliferation, arms control and deterrence are distinct tools that states have at their disposal to contain and prevent the production, the proliferation, the deployment and the employment (PPDE) of weapon technologies that threaten strategic stability. This report looks at these tools to assess new solutions for a new generation of durable arrangements

2 See the 2018 Nuclear Posture Review. This has also been confirmed in dozens of interviews held by Paul van Hooft with current and former senior US government officials in Washington DC in the period 2018-2020.

3 Michael J. Mazarr et al., *What Deters and Why: Exploring Requirements for Effective Deterrence of Interstate Aggression* (Rand Corporation, 2018), 7–8.

within the geopolitical and technological environment that has drastically evolved over the past quarter century. Rather than singling out one weapon technology or one specific arms control regime, it introduces a new analytical framework that assesses the feasibility of policy measures to control weapon technologies along the PPDE-chain. Applying this framework to ten emerging technologies, the report identifies specific policy measures to curtail the risks associated with each of them. Considering these policy measures within the evolving geopolitical context that has reshaped the incentives for pursuing various nuclear and non-nuclear technologies, the report offers a set of policy recommendations to policymakers to bolster strategic stability. The overview of measures thus generated offers policymakers a blueprint for a broader integrated arms control agenda, and facilitates careful consideration of the appropriate balance of policy mixes along the PPDE-chain included therein.

This report sets out to address the following research questions:

1. How are emerging technologies – or interactions between new and old technologies – most likely to affect strategic stability?
2. What are the consequences of nuclear (and advanced conventional weapons) multipolarity and strategic competition between Russia, China, and the United States for strategic stability in general, and European security in particular?
3. What is the level of difficulty involved in each of the steps of the production-proliferation-deployment-employment chain of emerging technologies? How to identify where best to intervene?
4. What combination of non-proliferation, arms control measures and deterrence measures are most appropriate to curtail the risks associated with each of these emerging technologies?

In answering these research questions, this report proceeds as follows:

Chapter 1 situates the concept of strategic stability in its historical context, explains the material and non-material pillars of strategic stability, and explains how strategic stability consists of deterrence stability and crisis stability. Against this background it reflects on the traditionally uneasy relationship between arms control and deterrence efforts arguing that a keen understanding of the different motivations and effects of these efforts is necessary to design an effective strategic stability agenda.

Chapter 2 looks at the consequences of nuclear and advanced conventional weapons multipolarity and strategic competition of the nuclear powers including China, France, India, Israel, North Korea, Pakistan, Russia, the United Kingdom and the United States for strategic stability in general, and European security in particular, discussing these from the context of the most important dyads within this context. The purpose of this chapter is to provide a better understanding of the most important consequences for strategic stability of the emerging geopolitical landscape and the subsequent constraints and opportunities for arms control initiatives.

Chapter 3 identifies ten emerging technologies that threaten to upset strategic stability. Some are indeed emerging in the sense that these technologies did not exist (or were not fully developed) a few decades ago, including hypersonic missiles, anti-satellite weapons (ASATs), directed energy weapons, cyber technology, artificial intelligence, and lethal autonomous weapons systems (LAWS). Other technologies are not strictly new, but include new applications of existing technologies, such as dual-capable (i.e. serving both conventional and nuclear forces) command, control, communications and intelligence (3CI) assets or missiles;

or technologies that have new implications for strategic stability, either due to their rapid proliferation (remote sensing) or due to the breakdown of important arms control regimes (missile defense). Chapter 3 assesses their effect on strategic stability through their interactions with existing (missile) technologies based on a synthesis of existing scholarly literature and expert contributions.

Chapter 4 then examines the level of difficulty with which these weapon technologies can be produced, proliferated, deployed and employed. Production encompasses possession of the technological knowledge, basic skills, and access to materials to indigenously produce a weapon technology. Proliferation includes the ability to acquire technologies and materials from other states or non-state actors. Deployment refers to other hard constraints, such as platform technologies or access to specific locations that allow the weapon technology to be put to use. Employment covers all the soft constraints, such as organizational aptitude and fit to effectively put the technology to use. Each technology is evaluated and scored using a standard list of questions for each of the four stages. Based on in-depth desk research and independent expert judgment, the chapter offers concise technical descriptions along the PPDE chain and concludes with an overall assessment of the level of difficulty associated with the ten technologies.

Chapter 5 uses the insights offered by Chapter 4 as the baseline for the assessment of arms control, non-proliferation and deterrence policy measures are most likely to be effective in reducing the risks posed by these ten emerging technologies to strategic stability. The technical level of detail in Chapter 5 effectively generates a series of specific policy recommendations, as well as a more generic overview of the balance of policy mixes that are indispensable to a more comprehensive policy portfolio to address risks posed to strategic stability by emerging technologies in the years to come.

Chapter 6, finally, explains how policymakers in foreign and defense ministries can use this overview to examine the proper balance of policy mixes, and to subsequently calibrate their parallel efforts to uphold strategic stability in the context of these emerging technologies.

1. Strategic stability and arms control

Key takeaways

- Strategic stability is challenged more and more by the shift towards nuclear multipolarity and the emergence of new technologies.
- As a result, the traditional arms control, non-proliferation and deterrence architecture, which sought to establish a balance of terror, is no longer adequate.

War prevention is best served by upholding strategic stability

Arms control arrangements are time and context specific to the geopolitical and technological conditions in which they were created. The strategic context of the third and fourth decades of the twenty-first century no longer reflects the one in which the existing non-proliferation and arms control agreements were created and deterrence postures developed. The abandonment of the Intermediate-Range Nuclear Forces Treaty (INF) in 2019, the death of the Open Skies Treaty, which enhanced transparency and mutual confidence through aerial observation; and discrepancies over the Non-Proliferation Treaty (NPT) are a few examples of the demise of arms control treaties.[4] Yet, "progress in arms control is not an end in and of itself".[5] The objective is to prevent catastrophic war where nuclear weapons are used. War prevention is best served by upholding strategic stability. Strategic stability, in turn, is achieved through a mix of policy measures in the realm of non-proliferation and arms control, as well as those aimed at strengthening deterrence, counterintuitive as the latter might seem.

Strategic stability is currently under pressure from two broad trends. The first is the return and intensification of geopolitical competition. Unlike the largely bipolar distribution during the Cold War that largely focused on control over Europe, we can now see multiple regional competitions expressed both on the nuclear and the advanced conventional level. Rather than the Russian-American relationship that primarily drives the dynamics of deterrence and arms control, we now find a trilateral relationship that includes the People's Republic of China, but where the conventional elements are arguably more important. Interacting with the competition between the great powers are multiple regional nuclear competitions in East

4 Tomáš Petříček, "Strengthening Arms Control Through Multilateralism, and Multilateralism Through Arms Control," *Royal United Services Institute* (blog), June 19, 2020, https://rusi.org/commentary/Strengthening_Arms_Control_Through_Multilateralism.

5 Office of the Secretary of Defense, "Nuclear Posture Review" (Washington D.C.: Office of the Secretary of Defense; Department of Defense, February 2018), 73, https://media.defense.gov/2018/Feb/02/2001872886/-1/-1/1/2018-NUCLEAR-POSTURE-REVIEW-FINAL-REPORT.PDF.

Asia, South Asia, and the Middle East. Advanced conventional weapons to offset the conventional superiority and power projection capabilities of the United States further complicate the nuclear competition.[6] The second development is the creation of new weapons that are more precise, faster, but also less tangible and that also boost the effectiveness of existing weapons. Moreover, these weapons do not conform as well to traditional distinctions between civilian and military or between conventional and nuclear categories. Multiple technologies that have not seen large-scale implementation could potentially destabilize deterrence and crises dynamics: the sensing and computing revolution; artificial intelligence; autonomy; cyber capabilities; as well as new long-range weapons. Certain weapons, like hypersonic glide vehicles, have the potential of inducing arms races or crises not only due to the potential breakthroughs in offensive attacks but also due to the anxieties associated to these capabilities.

Arms control and stability thus require a constant gardening, as the underlying strategic context shifts and shifts again

Before seeking to understand the current challenges that seem so uncertain and unstable, it is worth noting the Cold War period was never as stable as we like to remember it. At its core, deterrence is about raising the costs of aggression or other unwanted actions beyond what can be sustained. Historically, it has existed in many forms. However, the introduction of nuclear weapons would seem to have made the costs of aggression unsustainable for any actor. Famously, Robert Jervis emphasized that a nuclear revolution had taken place after the superpowers had achieved a nuclear stalemate which had removed the incentives for nuclear powers to compete or seek advantages vis-à-vis one another.[7] But as Kier Lieber and Daryll Press note, destabilizing dynamics persisted nonetheless because the stalemate remains reversible.[8] Brendan Green argues that the revolution never even took place: the United States continued to look for counterforce options to destroy the Soviet's first strike capability despite the obvious risks such efforts entailed in terms of unsettling relations with the Soviets.[9] Arms control and stability thus require consistent attention, a constant gardening, as the underlying strategic context shifts and shifts again.

Nor was stability the only motive that drove successful arms control initiatives. As John Maurer reminds us, arms control arrangements have always served multiple interests for participating states. Broader pacifist preferences towards complete disarmament sat next to attempts to lock in temporary advantages in the military balance of power. Stability was the preference for those more skeptical of the former, but wary of the latter.[10] Of course, "strategic stability is in the eye of the beholder", as definitions of stability vary over time, as well as interests.[11] Yet, noting that states may find agreement despite not sharing the same perspective

6 Fiona S. Cunningham and M. Taylor Fravel, "Assuring Assured Retaliation: China's Nuclear Posture and US-China Strategic Stability," *International Security* 40, no. 2 (2015): 7–50; Tong Zhao, "Conventional Long-Range Strike Weapons of US Allies and China's Concerns of Strategic Instability," *The Nonproliferation Review*, 2020, 1–14; Andrew Futter and Benjamin Zala, "Strategic Non-Nuclear Weapons and the Onset of a Third Nuclear Age," *European Journal of International Security*, 2018, 1–21.

7 Robert Jervis, *The Meaning of the Nuclear Revolution: Statecraft and the Prospect of Armageddon* (Cornell University Press, 1989).

8 Keir A. Lieber and Daryl G. Press, *The Myth of the Nuclear Revolution: Power Politics in the Atomic Age* (London: Cornell University Press, 2020), http://www.jstor.org/stable/10.7591/j.ctvqc6jj1.

9 Brendan Rittenhouse Green, *The Revolution That Failed: Nuclear Competition, Arms Control, and the Cold War* (Cambridge University Press, 2020); Austin Long and Brendan Rittenhouse Green, "Stalking the Secure Second Strike: Intelligence, Counterforce, and Nuclear Strategy," *Journal of Strategic Studies* 38, no. 1–2 (2015): 38–73.

10 John D. Maurer, "The Purposes of Arms Control (November 2018)," *Texas National Security Review*, 2018. Relative preferences approximately accord to the assumed role of influence groups, weapons, and actors.

11 Heather Williams, "Asymmetric Arms Control and Strategic Stability: Scenarios for Limiting Hypersonic Glide Vehicles," *Journal of Strategic Studies* 42, no. 6 (September 19, 2019): 789–813, https://doi.org/10.1080/01402390.2019.1627521, 794.

matters because arms control is not always a cooperative exercise.[12] Awareness of the inherently strategic nature of arms control efforts and keen recognition of its close relationship with efforts to gain a competitive edge in support of deterrence,[13] is therefore vital.

The rest of this chapter looks at strategic stability, what it comprises, and how arms control and deterrence relate to strategic stability.

Deconstructing strategic stability

Improvements to the accuracy of the weapons or redundancy through numbers of weapons were no panacea for survivability

Strategic stability and the requirements of deterrence uneasily coexist. The key problem is whether a state's nuclear arsenal can survive; though tempting to destroy the adversary's arsenal, policymakers in the United States and the Soviet Union eventually came to the realization that they shared an interest in diminishing the temptation to gain a first strike advantage. Yet, the dilemma was apparent to the emerging class of nuclear theorists already from the start of the atomic age. As early as 1946, Bernard Brodie argued that if the outcome of any conflict was annihilation, stability would emerge if both parties remained threatened.[14] In contrast, William Borden believed that the possibility of a disarming strike should be considered.[15] Albert Wohlstetter argued that greater survivability of nuclear forces guaranteed catastrophic retaliation in response to aggression.[16] In contrast, Herman Kahn was in favor of lowering vulnerability through passive and active defenses.[17] Yet, diminishing one's own vulnerability through defenses in fact decreased one's security in other ways. After all, it increased the likelihood of a preemptive strike by the adversary. Thomas Schelling built on Wohlstetter's work and underlined how societal vulnerability increased confidence in the willingness and ability to launch a retaliatory second strike.[18] The point here is that many counterintuitive contradictions were present in nuclear theology from its inception.

Mutual vulnerability thus became a tenet of strategic stability that nuclear-armed states mostly came to accept. But an unresolvable tension remained between ensuring a survivable second strike and lessening the inherent vulnerability of one's own armed forces and societies in the face of nuclear weapons.[19] Improvements to the accuracy of the weapons or redundancy through numbers of weapons were no panacea for survivability. Each attempt provoked mirroring responses from the adversary. Advantages on one side would trigger arms races in quantity or quality of weapon systems. Looking for parity between nuclear arsenals became a core tenet of strategic stability.[20] Yet, much of the acceptance of vulnerabilities

12 Maurer, "The Purposes of Arms Control (November 2018)," 9–10.

13 Arms control relies on transparency, but must avoid undermining the security of the state being monitored. Andrew J. Coe and Jane Vaynman, "Why Arms Control Is So Rare," *American Political Science Review* 114, no. 2 (2020): 342–55.

14 Bernard Brodie, *The Absolute Weapon: Atomic Power and World Order* (New Haven, Connecticut: Yale Institute of International Studies, 1946), https://www.osti.gov/opennet/servlets/purl/16380564.

15 William L. Borden, *There Will Be No Time: The Revolution in Strategy* (New York: The Macmillan Co., 1947), https://journals.sagepub.com/doi/abs/10.1177/000271624725200149.

16 Albert Wohlstetter, "The Delicate Balance of Terror," *Survival* 1, no. 1 (March 1, 1959): 8–17, https://doi.org/10.1080/00396335908440116.

17 Herman Kahn, *On Thermonuclear War* (Princeton: Princeton University Press, 1960).

18 Thomas C. Schelling, *The Strategy of Conflict* (Cambridge, MA: Harvard University Press, 1960), http://library.lol/main/796031E27754593B9BB78BC7FE07E0D9.

19 Michael S. Gerson, "The Origins of Strategic Stability," in *Strategic Stability: Contending Interpretations* (Carlisle, PA: Strategic Studies Institute and U.S. Army War College Press, 2013), 117–47, 10.21236/ada572928.

20 C. Dale Walton and Colin S. Gray, "The Geopolitics of Strategic Stability: Looking Beyond Cold Warriors and Nuclear Weapons," in *Strategic Stability: Contending Interpretations* (Strategic Studies Institute, US Army War College, 2013), 85–116, https://www.jstor.org/stable/resrep12086.6.

was not derived from arsenal sizes, but related to assessments of adversarial intentions over the long-term and their temperament in the short-term. Strategic stability thus came to be understood as having two faces, one that centered on the military-technological aspects – deterrence (first strike) stability – and one that centered on the perceptual-psychological aspects – crisis stability.

Deterrence stability and crisis stability

The time horizon is very short for crisis stability

Deterrence stability and *crisis stability* highlight different aspects of strategic stability. Nuclear deterrence aims to raise the costs of aggression to unacceptable levels. Its credibility depends on ensuring that a state will always have a secure second strike capability to inflict catastrophic damage on their opponent even after a first strike by the adversary. Deterrence stability can then be defined as a situation in which both adversaries remain confident of their capability to conduct a retaliatory second strike. If neither party believes they nor their adversary can gain an advantage by attacking first, neither has an incentive to engage in quantitative or qualitative arms racing over extended periods of time. Crisis stability, in turn, can be defined as a situation in which actors believe their ability to retaliate remains intact even if they do not immediately respond to aggression. When they do not believe this, we see use it or lose it dynamics. Crisis stability lies close to *escalation control*, the ability to prevent conventional or limited nuclear use to escalate uncontrollably into a catastrophic conflagration.[21] Unlike the former, the time horizon is very short for crisis stability.[22]

The two concepts of strategic stability are distinct and parallel the discussion on whether to place greater emphasis on material or on non-material factors – though military-technological aspects are not exclusive to deterrent stability, nor are perceptual-psychological aspects exclusive to crisis stability. The classic work on strategic stability by Thomas Schelling and Morton Halperin focused on the material aspects through reducing the incentives for pre-emptive attack by establishing reciprocal limitations on military capabilities and by increasing transparency into the adversary's capabilities to verify said limitations.[23] However, Robert Powell believed Schelling and Halperin focused too narrowly on the size of first strike advantages while ignoring other destabilizing factors.[24] Kent and Thaler expanded on this critique by distinguishing between first-strike stability and crisis stability. While the former, they argue, arises solely from the strategic force structure, the latter arises due to a variety of factors, such as psychological factors, ambiguous information, erroneous assessments of enemy intent, miscalculation and misperception.[25] Inadvertent nuclear escalation is one such an avenue: when an adversary's actions are perceived as the opening stage of a nuclear first strike, or as the use of conventional capabilities to soften up the systems used for the second

21 Thinking about escalation control was central to the American Cold War strategic lexicon, and thus central to NATO's flexible response posture. William M. Jones, "A Framework for Exploring Escalation Control" (RAND CORP SANTA MONICA CALIF, 1974).

22 Elbridge A. Colby, "Defining Strategic Stability: Reconciling Stability and Deterrence," in *Strategic Stability: Contending Interpretations*(Carlisle, PA: Strategic Studies Institute, US Army War College, 2013), https://apps.dtic.mil/dtic/tr/fulltext/u2/a572928.pdf.

23 Thomas C. Schelling and Morton H. Halperin, *Strategy and Arms Control* (New York: The Twentieth Century Fund, 1961), http://hdl.handle.net/2027/mdp.39015001553810.

24 Robert Powell, "Crisis Stability in the Nuclear Age," *The American Political Science Review* 83, no. 1 (1989): 61–76, https://doi.org/10.2307/1956434.

25 James M. Acton, "Reclaiming Strategic Stability" (Fort Belvoir, VA: Defense Technical Information Center, 2013), https://doi.org/10.21236/ADA572928. Alan Cummings, "Crisis Stability, Ooda Loops, and Hypersonic Weapons," in *On the Horizon: A Collection of Papers from the Next Generation*, vol. 3 (Center for Strategic and International Studies, 2021), 24–39, https://www.csis.org/analysis/horizon-vol-3-collection-papers-next-generation.Glenn A. Kent and David E. Thaler, "First-Strike Stability: A Methodology for Evaluating Strategic Forces," January 1, 1989, 1–73.

deterrent. The risk of inadvertent nuclear escalation exists when targeting the command and control, communication networks, missile storage facilities, air and missile defense radars, or satellites capabilities of a state, as these systems support both conventional and nuclear missions.[26] They also exist when a state attacks platforms dedicated to the nuclear mission. For example, inadvertent escalation may take place when a state mistakenly attacks an adversary's strategic missile submarines (SSBN) during an antisubmarine warfare (ASW) mission directed at destroying the attack submarines (SSN) that threatens its sealines of communication.[27] Though the initial 'weapons-oriented' conceptualizations of strategic stability suffered from oversimplifying deterrence to calculations on first strike technical capabilities, the concept evolved away from sole numerical rationalizations of force levels and led to 'holistic' conceptions.[28]

Weighing whether to emphasize the material or the non-material aspects was and is not solely an academic exercise, but one very much mirrored by struggles of policymakers to come to terms with strategic stability. For example, President Kennedy's Secretary of Defense, Robert McNamara, understood it very much in the former manner, leading him to conduct an assured destruction calculus based on assured societal vulnerability of the Soviet Union and quantifiable and assured levels of damage.[29] Paul Nitze, in contrast, highlighted the relevance of establishing a common understanding of strategic stability for arms control efforts to be successful by offering definitions on the Soviet and American understandings of strategic parity.[30] Indeed, a set of criticism was whether its effectiveness relied on adversaries sharing the same understanding of what constitutes stability, and how stability is affected by technologies. This debate has become newly relevant in the contemporary context of emerging technologies that threaten to upset strategic stability.[31]

Deterrence and arms control: two sides of the same coin?

Arms control arrangements cannot be separated from what actors perceive as their strategic needs. The central notion of deterrence – to raise the costs of an adversary's aggression beyond what it would find acceptable – had implicitly or explicitly been part of strategy in the pre-nuclear era. Yet, deterrence now became central to strategy in a way that it arguably had not been before. Was deterrence intended to deter aggression broadly (general deterrence)

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26 Caitlin Talmadge, "Would China Go Nuclear? Assessing the Risk of Chinese Nuclear Escalation in a Conventional War with the United States," *International Security* 41, no. 4 (April 2017): 50–92, https://doi.org/10.1162/ISEC_a_00274; Barry R. Posen, *Inadvertent Escalation: Conventional War and Nuclear Risks*, 2014 edition (Cornell University Press, 1991).

27 Talmadge, "Would China Go Nuclear?"

28 Elbridge A. Colby, "Defining Strategic Stability: Reconciling Stability and Deterrence," in *Strategic Stability: Contending* Interpretations (Carlisle, PA: Strategic Studies Institute, US Army War College, 2013),85 https://apps.dtic.mil/dtic/tr/fulltext/u2/a572928.pdf. See also: Forrest E. Morgan, "Crisis Management, Crisis Stability, and Force Structure," in *Crisis Stability and Long-Range Strike*, A Comparative Analysis of Fighters, Bombers, and Missiles (RAND Corporation, 2013), 9–34, https://www.jstor.org/stable/10.7249/j.ctt3fh1db.10.

29 Robert S. McNamara, "The Military Role of Nuclear Weapons: Perceptions and Misperceptions," *Foreign Affairs* 62, no. 1 (1983): 59–80, https://doi.org/10.2307/20041735.

30 Paul H. Nitze, "Assuring Strategic Stability in an Era of Détente," *Foreign Affairs* 54, no. 2 (1976): 207–32, https://doi.org/10.2307/20039569.

31 David S. Yost, "Strategic Stability in the Cold War," Proliferation Papers (Security Studies Center, 2011), https://www.ifri.org/sites/default/files/atoms/files/pp36yost.pdf. ; Heather Williams, "Asymmetric Arms Control and Strategic Stability: Scenarios for Limiting Hypersonic Glide Vehicles," *Journal of Strategic Studies* 42, no. 6 (September 19, 2019): 789–813, https://doi.org/10.1080/01402390.2019.1627521.

or at specific points (immediate deterrence)? Was the intention to deter aggression directed at the state itself or at allies that it had promised protection and extended deterrence to?[32] The distinctions within deterrence may have always existed but their implications became more dramatic with the advent of nuclear weapons.

Extended deterrence, in particular, created and continues to create escalatory pressures. In the context of the Cold War, both superpowers, but specifically the United States, had extended deterrence to their allies. But the credibility of those promises was inherently dubious. As Richard Betts notes, "once basic deterrence becomes mutual, it negates extended deterrence by definition, since the latter requires the willingness to initiate nuclear attack".[33] Moreover, as the United States had given guarantees to multiple allies at some geographic remove from its homeland, it had to make a greater effort to ensure credibility.[34] Ironically, the United States had made those alliance commitments in part to dampen the incentives for proliferation among its allies. Yet, the credibility of those commitments required a large physical presence and constant demonstrations of US resolve.[35] Though arguments about international status are often invoked, the French nuclear program was driven by concerns about the credibility of the US promises of protection to Europe.[36] Its current extended deterrence arrangements continue to suffer from the same set of structural instabilities.[37] Moreover, given the perceived conventional imbalance in Europe, where the Soviet Union was perceived to be at a clear advantage, the US and NATO planners had to consider an early use of nuclear weapons to readdress that imbalance – a policy which has not changed.[38]

Historically, arms control thus sought to grapple with the paradoxical qualities of strategic stability

Historically, arms control thus sought to grapple with the paradoxical qualities of strategic stability. In the nuclear era,[39] classic arms control theorists like Thomas Schelling, Morton Halperin, and Hedley Bull looked to construct a stable "balance of terror". In its original iteration, Schelling defined arms control as "all the forms of military cooperation among potential

32 Michael J. Mazarr, "Understanding Deterrence," in *Netherlands Annual Review of Military Studies 2020: Deterrence in the 21st Century - Insights from Theory and Practice* (Santa Monica, CA: RAND Corporation, 2021), 13–28, https://www.springerprofessional.de/en/understanding-deterrence/18654910.

33 Richard K. Betts, *Nuclear Blackmail and Nuclear Balance* (Brookings Institution Press, 2010), 10. See also: Lawrence Freedman, *The Evolution of Nuclear Strategy*, Third edition, 2003 (New York, NY: Palgrave Macmillan, 1981), 276.

34 Paul Van Hooft, "The US and Extended Deterrence," in *NL Netherlands Annual Review of Military Studies 2020* (The Hague: TMC Asser Press, The Hague, 2020), 87–107, https://link.springer.com/chapter/10.1007/978-94-6265-419-8_6.

35 Marc Trachtenberg, *A Constructed Peace: The Making of the European Settlement, 1945-1963* (Princeton University Press, 1999); Gene Gerzhoy, "Alliance Coercion and Nuclear Restraint: How the United States Thwarted West Germany's Nuclear Ambitions," *International Security* 39, no. 4 (2015): 91–129; Francis J. Gavin, "Strategies of Inhibition: US Grand Strategy, the Nuclear Revolution, and Nonproliferation," *International Security* 40, no. 1 (2015): 9–46.

36 Celine Jurgensen et al., *Resistance and Deterrence. From the Origins of the French Nuclear Programme until Today* (Paris, France: Odille Jacob, 2018); Van Hooft, "The US and Extended Deterrence."

37 Paul Van Hooft, "All-In or All-Out: Why Insularity Pushes and Pulls American Grand Strategy to Extremes," *Security Studies* 29, no. 4 (2020): 701–729.

38 "Effective U.S. deterrence of nuclear attack and non-nuclear strategic attack requires ensuring that potential adversaries do not miscalculate regarding the consequences of nuclear first use, either regionally or against the United States itself. They must understand that there are no possible benefits from non-nuclear aggression or limited nuclear escalation. Correcting any such misperceptions is now critical to maintaining strategic stability in Europe and Asia" Office of the Secretary of Defense, "Nuclear Posture Review," vii.

39 Arms control is primarily associated with dampening the nuclear arms race between the United States and the Soviet Union during the Cold War, which was escalating rapidly in the 1960s and 1970s. However, precedents for controlling the number and types of armed forces at the disposal of a state existed before; most prominently, the 1922 Washington Naval Treaty placed limits on both battleship numbers and fortified bases in order to create a defense-dominant environment in the Pacific. Emily O. Goldman, *Sunken Treaties: Naval Arms Control between the Wars* (Penn State Press, 2010), 80–109; Maurer, "The Purposes of Arms Control (November 2018)," 14. In parallel, the League of Nations was supposed to play a significant role in limiting offensive arms.

enemies that may reduce the risk of war, its scope and violence if it occurs, or the costs of being prepared for it".[40] This definition is based on three assumptions: (1) there is a common interest between political rivals, (2) common expectations about how current weapons can exacerbate the dangers of conflict; and (3) about how the character of weaponry can be shaped to sustain deterrence. The last two points specifically are relevant to questions of emerging technologies. Specifically, mutual deterrence – and thus strategic stability – would be reinforced by restraining access to damage-limiting capabilities, like large and accurate Intercontinental Ballistic Missiles (ICBM) and Anti-Ballistic Missile (ABM) defenses, and reducing missiles with Multiple Independent Reentry Vehicles (MIRV).[41] Large surface-based missiles were considered destabilizing because they invite attack by other large surface-based ballistic missiles,[42] while Strategic Missile Submarines (SSBN), inherently difficult to find and destroy, were considered stabilizing. Deterrence stability and crisis stability interacted with each other: new weapons like MIRVed missiles increase crisis instability, crisis instability increases incentives for diversifying delivery systems such as SSBNs.[43]

These notions have consequences for the present. Neither geopolitical competition nor technological innovations have stopped since the end of the Cold War. Building 21st century arms control frameworks on the strategic incentives of the bipolar Cold War would be misguided, as would solely relying on 20th century frameworks of military technology.[44] The following chapters discuss the consequences of the multiple geopolitical trends and technological trends on deterrence and crisis stability.

40 Thomas C. Schelling, "The Future of Arms Control," *Operations Research* 9, no. 5 (1961): 722–31, https://www.jstor.org/stable/166817, 724.

41 Jürgen Altmann and Frank Sauer, "Autonomous Weapon Systems and Strategic Stability" 59, no. 5 (September 3, 2017): 120.

42 Maurer, "The Purposes of Arms Control (November 2018)," 14.

43 Altmann and Sauer, "Autonomous Weapon Systems and Strategic Stability," 122.

44 The comparison with a period of open technological innovation, such as the 19th century, where technology developed in conjunction to the rest of society, is more appropriate. This analogy comes closer to reflecting the current, open nature of many military technologies where commercial actors, such as tech companies, play a prominent role. Audrey Cronin, "Technology and Strategic Surprise: Adapting to an Era of Open Innovation," *The US Army War College Quarterly: Parameters* 50, no. 3 (August 14, 2020), https://press.armywarcollege.edu/parameters/vol50/iss3/8.

2. Geopolitical trends and strategic stability

Key takeaways

- Increased international competition has led major military powers to seek competitive advantages in their nuclear arsenals; to expand and modernize their conventional weapon arsenals; and to raise the costs of adversaries' power projection efforts.
- Simultaneously, smaller powers are investing in nuclear and conventional capabilities, with regional rivalries intensifying.
- The second nuclear age that has emerged from these two trends has created an international order that is first characterized by a triangular power dynamic between the United States, Russia and China; and second by a multiplicity of nuclear dyads, each with their unique risks, constraints and opportunities.
- Consequently, deterrence stability is impacted in two key ways. First, first strike incentives have accumulated, whether through nuclear or conventional means. Second, the strategic calculus has become ever more complex, complicating political signaling and trust-building.
- Crisis stability in turn is undermined as the nature and direction of adversary policies (including attacks) become harder to assess; and as the ties between nuclear states are becoming less institutionalized, increasing the risks of judgement errors during crises.

Current geopolitical trends have changed the conditions for arms control. Two major trends stand out: the intensification of competition between the great powers in both the nuclear and the conventional realms, and the continuing improvements of the nuclear arsenals and delivery systems of the states that acquired nuclear weapons after the Cold War. Both trends are impacting strategic stability, and thus arms control.

The renewed intensification of the competition between great powers has had three major consequences. First, the great powers have again begun to look for competitive advantages in their nuclear arsenals, looking for first strike advantages and greater flexibility between low-yield, so-called tactical and high-yield, so-called strategic weapons in their nuclear arsenals.[45] These attempts fly in the face of the assumption common in arms control scholarship

45 Christopher A Ford, "Strategic Stability and the Global Race for Technology Leadership," *Arms Control and International Security* 1, no. 21 (2020): 9. ; Dmitri Trenin, "Strategic Stability in the Changing World," *Carnegie Moscow Center*, March 2019, 12, https://carnegieendowment.org/files/3-15_Trenin_StrategicStability.pdf.

The United States needs a physical presence in the regions under its protection to give itself skin in the game

that the introduction of nuclear weapons created a so-called nuclear revolution that negated the benefits of aggression and removed the incentive to look for advantages due to the immense risk of nuclear war.[46] Instead, recent scholarship underlines the continuing attempts to gain a first strike advantage, particularly on the part of the United States.[47] Second, great powers have invested in significant advanced conventional weapons, generally ballistic missiles. These particularly include the so-called Anti-Access Area Denial capabilities that China and Russia intend to offset the conventional advantages the United States enjoys, and specifically to undermine US power projection.[48] The most prominent examples are the Chinese DF-21D and DF-26 ballistic missiles. These missiles can be mated with both conventional and nuclear warheads additionally unsettles the nuclear dimension of their relationship.[49] Both conventional- and nuclear-armed missiles use the same sensors, launch platforms, and command and control elements. Due to the lack of clarity, a strike against conventional weapons risks inadvertent nuclear escalation.[50] Third, the central role of the United States as a guarantor of extended deterrence to its allies ensures the first two trends take on additional significance in the regions the United States acts as guarantor.[51] Because of its role as guarantor, the United States needs a physical presence in the regions under its protection to give itself skin in the game, as well as the ability to project power there. In turn, this triggers its rivals to look for the conventional means to raise the costs of power projection for the US.[52]

At the same time, the nuclear powers that emerged on the scene after the end of the Cold War – India, Pakistan, and North Korea – are developing their nuclear arsenals and involved in intensifying rivalries. Moreover, some of the same conventional dynamics are taking place at the regional level with both nuclear and non-nuclear powers; investments in conventional precision-strike weapons to offset the conventional advantages of major powers, particularly the United States. In addition, the established minor nuclear powers – the UK, France, and (presumably) Israel – are reviewing their nuclear postures.

Together, the trends of great power competition and new regional powers have led to a second nuclear age,[53] one that is no longer characterized by the bilateral relationship between the United States and the Soviet Union.[54] During the Cold War, the two superpowers held large and dispersed nuclear arsenals that were, for all intents and purposes, impossible to eliminate in a first strike (and, despite significant reductions in total nuclear weapons, their arsenals should still be considered impossible to eliminate with a conventional or a nuclear strike – and probably a cyberattack). The smaller nuclear arsenals by France, the United Kingdom and China – intended only for minimal deterrence – were subsumed by the

46 Jervis, *The Meaning of the Nuclear Revolution*.

47 Lieber and Press, *The Myth of the Nuclear Revolution: Power Politics in the Atomic Age*; Green, *The Revolution That Failed*.

48 Sam Tangredi, *Anti-Access Warfare: Countering Anti-Access and Area-Denial Strategies* (Naval Institute Press, 2013); Stephen Biddle and Ivan Oelrich, "Future Warfare in the Western Pacific: Chinese Antiaccess/Area Denial, US AirSea Battle, and Command of the Commons in East Asia," *International Security*, 2016; Van Hooft, "All-In or All-Out: Why Insularity Pushes and Pulls American Grand Strategy to Extremes."

49 Cunningham and Fravel, "Assuring Assured Retaliation."

50 Talmadge, "Would China Go Nuclear?"; Cunningham and Fravel, "Assuring Assured Retaliation"; Posen, *Inadvertent Escalation*.

51 Van Hooft, "The US and Extended Deterrence."

52 Van Hooft, "All-In or All-Out: Why Insularity Pushes and Pulls American Grand Strategy to Extremes."

53 Paul Bracken, *The Second Nuclear Age: Strategy, Danger, and the New Power Politics* (Macmillan, 2012).

54 Steven E. Miller and Alexey Arbatov, "The Rise and Decline of Global Nuclear Order?," in *Nuclear Perils in a New Era: Bringing Perspective to the Nuclear Choices Facing Russia and the United States* (Cambridge, Mass.: American Academy of Arts & Sciences, 2021), https://www.amacad.org/publication/nuclear-perils-new-era/section/2.

dynamics of the two greater nuclear powers.[55] Strategic stability was difficult to established and uphold, as the previous section made clear. Yet, while the central Soviet-American rivalry came attached with risks and dangers, a sense of mutual understanding was established between the two rival states through ongoing arms control processes and bilateral agreements that helped create a sense of predictability.[56] The second nuclear age, however, is defined by the proliferation of nuclear weapons to states that were not directly involved in the central Soviet-American rivalry of the Cold War. This has created new challenges for strategic calculations and arms control.[57] Strikingly, even American and Russian leaders have become incautious in their rhetoric regarding the nuclear threshold.[58]

The sources of global instability are not anymore confined to the bilateral US-Russian relationship

At the center of the current nuclear age is the triangular relationship between the United States, Russia, and China.[59] Interacting with this core of great powers, are the UK, France, and Israel, as well as three states that have acquired nuclear weapons after the Cold War: Pakistan, India, and North Korea.[60] The smaller nuclear powers tend to direct their deterrents at specific rivals within their geographic region.[61] As the extra-regional hegemonic power in Europa and the Middle East, and arguably still in Asia as well, the United States occupies a uniquely central position in the dyads. Its nuclear rivals aim to deter the US from involvement in regional issues, whether through nuclear or conventional means.[62] The competitive pressures therefore exist at the regional level and secondarily on the global level.[63] As a result, the sources of global instability are not anymore confined to the bilateral US-Russian relationship, but cascade from and to multiple nuclear subsystems.

Focusing only on the central triangular power dynamic is insufficient for understanding the consequences of the regional dynamics that have created a truly multipolar nuclear world. The rest of the chapter looks at the relevant nuclear dyads to clarify the incentive structures for each. In doing so, it clarifies why various states are pursuing not only nuclear options, but also advanced conventional weapons – many of which use emerging technologies. The closing section of the chapter delineates the consequences for deterrent and crisis stability.

55 Keir A. Lieber and Daryl G. Press, "The Nukes We Need: Preserving the American Deterrent," *Foreign Affairs* 88, no. 6 (2009): 39–51.

56 Robert Legvold and Christopher F. Chyba, "Introduction: The Search for Strategic Stability in a New Nuclear Era," *Meeting the Challenges of a New Nuclear Age* 149, no. 2 (2020): 6–16. Thomas C. Schelling, "Foreword," in Strategic Stability: Contending Interpretations, ed. Elbridge A. Colby and Michael S. Gerson (Carlisle, Pa.: U.S. Army War College Press, 2013), vii–viii. Steven E. Miller, "A Nuclear World Transformed: The Rise of Multilateral Disorder," *Daedalus* 149, no. 2 (April 2020): 17–36, https://doi.org/10.1162/daed_a_01787.

57 Miller and Arbatov, "The Rise and Decline of Global Nuclear Order?"; Legvold and Chyba, "Introduction"; Miller, "A Nuclear World Transformed"; Bracken, *The Second Nuclear Age*; Barry R. Posen, "Emerging Multipolarity: Why Should We Care?," *Current History* 108, no. 721 (November 1, 2009): 347–52, https://doi.org/10.1525/curh.2009.108.721.347.

58 "Ukraine Conflict: Putin 'Was Ready for Nuclear Alert,'" *BBC News*, March 15, 2015, sec. Europe, https://www.bbc.com/news/world-europe-31899680; Lauren Gambino, "Donald Trump Boasts That His Nuclear Button Is Bigger than Kim Jong-Un's," *The Guardian*, January 3, 2018, https://www.theguardian.com/us-news/2018/jan/03/donald-trump-boasts-nuclear-button-bigger-kim-jong-un.

59 Miller and Arbatov, "The Rise and Decline of Global Nuclear Order?"

60 Miller, "A Nuclear World Transformed."

61 Brad Roberts, "Nuclear Polarity and Stability" (Institute for Defense Analyses, November 2000).

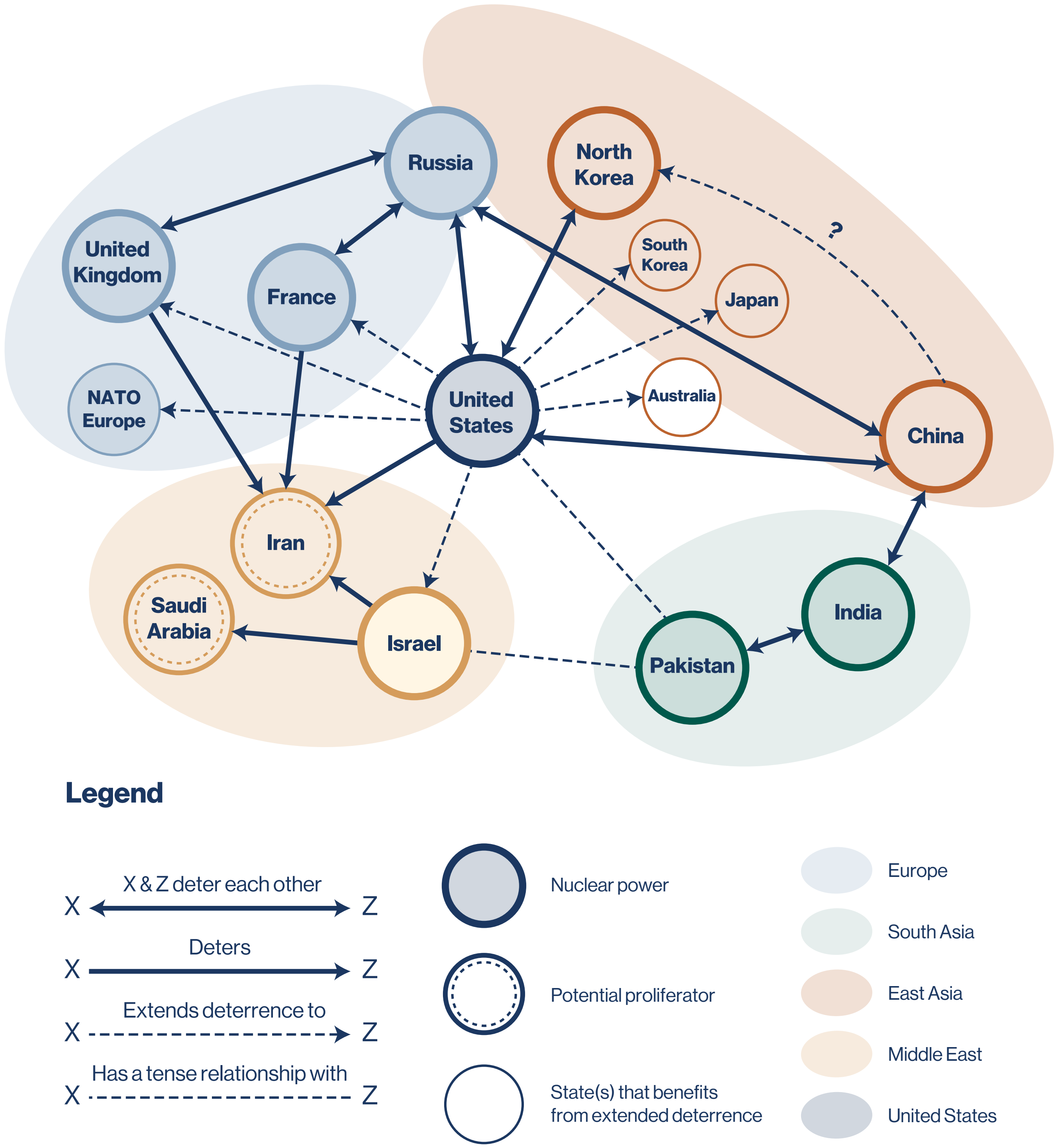
62 Joshua Rovner, "Was There a Nuclear Revolution? Strategy, Grand Strategy, and the Ultimate Weapon," *War on the Rocks*, 2018; Dean A. Wilkening and Ken Watman, "Nuclear Deterrence in a Regional Context" (RAND Corporation, January 1, 1995), https://www.rand.org/pubs/monograph_reports/MR500.html.

63 Legvold and Chyba, "Introduction"; Robert Einhorn and W P S Sidhu, "The Strategic Chain: Linking Pakistan, India, China, and the United States," Paper, Arms Control and Non-Proliferation Series (Washington D.C., US: Brookings Institution, March 2017), https://www.brookings.edu/wp-content/uploads/2017/03/acnpi_201703_strategic_chain.pdf; Miller, "A Nuclear World Transformed."

Nuclear dyads

Adopting a dyad approach allows us to zero in on the key nuclear relationships to allow for the identification of risks, constraints and opportunities of each dyad respectively, as well as how this impacts modern global power relations. (see Figure 3).

Figure 3. Interacting nuclear dyads and strategic relationships



The United States and Russia

The US-Russian relationship has deteriorated since the early 2000s.[64] US concerns of a Russian military threat to NATO's eastern member states are fueled by a comprehensive military reform program since 2008 and a willingness to utilize force as foreign policy tool. Russia demonstrated this willingness in its annexation of Crimea and intervention in eastern Ukraine. These Russian policies have been paired with an aggressive anti-Western foreign policy. In turn, Russia maintains that NATO's expansion eastward and its support for the color revolutions are threatening its immediate security environment.[65] After a period of significant cooperation to reduce nuclear forces and arms control, both countries are again modernizing and developing new nuclear arms technologies.[66] Leaders of both states have also made explicit nuclear threats,[67] reversing decades of institutionalized norms to avoid exactly that. While no longer the primary geopolitical competition in other domains, the Russian-American nuclear competition is still the most profound due to their massive arsenals. However, the particular imbalances between the two have created new incentives for conventional and nuclear arms racing; the INF Treaty's end was as much precipitated by Russian introduction of SSC-8, as the US desire to have more leeway to deploy intermediate range missiles in the Pacific theater.

The Russian-American nuclear competition is still the most profound due to their massive arsenals

The US nuclear posture was strongly shaped by the demands of its status as a guarantor of extended nuclear deterrence to allies in Europe, Asia, and elsewhere. As a consequence, the United States maintains a first-use-if-necessary nuclear doctrine.[68] After the Cold War, US nuclear strategy largely aimed to substitute conventional forces for nuclear capabilities. Russia has also begun to reemphasise the development of conventional capabilities, yet the purpose appears to lend more credibility to its nuclear threats.[69] This aims at reducing Russian dependency on nuclear options for handling local and regional wars that do not represent vital interests. In contrast to the Cold War, Russia now finds itself at a conventional disadvantage vis-à-vis the US on the regional level, though with a local advantage in the Baltics. To offset its theaterwide conventional disadvantage vis-à-vis NATO, Russian planners have modernized the nuclear arsenal and are believed to pursue an escalate-to-deescalate nuclear strategy.[70] This strategy is believed to see Russia threatening the limited first use of tactical nuclear weapons in the early stages of a conflict with NATO. In doing so, Russia would prevent a larger conventional war that the Kremlin believes NATO is likely to win, and allow

64 Anya Loukianova Fink and Olga Oliker, "Russia's Nuclear Weapons in a Multipolar World: Guarantors of Sovereignty, Great Power Status & More," *Daedalus* 149, no. 2 (April 2020): 37–55, https://doi.org/10.1162/daed_a_01788.

65 Richard Sokolsky, "The New NATO-Russia Military Balance: Implications for European Security," Carnegie Endowment for International Peace, accessed August 18, 2021, https://carnegieendowment.org/2017/03/13/new-nato-russia-military-balance-implications-for-european-security-pub-68222. Fink and Oliker, "Russia's Nuclear Weapons in a Multipolar World"; Kimberly Marten, "NATO Enlargement: Evaluating Its Consequences in Russia," *International Politics*, 2020, 1–26. n

66 Alexey Arbatov, "Nuclear Deterrence: A Guarantee or Threat to Strategic Stability?," Carnegie Moscow Center, accessed August 31, 2021, https://carnegie.ru/2019/03/22/nuclear-deterrence-guarantee-or-threat-to-strategic-stability-pub-78663.

67 John Erath, "In Ukraine, Putin Tries His Hand at Nuclear Blackmail. Here Are Seven Ways to Thwart Him.," *Bulletin of the Atomic Scientists* (blog), December 17, 2021, https://thebulletin.org/2021/12/in-ukraine-putin-tries-his-hand-at-nuclear-blackmail-here-are-seven-ways-to-thwart-him/; Gambino, "Donald Trump Boasts That His Nuclear Button Is Bigger than Kim Jong-Un's"; "Ukraine Conflict."

68 Francis J. Gavin, *Nuclear Weapons and American Grand Strategy* (Brookings Institution Press, 2020); Alexander Gabuev, "Why Russia and China Are Strengthening Security Ties," *Carnegie Moscow Center* (blog), September 24, 2018, https://carnegie.ru/2018/09/24/why-russia-and-china-are-strengthening-security-ties-pub-77333.

69 Kristin Ven Bruusgaard, "Russian Nuclear Strategy and Conventional Inferiority," *Journal of Strategic Studies* 44, no. 1 (January 2, 2020): 3–35, https://doi.org/10.1080/01402390.2020.1818070.

70 Ven Bruusgaard. Sokolsky, "The New NATO-Russia Military Balance"; Fink and Oliker, "Russia's Nuclear Weapons in a Multipolar World."

The history of bilateral arms agreements leaves hope that a constructive dialogue on arms control between the two states is possible

itself to consolidate the gains of its aggression.[71] In turn, the United States considers greater flexibility in its arsenal important to manage the imbalances at subregional level, specifically the Baltics. The US NPR from 2018 hints at the development of new low-yield nuclear weapons for the purpose of smaller-scale nuclear conflict.[72] In fact, the United States may never have given up on its efforts to seek a disarming first strike capability,[73] made possible by improvements in precision strikes.[74] The US capability to conduct such an attack remains in many ways imperfect and a "distant mirage".[75] From the Russian point of view, however, a flexible nuclear arsenal remains central to its deterrence policy.[76]

The history of bilateral arms agreements and the recent extension of the New START Treaty between the US and Russia[77] leaves hope that a constructive dialogue on arms control between the two states is possible. Nevertheless, both the increasingly tense relationship and the development of new low-yield nuclear weapons pose a challenge to arms control. [78]

The United States and China

The key current geopolitical rivalry, however, is between the United States and China. [79] The 2017 US National Security Strategy published by the Trump administration explicitly frames China as the major threat to the Indo-Pacific, with the ultimate Chinese ambition to be displacing the United States as the global hegemon.[80] The Biden administration reiterated that China is the pacing threat for American defense planning.[81] Vice versa, the 2019

71 Ven Bruusgaard, "Russian Nuclear Strategy and Conventional Inferiority."Gustav Gressel, "Russia's Quiet Military Revolution and What It Means for Europe – European Council on Foreign Relations," *ECFR* (blog), October 12, 2015, https://ecfr.eu/publication/russias_quiet_military_revolution_and_what_it_means_for_europe4045/.

72 David J. Lonsdale, "The 2018 Nuclear Posture Review: A Return to Nuclear Warfighting?," *Comparative Strategy* 38, no. 2 (March 4, 2019): 98–117, https://doi.org/10.1080/01495933.2019.1573074; Katarzyna Zysk, "Escalation and Nuclear Weapons in Russia's Military Strategy," *The RUSI Journal* 163, no. 2 (March 4, 2018): 4–15, https://doi.org/10.1080/03071847.2018.1469267. Office of the Secretary of Defense, "Nuclear Posture Review"; Francis J. Gavin et al., "Policy Roundtable: The Trump Administration's Nuclear Posture Review," Texas National Security Review, February 2018, https://tnsr.org/roundtable/policy-roundtable-trump-administrations-nuclear-posture-review/.

73 Keir A. Lieber and Daryl G. Press, "The End of MAD? The Nuclear Dimension of U.S. Primacy," *International Security* 30, no. 4 (April 2006): 7–44, https://doi.org/10.1162/isec.2006.30.4.7; Long and Green, "Stalking the Secure Second Strike."

74 Keir A. Lieber and Daryl G. Press, "The New Era of Counterforce: Technological Change and the Future of Nuclear Deterrence," *International Security* 41, no. 4 (April 2017): 9–49, https://doi.org/10.1162/ISEC_a_00273.

75 Elbridge Colby, "The Role of Nuclear Weapons in the U.S.-Russian Relationship," Carnegie Endowment for International Peace, February 26, 2016, https://carnegieendowment.org/2016/02/26/role-of-nuclear-weapons-in-u.s.-russian-relationship-pub-62901.

76 Pavel Podvig, "Russia's Current Nuclear Modernization and Arms Control," *Journal for Peace and Nuclear Disarmament* 1, no. 2 (July 3, 2018): 256–67, https://doi.org/10.1080/25751654.2018.1526629.

77 Antony J. Blinken, "On the Extension of the New START Treaty with the Russian Federation," *U.S. Department of State* (blog), February 3, 2021, https://www.state.gov/on-the-extension-of-the-new-start-treaty-with-the-russian-federation/.

78 Congressional Research Service, "Nonstrategic Nuclear Weapons," March 16, 2021. Besides their lower yield, the reason these weapons are not considered strategic is because they are designed for field use to target troops or facilities on a battlefield, not for the mutually assured destruction (MAD) that is core to nuclear deterrence. The continued development of NNWs therefore raises questions regarding their purpose.

79 Fiona S. Cunningham, "Cooperation under Asymmetry? The Future of US-China Nuclear Relations," *The Washington Quarterly* 44, no. 2 (April 3, 2021): 159–80, https://doi.org/10.1080/0163660X.2021.1934253.

80 U.S. Department of Defense, Sharpening the American Military's Competitive Edge: Summary of the 2018 National Defense Strategy of the United States of America (Washington, D.C.: Office of the Secretary of Defense, 2018).

81 Joseph R. Biden, "Interim National Security Strategic Guidance," March 3, 2021, https://www.whitehouse.gov/briefing-room/statements-releases/2021/03/03/interim-national-security-strategic-guidance/.

Chinese defense white paper the United States is pursuing "absolute military superiority".[82] China believes that the US is seeking to curtail China's growing influence by enhancing its alliance system in the Indo-Pacific region (including coordinating with India).[83] Yet, the focus of Chinese strategy remains the United States rather than the latter.[84]

Significant risks for nuclear escalation exist within the Sino-American strategic rivalry. The relationship is characterized by an imbalance of power where the US enjoys both a conventional and nuclear advantage. As Fiona Cunningham points out, the nuclear and conventional military asymmetries separately and together create incentives for the two states to escalate conflict.[85] To compensate for its conventional inferiority, China may be tempted to threaten nuclear first use in a possible conflict over Taiwan.[86] Whereas some scholars suggest that this violation of its NFU is highly unlikely,[87] others have concluded that China's NFU policy clearly does not apply to the case of Taiwan.[88]

China's nuclear arsenal has historically been designed to match its policy of minimum deterrence, centered on assured retaliation through a secure second strike. This modest nuclear posture represented a striking difference to that of the US and the Soviet Union during the Cold War, as both developed much larger and more flexible arsenals. China appeared content with a small vulnerable nuclear arsenal with questionable survivability.[89] Recent Chinese nuclear modernization efforts are therefore creating a more capable force that aims to address its nuclear strategic mismatch vis-à-vis the US.[90] This has sparked a debate with some arguing that China's nuclear capacities now match a limited deterrence policy more closely.

The modernization and expansion of the Chinese arsenal is likely driven by the damage limitation options, whether through missile defense or a disarming strike, that Chinese planners

82 The State Council Information Office of the People's Republic of China, "China's National Defense in the New Era," July 2019, http://english.www.gov.cn/archive/whitepaper/201907/24/content_WS5d3941ddc6d08408f502283d.html.

83 Einhorn and Sidhu, "The Strategic Chain: Linking Pakistan, India, China, and the United States."

84 Mark Schneider, "The Nuclear Doctrine and Forces of the People's Republic of China," *Comparative Strategy* 28, no. 3 (August 12, 2009): 244–70, https://doi.org/10.1080/01495930903025276; Gaurav Kampani, "China–India Nuclear Rivalry in the 'Second Nuclear Age,'" INF Insights (Norwegian Institute for Defence Studies, March 2014), https://fhs.brage.unit.no/fhs-xmlui/bitstream/handle/11250/226454/Insight2014_3.pdf; Hans M. Kristensen and Robert S. Norris, "Chinese Nuclear Forces, 2016," *Bulletin of the Atomic Scientists* 72, no. 4 (July 3, 2016): 205–11, https://doi.org/10.1080/00963402.2016.1194054; Fiona S. Cunningham and M. Taylor Fravel, "Dangerous Confidence? Chinese Views on Nuclear Escalation," *International Security* 44, no. 2 (October 1, 2019): 61–109, https://doi.org/10.1162/isec_a_00359.

85 Cunningham, "Cooperation under Asymmetry?"

86 Schneider, "The Nuclear Doctrine and Forces of the People's Republic of China."

87 Cunningham and Fravel, "Dangerous Confidence?"

88 Schneider, "The Nuclear Doctrine and Forces of the People's Republic of China."

89 M. Taylor Fravel and Evan S. Medeiros, "China's Search for Assured Retaliation: The Evolution of Chinese Nuclear Strategy and Force Structure," *International Security* 35, no. 2 (October 2010): 48–87, https://doi.org/10.1162/ISEC_a_00016; Masahiro Kurita, "China-India Relationship and Nuclear Deterrence," *NIDS Security Studies* 19, no. 2 (2017): 37–61.

90 Miller, "A Nuclear World Transformed." "Beijing's nuclear plans are also likely designed to hedge against advancing U.S. missile defense capabilities, such as the sea-based Standard Missile-3 Block IIA system, which could potentially compromise China's nuclear retaliatory potential." Daryl Kimball, "Engage China on Arms Control? Yes, and Here's How | Arms Control Association," Arms Control Today, June 2021, https://www.armscontrol.org/act/2021-06/focus/engage-china-arms-control-yes-heres-how.

believe United States is exploring.[91] However, most of the literature tends to argue that minimum deterrence remains the guiding policy within the Chinese posture.[92]

The risk of inadvertent nuclear escalation in the Sino-American rivalry has increased due to a growing overlap between conventional and nuclear strategic weapons.[93] China may not have entangled its non-nuclear and nuclear forces on purpose but, having discovered the usefulness of entanglement, it is now reluctant to make its conventional weaponry vulnerable by engaging in separation.[94] Moreover, the increasing overlap between strategies designed for distinct adversaries also undermines strategic stability. The US Ground-Based Midcourse Defense system may ostensibly be "designed exclusively to counteract emerging threats from North Korea and Iran", but it could provide Americans with the ability to blunt a Chinese retaliatory strike, incentivizing Chinese planners to look for countermeasures and increasing the risk of escalation during a crisis between the United States and North Korea.[95]

China may not have entangled its non-nuclear and nuclear forces on purpose

Calls to include China into arms control efforts are increasing, and the Trump administration sought linkage between the European and Asian theaters when it left the INF Treaty. The Biden administration also considers Chinese participation to be crucial.[96] But the Chinese perception appears to be that US arms control efforts are aimed at maintaining its hegemonic power position and nuclear supremacy using the moral high ground, while constraining China's nuclear deterrent. Creating an environment in which China is willing to participate will therefore most likely necessitate the US to make concessions and to "address (its own) non-nuclear strategic capabilities such as missile defense".[97]

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91 Charles L. Glaser and Steve Fetter, "Should the United States Reject MAD? Damage Limitation and U.S. Nuclear Strategy toward China," *International Security* 41, no. 1 (2016): 49–98, https://doi.org/10.1162/ISEC_a_00248. Einhorn and Sidhu, "The Strategic Chain: Linking Pakistan, India, China, and the United States." "Since the demise of the INF treaty in 2019, the United States has sought to deploy land-based conventional medium- and intermediate-range missiles in the Asia-Pacific region to counter China's so-called anti-access, area denial (A2AD) capabilities. Such deployment, if implemented, may cause new concerns in China about the survivability of its small nuclear forces, as those U.S. land-based missiles deployed near China could enhance the American capability to execute a conventional counterforce strike against Chinese nuclear forces, including China's road-mobile nuclear missile launch vehicles."Tong Zhao, "Modernizing Without Destabilizing: China's Nuclear Posture in a New Era," Carnegie-Tsinghua Center, August 25, 2020, https://carnegietsinghua.org/2020/08/25/modernizing-without-destabilizing-china-s-nuclear-posture-in-new-era-pub-82454. Fravel and Medeiros, "China's Search for Assured Retaliation."

92 Hans M. Kristensen and Matt Korda, "Chinese Nuclear Forces, 2020," *Bulletin of the Atomic Scientists* 76, no. 6 (November 1, 2020): 443–57, https://doi.org/10.1080/00963402.2020.1846432; Liping Xia and Liping Xia, "China's Nuclear Doctrine: Debates and Evolution," Carnegie Endowment for International Peace, June 30, 2016, https://carnegieendowment.org/2016/06/30/china-s-nuclear-doctrine-debates-and-evolution-pub-63967; Fravel and Medeiros, "China's Search for Assured Retaliation."

93 Joshua Pollack, "Emerging Strategic Dilemmas in U.S.-Chinese Relations," *Bulletin of the Atomic Scientists* 65, no. 4 (July 1, 2009): 53–63, https://doi.org/10.2968/065004006; Lieber and Press, "The New Era of Counterforce."

94 Tong Zhao and Bin Li, "The Underappreciated Risks of Entanglement: A Chinese Perspective," in *Entanglement: Russian and Chinese Perspectives on Non-Nuclear Weapons and Nuclear Risks*, ed. James M. Acton (Washington D.C.: Carnegie Endowment for International Peace, 2017), 47–76, https://carnegieendowment.org/files/Entanglement_interior_FNL.pdf.

95 Pollack, "Emerging Strategic Dilemmas in U.S.-Chinese Relations."

96 In an effort to highlight the consequences of a Chinese refusal to join this conversation, the arms control envoy of the Trump administration argued in 2020 that the US is capable of winning an arms race by "spend(ing) the adversary into oblivion". Kimball, "Engage China on Arms Control? Yes, and Here's How | Arms Control Association"; Henrik Stålhane Hiim and Magnus Langset Trøan, "China's Atomic Pessimism and the Future of Arms Control," War on the Rocks, June 21, 2021, https://warontherocks.com/2021/06/chinas-atomic-pessimism-and-the-future-of-arms-control/.

97 Henrik Stålhane Hiim and Magnus Langset Trøan, "Hardening Chinese Realpolitik in the 21st Century: The Evolution of Beijing's Thinking about Arms Control," *Journal of Contemporary China*, May 24, 2021, 1–15, https://doi.org/10.1080/10670564.2021.1926095.

India and Pakistan

The India-Pakistan nuclear dyad is mostly self-contained and a continuation of their ongoing conflict at the highest level.[98] Similar to British and French calculations during the Cold War, Pakistan believes its nuclear arsenal offsets India's conventional superiority.[99] In turn, India developed its nuclear arsenal in parallel to maintain the strategic advantage.[100] Yet, in stark contrast to the other dyads discussed here, the Indo-Pakistani relationship is characterized by actual low-intensity conflict, through the direct use of force or proxies like terrorist organizations. This is the *stability-instability paradox:* the extreme nature of nuclear weapons makes a full-scale war unlikely but incentivises conflict on a sub-strategic level where vital interests are not believed to be at stake. The high level of stability has allowed Pakistan to initiate conventional conflict and to wage a low-intensity war against India.[101]

Despite its explicit no-first-use stance, India's nuclear strategy toward Pakistan appears to be developing towards nuclear counterforce.[102] India would possibly have the ability to disarm Pakistan's strategic nuclear weapons left-of-launch. The shift in Indian doctrine seems a response to Pakistan's threat to use tactical nuclear weapons against India's conventional forces if they cross certain red lines.[103] Due to the doubts whether India would target urban centers after a nuclear strike on its conventional forces operating on Pakistani soil,[104] Indian policymakers may be tempted to focus retaliation on Pakistan's tactical weapons.[105] In turn, this incentivizes Pakistan to adopt a use it-or-lose-it doctrine that would involve unleashing its entire arsenal before it could be destroyed. But this would provide further encouragement for India to strike Pakistan's tactical weapons preemptively. Consequently, a debate is taking place among Indian officials to revise their NFU policy.

The current state of the Indo-Pakistani relationship therefore poses significant risks for escalation and leaves little room for arms control. Pakistan's military strategy is centered around

98 Christoph Bluth, "India and Pakistan: A Case of Asymmetric Nuclear Deterrence," *Korean Journal of Defense Analysis* 22, no. 3 (September 1, 2010): 387–406, https://doi.org/10.1080/10163271.2010.500027.

99 Feroz Hassan Khan, "Minimum Deterrence," *The RUSI Journal*, Nuclear Security, 156, no. 5 (October 1, 2011): 44–51, https://doi.org/10.1080/03071847.2011.626274.

100 Karthika Sasikumar, "India-Pakistan Crises under the Nuclear Shadow: The Role of Reassurance," *Journal for Peace and Nuclear Disarmament* 2, no. 1 (January 2, 2019): 151–69, https://doi.org/10.1080/25751654.2019.1619229.

101 Kampani, "China–India Nuclear Rivalry in the 'Second Nuclear Age'"; Dinshaw Mistry, "Tempering Optimism about Nuclear Deterrence in South Asia," *Security Studies* 18, no. 1 (February 18, 2009): 148–82, https://doi.org/10.1080/09636410802678072. Other argue that the real risk of nuclear escalation empowers Pakistan by adding credibility to its nuclear threats. This deters India from taken advantage of its conventional superiority. Paul Kapur, *Dangerous Deterrent: Nuclear Weapons Proliferation and Conflict in South Asia*, Studies in Asian Security 5 (Stanford: Stanford University Press, 2007), https://www.eastwestcenter.org/publications/dangerous-deterrent-nuclear-weapons-proliferation-and-conflict-south-asia; Paul Kapur, "Ten Years of Instability in a Nuclear South Asia," *International Security* 33, no. 2 (October 2008): 71–94, https://doi.org/10.1162/isec.2008.33.2.71; Bluth, "India and Pakistan."

102 Christopher Clary and Vipin Narang, "India's Counterforce Temptations: Strategic Dilemmas, Doctrine, and Capabilities," *International Security* 43, no. 3 (February 1, 2019): 7–52, https://doi.org/10.1162/isec_a_00340.

103 Frank O'Donnell, "Managing Nuclear Multipolarity: A Multilateral Missile Test Pre-Notification Agreement," *The Washington Quarterly* 43, no. 3 (July 2, 2020): 177–96, https://doi.org/10.1080/0163660X.2020.1810419. Such threats are consistent with Pakistan's first-use nuclear doctrine that states it will use "any weapon in its arsenal to defend itself" if invaded or attacked J. N. Dixit, *India-Pakistan in War and Peace* (Routledge, 2003), 65.

104 Rajesh Rajagopalan, "India's Nuclear Doctrine Debate," Carnegie Endowment for International Peace, June 30, 2016, https://carnegieendowment.org/2016/06/30/india-s-nuclear-doctrine-debate-pub-63950; P. R. Chari, "India's Nuclear Doctrine: Stirrings of Change," Carnegie Endowment for International Peace, June 4, 2014, https://carnegieendowment.org/2014/06/04/india-s-nuclear-doctrine-stirrings-of-change-pub-55789; Kumar Sundaram and M. V. Ramana, "India and the Policy of No First Use of Nuclear Weapons," *Journal for Peace and Nuclear Disarmament* 1, no. 1 (January 2, 2018): 152–68, https://doi.org/10.1080/25751654.2018.1438737.

105 Clary and Narang, "India's Counterforce Temptations."

India's conventional superiority, which it makes it difficult to move away from a first-use nuclear doctrine and to detach a deterrence policy from India.[106] India itself has acquired nuclear capabilities greater than what would be required for a strictly retaliatory arsenal to maintain deterrence directed at Pakistan.[107] Moreover, because India's nuclear strategy is not only directed at Pakistan, but also China, it may be sending confusing signals about its intent to the latter. Due to India's dual strategic engagement, an Indian attempt to catch up with China would inadvertently start an arms race with Pakistan as "it is impossible to gain 'credible minimum' deterrence against both of its geopolitical opponents".[108]

The United Kingdom, France and Russia

An Indian attempt to catch up with China would inadvertently start an arms race with Pakistan

Russian revisionism from 2014 has also triggered a reappraisal of the role of nuclear deterrence in France and, especially, the UK. Russia's military modernization efforts since the 2008 Georgia conflict have meant an improvement in its ability to unleash discriminate, coercive conventional strikes against any European country.[109] As a result, it again poses a credible threat to the territory of European states and as well as the crucial air and sea lines of communication to Europe.[110] These developments have led to some NATO efforts to boost conventional deterrence in an effort to reassure the Baltic states.

As the only two nuclear powers in Europe, both the UK and France are modernizing and/or expanding their nuclear arsenals. The British and French nuclear doctrine are similar in emphasizing a minimum deterrent, based on a secure submarine-based second strike capability. As a result, neither arsenal is designed for active warfighting and contains little or no pre-strategic weapons.[111]

The UK has departed from an earlier pledge in 2010 to reduce its nuclear capacities and announced in its 2021 Integrated Review that it will increase its nuclear stockpile by 40%, aims to modernize its existing arsenal, and will reduce transparency by no longer publishing information about the number of warheads it maintains operational.[112] After decades of reductions in nuclear weapons, this represents a stark reversal from British policy since the

106 Khan, "Minimum Deterrence."

107 Clary and Narang, "India's Counterforce Temptations." While India's arsenal has the declared purpose to "maintain credible deterrence", its doctrine does not define what precisely "minimum" means nor at whom this is directed at. "The Cabinet Committee on Security Reviews Operationalization of India's Nuclear Doctrine," Ministry of Foreign Affairs of the Indian Government, April 1, 2003, https://mea.gov.in/press-releases.htm?dtl/20131/The_Cabinet_Committee_on_Security_Reviews_perationalization_of_Indias_Nuclear_Doctrine+Report+of+National+Security+Advisory+Board+on+Indian+Nuclear+Doctrine.

108 Amit R. Saksena, "The Paradox of India's 'Credible Minimum Deterrence,'" The Diplomat, accessed August 31, 2021, https://thediplomat.com/2014/08/the-paradox-of-indias-credible-minimum-deterrence/.

109 Elbridge Colby and Jonathan Solomon, "Facing Russia: Conventional Defence and Deterrence in Europe," *Survival* 57, no. 6 (November 2, 2015): 21–50, https://doi.org/10.1080/00396338.2015.1116146.

110 David A. Shlapak and Michael Johnson, "Reinforcing Deterrence on NATO's Eastern Flank," Product Page (RAND Corporation, 2016), https://www.rand.org/pubs/research_reports/RR1253.html.

111 Bruno Tertrais, "A Comparison between US, UK and French Nuclear Policies and Doctrines" (Centre de Recherches Internationales, March 2007), http://www.ceri-sciences-po.org/; Hans M. Kristensen and Matt Korda, "United Kingdom Nuclear Weapons, 2021," *Bulletin of the Atomic Scientists* 77, no. 3 (May 4, 2021): 153–58, https://doi.org/10.1080/00963402.2021.1912309; Hans M. Kristensen and Matt Korda, "French Nuclear Forces, 2019," *Bulletin of the Atomic Scientists* 75, no. 1 (January 2, 2019): 51–55, https://doi.org/10.1080/00963402.2019.1556003; Niklas Granholm and John Rydqvist, "Nuclear Weapons in Europe: British and French Deterrence Forces" (Försvarsdepartementet, April 2018).

112 "Integrated Review of Security, Defence, Development and Foreign Policy 2021: Nuclear Deterrent," GOV.UK, accessed January 24, 2022, https://www.gov.uk/guidance/integrated-review-of-security-defence-development-and-foreign-policy-2021-nuclear-deterrent.

1990s.[113] Russia has historically been the UK's principal criterion to judge the effectiveness of its nuclear arsenal. While no formal move away from the UK's traditional minimum deterrence posture has been announced, the decision to modernize and expand the UK nuclear arsenal indicates that what constitutes credible minimum deterrence varies over time and according to context.[114]

The desire to maintain international status and strategic autonomy has required French security to not rely entirely on the American "nuclear umbrella"

French nuclear capabilities are based on the notion of sufficiency.[115] Traditionally, French doctrine is intended to deter aggression against attacks on vital national interests. French doctrine presently excludes a graduated response where it would rely on nuclear weapons with varying yields and it has disassembled its tactical nuclear weapons in the 1990s. Whereas France has not excluded the option of a nuclear first-use, there is no evidence that it ever considered this option and its arsenal does not seem designed for such purpose. Instead, it is the threat of "unacceptable damage" from a potential second strike that acts as deterrent, ensured by the continuous deployment of nuclear warheads at sea.[116] France plans to modernize its SSBN fleet in the coming decades.[117] The choice is largely informed by the negative developments in the European security domain, including Russia's reemphasis on the role of a full-spectrum arsenal.[118] However, France continues to aim for a defense policy that is less dependent relatively on the United States than that of other European states.[119] Historically, the desire to maintain international status and strategic autonomy has required French security to not rely entirely on the American "nuclear umbrella".[120] In contrast, the UK's strategic deterrent relies on American components and infrastructure to such an extent, that its independence has long been in question.[121]

In response to Russian aggression in eastern Europe, Brexit, and the uncertainty of the US commitment during the Trump administration, European strategic autonomy and sovereignty has returned on the agenda.[122] Consequently, the role the French deterrent could potentially play for European allies has again become relevant. French presidents have stated that French security is indivisible from that of Europe and President Macron has noted that the

113 Kristensen and Korda, "United Kingdom Nuclear Weapons, 2021"; Frank Boulton, "Response to the UK Government's Integrated Review of Security, Defence, Development and Foreign Policy," *Medicine, Conflict and Survival* 37, no. 2 (April 3, 2021): 102–11, https://doi.org/10.1080/13623699.2021.1914807.

114 Tom Plant and Matthew Harries, "Going Ballistic: The UK's Proposed Nuclear Build-Up," accessed September 6, 2021, https://rusi.org/explore-our-research/publications/commentary/going-ballistic-uks-proposed-nuclear-build.

115 Bruno Tertrais, "Chapter 2: The French Deterrence Doctrine," in *French Nuclear Deterrence Policy, Forces and Future*, 2020, https://www.frstrategie.org/web/documents/publications/recherches-et-documents/2019/201901.pdf.

116 Bruno Tertrais, *French Nuclear Deterrence Policy, Forces and Future*, 2019, https://www.frstrategie.org/web/documents/publications/recherches-et-documents/2019/201901.pdf.

117 Timothy Wright and Hugo Decis, "Counting the Cost of Deterrence: France's Nuclear Recapitalisation," IISS, accessed September 6, 2021, https://www.iiss.org/blogs/military-balance/2021/05/france-nuclear-recapitalisation; Amruta Karambelkar, "An Analysis of the French Strategy in the Indo-Pacific," *Maritime Affairs: Journal of the National Maritime Foundation of India* 0, no. 0 (August 6, 2021): 1–18, https://doi.org/10.1080/09733159.2021.1962040.

118 Granholm and Rydqvist, "Nuclear Weapons in Europe: British and French Deterrence Forces."

119 Mark Fitzpatrick, "How Europeans View Tactical Nuclear Weapons on Their Continent," *Bulletin of the Atomic Scientists* 67, no. 2 (March 1, 2011): 57–65, https://doi.org/10.1177/0096340211399405.

120 Fitzpatrick.

121 Kristensen and Korda, "United Kingdom Nuclear Weapons, 2021."

122 John Henley, "Angela Merkel: EU Cannot Completely Rely on US and Britain Any More | World News | The Guardian," *The Guardian*, May 28, 2017, https://www.theguardian.com/world/2017/may/28/merkel-says-eu-cannot-completely-rely-on-us-and-britain-any-more-g7-talks; "Transcript - Emmanuel Macron in His Own Words (English)," *The Economist*, November 7, 2019, https://www.economist.com/europe/2019/11/07/emmanuel-macron-in-his-own-words-english.

French-German Aachen Treaty includes de facto extended deterrence.[123] Placing collective defense of the EU at the heart of Paris' deliberations may play a part in scenarios where the EU needs to act without US assistance. These could include attacks on EU member states that are not a member of NATO, such as Finland or Sweden.[124] However, unlike the UK, France is not part of NATO's nuclear planning group and its nuclear deterrence currently does not explicitly apply to the protection of allies.[125]

The French and British developments underline the change of direction in European disarmament efforts, particularly on the part of the UK. Due to its emphasis on strategic autonomy, France has been the most skeptical about calls for complete disarmament and has explicitly made it contingent on the strategic context.[126] The UK, however, was considered to be the most committed to nuclear disarmament of all nuclear-armed states.[127] The British reversal is a tell-tale sign of the direction of the global trend.

China and India

China is central to India's deterrence considerations and acts as the crucial reference point to India's conception of credible minimum deterrence. In turn, China considers neither India nor Pakistan a major threat.[128] On the one hand, since the 1962 war, Sino-Indian relations have greatly improved including the development of an elementary military relationship that creates a mechanism to manage border dispute incidents.[129] On the other, China and India have in fact fought hand-to-hand skirmishes over their mutual border in the Himalayas in the past year, which has led to mutual casualties and illustrated the stability-instability paradox.[130] Taking into account India's perceptions of China's growing influence in the Indo-Pacific region and the Chinese perception of a strategic partnership between the US and India, there is growing potential for major conflict in the future, beyond the current stand-off in the mountains of Ladakh.[131]

The two states are not engaged in any discussions on deterrence stability and attempts to overcome a disparity in conventional and nuclear capabilities may further destabilize the region.[132] Currently, China's nuclear and missile technologies greatly out-match India's capabilities.[133] However, India has developed capabilities that could enable a counterforce

123 Bruno Tertrais, "The European Dimension of Nuclear Deterrence: French and British Policies and Future Scenarios," *The Finnish Institute of International Affairs*, 2018; Bruno Tertrais, "Will Europe Get Its Own Bomb?," *The Washington Quarterly* 42, no. 2 (2019): 47–66; William Drozdiak, "Opinion | France Is Prepared to Extend Its Nuclear Deterrent to Germany," *Washington Post*, March 1, 2019, https://www.washingtonpost.com/opinions/2019/02/28/france-is-prepared-extend-its-nuclear-deterrent-germany/.

124 Barbara Lippert et al., "European Strategic Autonomy: Actors, Issues, Conflicts of Interests," *SWP Research Paper*, 2019, https://doi.org/10.18449/2019RP04.

125 Granholm and Rydqvist, "Nuclear Weapons in Europe: British and French Deterrence Forces"; Tertrais, "The European Dimension of Nuclear Deterrence"; Barbara Kunz, "Switching Umbrellas in Berlin? The Implications of Franco-German Nuclear Cooperation," *The Washington Quarterly* 43, no. 3 (2020): 63–77.

126 Address by Jacques Chirac, President of the French Republic, during his visit to the strategic air and ocean forces, Landivisiau – L'Île Longue (Brest), 19 January 2006

127 Fitzpatrick, "How Europeans View Tactical Nuclear Weapons on Their Continent."

128 Schneider, "The Nuclear Doctrine and Forces of the People's Republic of China."

129 Iftikhar Ali and Jatswan S Sidhu, "India's Doctrinal Modifications: Counterforce Temptations in South Asia," *Journal of Asian and African Studies*, 2021, 1–22, https://doi.org/10.1177/00219096211019075.

130 "India-China Dispute: The Border Row Explained in 400 Words - BBC News," accessed January 21, 2022, https://www.bbc.com/news/world-asia-53062484.

131 Kampani, "China–India Nuclear Rivalry in the 'Second Nuclear Age.'"

132 Ali and Sidhu, "India's Doctrinal Modifications."

133 Clary and Narang, "India's Counterforce Temptations"; Ali and Sidhu, "India's Doctrinal Modifications."

strike on China. India's missile defense technologies and long range ballistic missiles, such as the Agni V and VI, are likely to further narrow the capability gap between China and India.[134] India begun developing the sea-based leg of its triad though a true sea-based deterrent still remains distant.[135] Despite these developments, the expectation remains that India will maintain its NFU and countervalue retaliation strategy vis-à-vis China.[136] However, an anticipated doubling of Chinese nuclear warheads and the possibility that China could low-yield nuclear warheads could cause India to reconsider its posture towards China.[137]

India has been a reluctant nuclear power and remains open to arms control measures.[138] Instead of contributing in an arms race, India could establish itself as a responsible nuclear actor.[139] But the current absence of any discussion on deterrence stability, and the prevailing negative outlook on arms control by Chinese policymakers as a consequence of China's stand-off with the United States, means that progress on arms control appears unlikely. India holds little leverage in negotiations with China, as any meaningful reduction in Chinese arms would primarily require US concessions. [140]

The Sino-Russian relationship appears to have evolved from a marriage of a convenience into one of great strategic value

China and Russia

Despite Sino-Russian animosity during the Cold War, the relationship today is stable.[141] In fact, the relationship appears to have evolved from a marriage of a convenience into one of great strategic value for both; something that is unlikely to change in the near future. Both states have wide- ranging incentives to seek closer ties, with ongoing power competition vis-à-vis the US being a key motivator. They share a desire to counter US global hegemony, its democracy promotion, and oppose US actions that undermine strategic stability in their respective bilateral US relations.[142] A joint statement from 2016 highlights a shared concern about US regional and national defense programs, as well as their conventional long-range strike capabilities that could "damage the strategic balance" and start an arms race aimed to maintain credible deterrence.[143]

Russia's deteriorating relationship with the US is further pushing it to seek closer relations with China, despite shared concerns about China's growing position of power.[144] However, Sino-Russian relations may not be as close as the Russia government likes to convey, with their respective nuclear postures still designed for mutual deterrence. Unity in anti-Western policy is lacking and Beijing does not appear to have the desire to get involved in renewed East-West

134 Hans M. Kristensen and Matt Korda, "Indian Nuclear Forces, 2020," *Bulletin of the Atomic Scientists* 76, no. 4 (2020): 217–25, https://doi.org/10.1080/00963402.2020.1778378; Clary and Narang, "India's Counterforce Temptations."

135 Einhorn and Sidhu, "The Strategic Chain: Linking Pakistan, India, China, and the United States."

136 Clary and Narang, "India's Counterforce Temptations"; Kristensen and Korda, "Indian Nuclear Forces, 2020"; Einhorn and Sidhu, "The Strategic Chain: Linking Pakistan, India, China, and the United States."

137 Zhao, "Modernizing Without Destabilizing"; Kristensen and Korda, "Chinese Nuclear Forces, 2020."

138 Vipin Narang, "India's Nuclear Strategy Twenty Years Later: From Reluctance to Maturation," *India Review* 17, no. 1 (January 1, 2018): 159–79, https://doi.org/10.1080/14736489.2018.1415289.

139 Manpreet Sethi, "Nuclear Arms Control and India: A Relationship Explored | Arms Control Association," Arms Control Today, 2010, https://www.armscontrol.org/act/2010-09/nuclear-arms-control-india-relationship-explored.

140 Hiim and Trøan, "Hardening Chinese Realpolitik in the 21st Century."

141 Tom Røseth, "Moscow's Response to a Rising China," *Problems of Post-Communism* 66, no. 4 (March 23, 2018): 268–86, https://doi.org/10.1080/10758216.2018.1438847.

142 Michael Chase et al., "Russia-China Relations: Assessing Common Ground and Strategic Fault Lines," NBR Special Report (The National Bureau of Asian Research, July 2017), https://carnegieendowment.org/files/SR66_Russia-ChinaRelations_July2017.pdf.

143 "China, Russia Sign Joint Statement on Strengthening Global Strategic Stability," Xinhua, June 27, 2016

144 Rajesh Rajagopalan, "India's Strategic Choices: China and the Balance of Power in Asia," Carnegie India, September 14, 2017, https://carnegieindia.org/2017/09/14/india-s-strategic-choices-china-and-balance-of-power-in-asia-pub-73108.

confrontations.[145] Additionally, while Russia maintains a significant nuclear advantage over China, its emphasis on non-strategic nuclear weapons to primarily counter NATO's superior conventional force appears to also be grounded in countering an increasing and capable Chinese conventional force.[146]

Nevertheless, the two countries share extensive security ties that include a reciprocal NFU nuclear posture, mutual diplomatic consultations, and cooperation on various topics such as counter- terrorism policies.[147] Such cooperation does not include arms control, however. China is exploring how to modernize and expand its nuclear arsenal to ensure it has a more robust deterrent (see above),[148] whereas Russian security experts emphasize the importance of engaging China (in addition to the US) in a dialogue to address strategic stability issues.[149] Yet, again in contrast to how Russia prefers to present the relationship, it lacks the diplomatic clout to bring China to the negotiation table.

Israel and region

Israel has had a nuclear arsenal since the 1960s and is estimated to have less than a hundred nuclear warheads.[150] Its strategy is based on the idea that it cannot afford to lose a single war – always an existential danger due to its size - and aggressively maintains deterrence to prevent such an event.[151] Since the inception of its nuclear program, its nuclear strategy, concerning both its nuclear capabilities and intentions, has been that of "deliberate ambiguity" which makes an evaluation difficult.[152] Nevertheless, from examining patterns of prior Israeli conflicts, it is believed that "first use but last resort" is the corner stone of the Israeli nuclear doctrine.[153]

Israel is the only nuclear power in the region and its interest in maintaining that status fuel its strong apprehensions towards the Iranian attempts of proliferation and Saudi interests in reducing any military imbalances. Iran's nuclear interests has been argued to be the biggest challenge to Israel's regional security in recent history.[154] It is clear that Iran's intention is to come as close to nuclear-weapon capabilities as the non-proliferation regime allows.[155] Not only is it

145 Axel Berkofsky, "Russia and China: The Past and Present of a Rocky Relationship," *Il Politico* 79, no. 3 (237) (2014): 108–23.

146 Hans M. Kristensen and Robert S. Norris, "Russian Nuclear Forces, 2018," *Bulletin of the Atomic Scientists* 74, no. 3 (April 30, 2018): 185–95, https://doi.org/10.1080/00963402.2018.1462912; Kristensen and Korda, "Chinese Nuclear Forces, 2020."

147 "Treaty of Good-Neighborliness and Friendly Cooperation between the People's Republic of China and the Russian Federation," July 24, 2001, available from the Ministry of Foreign Affairs (PRC) at http://www.fmprc.gov.cn/mfa_eng/wjdt_665385/2649_665393/t15771.shtml.

148 Hiim and Trøan, "Hardening Chinese Realpolitik in the 21st Century."

149 Fink and Oliker, "Russia's Nuclear Weapons in a Multipolar World."

150 Hans M. Kristensen and Robert S. Norris, "Israeli Nuclear Weapons, 2014," *Bulletin of the Atomic Scientists* 70, no. 6 (November 1, 2014): 97–115, https://doi.org/10.1177/0096340214555409.

151 Shlomo Ben Ami, "Nuclear Weapons in the Middle East: The Israeli Perspective," in *International Commission on n Nuclear Non-Proliferation and Disarmament* (Cairo: International Commission on Nuclear Non-prolifera-tion and Disarmament, 2009), 1–24.

152 Hans M. Kristensen and Robert S. Norris, "Worldwide Deployments of Nuclear Weapons, 2017," *Bulletin of the Atomic Scientists* 73, no. 5 (September 3, 2017): 289–97, https://doi.org/10.1080/00963402.2017.1363995; Shams Uz Zaman, "Evolution of Israel's Nuclear Programme: Implications in Post-Iran Nuclear Deal Era," *Regional Studies* XXXIV (January 1, 2016): 75–98. Yair Evron, "Opaque Proliferation: The Israeli Case", in Benjamin Frankel (ed) Opaque Nuclear Proliferation (London: Frank Cass, 1991), p. 45.

153 Zaman, "Evolution of Israel's Nuclear Programme." Zeev Moaz, "The Mixed blessing of Israel's Nuclear Policy," International Security, Vol.28, No.2, (Fall 2003), p.47.

154 S. Samuel C. Rajiv, "Deep Disquiet: Israel and the Iran Nuclear Deal," *Contemporary Review of the Middle East* 3, no. 1 (March 1, 2016): 47–62, https://doi.org/10.1177/2347798916632324.

155 Leonard Weiss, "Israel's Future and Iran's Nuclear Program," *Middle East Policy* 16, no. 3 (September 2009): 79–88, https://doi.org/10.1111/j.1475-4967.2009.00405.x.

perceived by Israel to be a threat to regional peace, but also as an existential threat.[156] Lack of Israeli trust in Iran to conscientiously engage in arms control is at the core of Israel's opposition to the US-led attempt to engage Iran in the Joint Comprehension Plan of Action (JCPOA).[157] Furthermore, despite some normalizations in the Saudi-Israeli relationship (fueled in part by a shared concern vis-à-vis Iran), Saudi Arabia remains a key Israeli antagonist in the region.[158] Israel's undeclared nuclear weapon program makes a dialogue on arms control impossible and could incentivize states like Saudi Arabia to seek nuclear weapon capacities in the future.[159]

North Korea and United States/region

North Korea represents one of the most persistent problems for US foreign policy. DC views the regime as an aggressive, unpredictable nuclear actor that threatens the regional interests of the US and its allies through its brinkmanship tactics.[160] On the other hand, for North Korea, nuclear weapons are a rational strategy to give it leverage that it otherwise would never have.[161] Its capabilities remain limited. Kristensen and Norris estimate that it has enough fissile material to hypothetically build 30 to 60 nuclear weapons; it also has the ability to mate these to cruise missiles and ballistic missiles to put US allies like Japan and US territories like Guam at risk.[162]

These limited capabilities might not be sufficient to directly deter the US, Japan or South Korea; arguably their intention is different. North Korea seems to pursue a catalytic nuclear posture, that depends on the patronage of a larger power, namely China. This posture aims to catalyzse "third-party military or diplomatic assistance when a state's vital interests are threat-ened".[163] The patron and the client do not need to have shared interests, except the former's strong preference for regional stability. Consequently, despite not having a robust or expan-sive nuclear arsenal, North Korea weapons suffice to accomplish its strategic objectives.[164]

It is unclear in which direction the Chinese cost-benefit analysis of protecting North Korea will trend. China is already displeased at the ballistic missile defenses deployed by the United States, Japan, and South Korea to counter the North Korean threat.[165] Paradoxically, the US may have an interest in North Korea maintaining the catalytic posture to cause Chinese patronage intervention. North Korea has little incentive to create a more capable – and thus more threatening – nuclear force.[166]

156 Rajiv, "Deep Disquiet."

157 Rajiv.

158 Roman Vladimirovich Penkovtsev, Timur Vasilevich Gafurov, and Natalia Aleksandrovna Shibanova, "The Nature of the Political Interaction between Israel and Saudi Arabia in the 21st Century," *Journal of Politics and Law* 12 (2019): 53.

159 Zaman, "Evolution of Israel's Nuclear Programme."

160 Emma Chanlett-Avery and Ian E Rinehart, "North Korea: U.S. Relations, Nuclear Diplomacy, and Internal Situation" (Congressional Research Service, April 5, 2013).

161 Daniel Byman and Jennifer Lind, "Pyongyang's Survival Strategy: Tools of Authoritarian Control in North Korea," *International Security* 35, no. 1 (July 1, 2010): 44–74, https://doi.org/10.1162/ISEC_a_00002.

162 Hans M. Kristensen and Robert S. Norris, "North Korean Nuclear Capabilities, 2018," *Bulletin of the Atomic Scientists* 74, no. 1 (January 2, 2018): 41–51, https://doi.org/10.1080/00963402.2017.1413062.

163 Vipin Narang, "Nuclear Strategies of Emerging Nuclear Powers: North Korea and Iran," *The Washington Quarterly* 38, no. 1 (January 2, 2015): 73–91, https://doi.org/10.1080/0163660X.2015.1038175.

164 Narang.

165 Thomas Plant and Ben Rhode, "China, North Korea and the Spread of Nuclear Weapons," *Survival* 55, no. 2 (May 1, 2013): 61–80, https://doi.org/10.1080/00396338.2013.784467; Brianni Lee, "THAAD Deployment in South Korea," *Harvard International Review* 38 (2017): 34–37.

166 Narang, "Nuclear Strategies of Emerging Nuclear Powers."

Conclusion: consequences of geopolitical trends for strategic stability

The consequences of the structural condition of multipolarity and the specific dyadic dynamics on strategic stability are manifold. Table 5 summarizes their effects on deterrent and crisis stability.

Deterrence stability

These geopolitical trends have clear consequences for deterrence stability. First, the second strike has become more vulnerable to nuclear and conventional first strikes, which increases the incentive to strike first. This trend applies not only to the revisionist, but also the status quo powers. Revisionist powers have pursed nuclear and conventional first strike capabilities, including China, Russia, and Pakistan. China has invested in conventional A2/AD capabilities to raise the costs of American power projection.[167] Russia has invested in A2/AD capabilities (though better referred to as active defense) as well as low-yield nuclear weapons to use within the battlefield.[168] Pakistan is looking to offset India's conventional advantages by pre-delegating the control of low-yield tactical nuclear weapons to military commanders.[169] However, status quo powers, including the United States and India, have followed suit in pursuing first strike capabilities. If risks of conventional *fait accompli* against American allies are high, the United States has committed itself to highly offensive conventional doctrines with which to destroy US aircraft carriers, ports, and airbases. To offset the Chinese A2/AD threat to US essential infrastructure in the Western Pacific, the United States has invested in the highly offensive AirSea Battle concept (renamed Joint Access and Maneuver in the Global Commons (JAM-GC).[170] In the European theater, the 2018 Nuclear Posture Review introduced low-yield tactical nuclear weapons on the US SSBNs to fill in the gaps in the escalation ladder, despite the obvious risks to discrimination and signaling demands during an NATO-Russian crisis.[171] If the risk of nuclear threat of low-yield nuclear weapons with high-pre-delegation in command and control arrangements is high, as is the case with the Pakistani threat to India, then the Indian counterforce doctrine to preempt attacks seems to largely negate its no-first-use declaratory posture.[172] The first trend has detrimental consequences for deterrent stability, both directly, and through stimulating the perceived pay-offs of investments into technology.

Second, as the number of nuclear actors increases, the complexity of the strategic calculus increases, making it more difficult to assess the state a certain policy is intended to deter.

167 Biddle and Oelrich, "Future Warfare in the Western Pacific"; Evan Braden Montgomery, "Contested Primacy in the Western Pacific: China's Rise and the Future of US Power Projection," *International Security* 38, no. 4 (2014): 115–149; Tangredi, *Anti-Access Warfare*; Van Hooft, "All-In or All-Out: Why Insularity Pushes and Pulls American Grand Strategy to Extremes."

168 Dmitry Dima Adamsky, *Moscow's Aerospace Theory of Victory: Western Assumptions and Russian Reality* (Washington: CNA, 2021).

169 Clary and Narang, "India's Counterforce Temptations."

170 Biddle and Oelrich, "Future Warfare in the Western Pacific"; Montgomery, "Contested Primacy in the Western Pacific"; Cunningham and Fravel, "Assuring Assured Retaliation"; Van Hooft, "All-In or All-Out: Why Insularity Pushes and Pulls American Grand Strategy to Extremes."

171 Gavin et al., "Policy Roundtable."

172 Clary and Narang, "India's Counterforce Temptations."

What is intended to deter one actor, might provoke another

What is intended to deter one actor, might provoke another.[173] Horizontal nuclear proliferation among regional actors, and vertical proliferation driven by competition dynamics between the three nuclear great powers, deepen the complexity.[174] Outside of the bipolar logic of the Cold War,[175] the complex interactions between the multiple actors in the system preclude straightforward interpretations of the effect of emerging technologies on strategic stability.[176] Disruptive technologies, like anti-satellite weapons, further increase mistrust among key players.[177] The United States has responded to this complexity by attempting to tailor its deterrence for each individual adversary, taking into consideration how they uniquely calculate costs and risks.[178] For example, the 2018 NPR sought to signal to Russia that it cannot benefit from non-nuclear aggression or limited nuclear escalation.[179] Yet, universal rules are more difficult to establish because it is more difficult to find a common understanding on the stakes in play for the various actors. The multidirectional nature of multipolarity makes political signaling and trust-building inherently more difficult. In sum, this trend has detrimental consequences for deterrence stability and reinvigorating arms control.

Crisis stability

The intensifying competitive dynamics in the international systems alongside its increasingly multipolar nature also ensure that judgments during a crisis have become more likely, in two ways.

First, it is more difficult to assess the direction of policies in the short-term as well, particularly as advanced conventional weapons become more and more accessible. During a crisis, the launch of a ballistic missile with a conventional warhead may be misunderstood as a first strike. Additionally, the direction of the attack may not be clear to a third party. The increasing access to non-kinetic weapons matters here as well, as what constitutes an attack on vital interests has also broadened due to the increasing interconnectedness between the economic, information and technological domains.[180] Consequently, major vulnerabilities of a state's critical infrastructure to hostile actions from other great powers are no longer limited to the military or nuclear domain.[181]

173 For instance, the Indian doctrinal adaptation to address one adversary, Pakistan, might unsettle a previously stable deterrence relationship with another such as China. Clary and Narang.

174 Christopher A. Ford argues that anxieties brought about by emerging technologies, specially, cyber technologies, in combination with the return of great power competition has led to technological competition dynamics. This technological race, he argues, must be tackled with a mix approach encompassing traditional arms control treaties with non-traditional norm development initiatives.Christopher A Ford, "Strategic Stability and the Global Race for Technology Leadership," *Arms Control and International Security*, Arms Control and International Security Papers, 1, no. 21 (2020): 9.

175 Robert Powell, "Crisis Stability in the Nuclear Age," *The American Political Science Review* 83, no. 1 (1989): 61–76, https://doi.org/10.2307/1956434.

176 Rupal N. Mehta, "Extended Deterrence and Assurance in an Emerging Technology Environment," *Journal of Strategic Studies*, 2019, 1–25, https://doi.org/10.1080/01402390.2019.1621173. Heather Williams, "Asymmetric Arms Control and Strategic Stability: Scenarios for Limiting Hypersonic Glide Vehicles," *Journal of Strategic Studies* 42, no. 6 (September 19, 2019): 789–813, https://doi.org/10.1080/01402390.2019.1627521.

177 Ford, "Strategic Stability and the Global Race for Technology Leadership."

178 Office of the Secretary of Defense, "Nuclear Posture Review," 26.

179 Office of the Secretary of Defense, 30.

180 Office of the Secretary of Defense, "Nuclear Posture Review." Dmitri Trenin, "Strategic Stability in the Changing World," *Carnegie Moscow Center*, March 2019, 12, https://carnegieendowment.org/files/3-15_Trenin_StrategicStability.pdf.

181 Dmitri Trenin, "Strategic Stability in the Changing World," *Carnegie Moscow Center*, March 2019, 12, https://carnegieendowment.org/files/3-15_Trenin_StrategicStability.pdf.

Second, crisis stability is undermined because there are more nuclear-armed states without the deeply institutionalized ties that the United States and the Soviet Union built up during the Cold War. Despite several near-misses, both superpowers eventually became well-attuned to interpreting the other's intentions. With the emergence of China as a major nuclear pole, as well as the addition of nuclear-armed states, that is no longer the case. These states do not have the long experience with the established nuclear powers, nor with each other, increasing the risks of errors in judgement during a crisis. Moreover, those established nuclear powers, the US and especially Russia, have themselves become more aggressive in their rhetoric regarding nuclear weapons.

The four geopolitical trends above have undermined strategic stability and the Cold War arms control arrangements.

Table 5. Effects of increased competition and multipolarity on deterrent and crisis stability

	Deterrence Stability	Crisis Stability
Competition	The intensification of conventional and nuclear competition diminishes the confidence in a secure second strike.	Misunderstandings during a crisis are likely to increase due to the unpredictability of purpose of policies and stark outcome differences.
Multipolarity	The complexity of long-term strategic calculus increases, given the growing number of nuclear actors and access to technology.	The lack of deeply institutionalized ties among powers increases uncertainty and the likelihood of errors in judgement.

There are more nuclear-armed states without the deeply institutionalized ties that the United States and the Soviet Union built up during the Cold War

3. Emerging technologies and strategic stability

Key takeaways

- Strategic stability is further impacted by a variety of technological trends that includes both the emergence of new technologies and novel ways in which existing technologies are being applied.
- Technological advancements are undermining the survivability of nuclear forces; eroding the distinction between conventional and nuclear warfighting; potentially incorporating space warfare in nuclear warfare; shortening decision-making times; and raising the uncertainty about adversarial intentions.
- More specifically, the speed of hypersonic weapons and directed energy weapons, and the difficult-to-detect nature of offensive cyber capabilities, create first strike advantages.
- Simultaneously, remote sensing, UAVs, and AI-driven data fusion increase the detectability of nuclear arsenals, while increased precision has also enabled conventional strikes for counterforce purposes.
- The entanglement of the conventional and nuclear command, control, communications and information and the proliferation of dual-capable missiles increase the risk of inadvertent escalation.
- Crisis escalation may further occur as the difficulty to assess adversarial intentions during a cyber-intrusion and to distinguish between reconnaissance or decapitation increases.
- Finally, increased autonomy that results from advancements in artificial intelligence risks pushing humans out of the loop at critical assessment moments.

On September 26 1983, the Soviet early-warning systems detected an incoming nuclear missile strike from the United States. Stanislav Petrov, the on-duty officer, looked at the data. Official protocol dictated that Petrov inform his superiors so the Soviet Union could initiate a retaliatory nuclear strike. He did not, rightly assuming that the low number of incoming missiles the system identified probably meant there was a bug in the system. He waited 25 minutes and nothing happened. Stanislav Petrov likely saved the world.[182]

182 Pavel Aksenov, "Stanislav Petrov: The Man Who May Have Saved the World," *BBC News*, September 26, 2013, sec. Europe, https://www.bbc.com/news/world-europe-24280831.

Technological trends are undermining strategic stability as well, both singlehandedly and in their interaction with the shifting sands of geopolitics. We examine ten technologies that are varied, both kinetic and non-kinetic in nature, and both weapons and enablers. On the whole, these are emerging technologies that have not yet been "overtly significantly deployed", such as hypersonic missiles, anti-satellite weapons (ASATs), directed energy weapons, cyber technology, artificial intelligence, and lethal autonomous weapons systems (LAWS).[183] Other technologies are not strictly new, but include new applications of existing technologies, such as dual-capable (i.e. serving both conventional and nuclear forces) command, control, communications and intelligence (3CI) assets or missiles; or technologies that have new implications for strategic stability, either due to their rapid proliferation (remote sensing) or due to the breakdown of important arms control regimes (missile defense). It should be added that these technologies are not necessarily exclusive and may overlap: cyber and laser technology for instance can be used as counterspace capabilities. A quality that many of the newer technologies share, and this is unlike earlier eras of innovations, is that they are generally not fearsome stand-alone weapons, but enablers of the effectiveness of already existing weapons (in our selection of ten technologies, this particularly applies to artificial intelligence, remote sensing, and dual-capable C3I systems). We thus examine both emerging technologies and distinct existing technologies that are now likely to become more effective due to these emerging technologies. The shared criterium is that they seem to promise clear military competitive advantages.[184] Without an appreciation for the potential advantages of the various weapon systems, it is difficult to assess how best to frame arms control measures. There is thus a real need to move beyond generic terms such as peace or security when discussing the benefits of arms control and non-proliferation measures, as well as the types of such measures.[185]

The effect of technological advancements on deterrence is two-fold. On the one hand, they have enhanced effective deterrence by increasing the usability and thus the credibility of nuclear weapons. On the other hand, they have raised concerns over the survivability of nuclear forces, blurred the line between conventional and nuclear warfighting, potentially incorporated space warfare as a key component of nuclear warfare, and decreased the decision-making timeframe in a crisis as well as the uncertainty about adversarial intentions.[186]

The increasing role of non-kinetic weapons and enablers has put Cold War interpretations of strategic deterrence under stress as they must now incorporate cyber, AI, and other hybrid tools to the previously nuclear and conventional weapons form of deterrence in order to constitute a "comprehensive deterrence mosaic".[187]

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183 Christopher F. Chyba, "New Technologies & Strategic Stability," *MIT Press*, Daedalus, 149, no. 2 (2020): 150–70, https://doi.org/10.1162/daed_a_01795. For example, ground-based midcourse ballistic missile defense (GMD) is not a new technology despite substantial improvements and doctrinal changes that can have serious effects on strategic stability. For some other weapons, like cyberweapons, though they have been used, their greatest potential impact is as of yet undemonstrated.

184 Altmann and Sauer, "Autonomous Weapon Systems and Strategic Stability," 121.

185 Maurer, "The Purposes of Arms Control (November 2018)," 10.

186 Rose Gottemoeller, "The Standstill Conundrum: The Advent of Second-Strike Vulnerability and Options to Address It (Fall 2021)," *Texas National Security Review*, 2021. Robert Legvold and Christopher F. Chyba, "Introduction: The Search for Strategic Stability in a New Nuclear Era," in *Meeting the Challenges of a New Nuclear Age* (Journal of the American Academy of Arts & Sciences, 2020), 6–16, https://www.amacad.org/publication/introduction-search-strategic-stability-new-nuclear-era.

187 Legvold and Chyba, "Introduction."

Ten technologies

In the sections below, we discuss the implications of the following ten technologies for strategic stability through their impact on deterrence and on crisis stability: hypersonic missiles, anti-satellite weapons, directed-energy weapons, dual-capable missiles, missile defense systems, offensive cyber capabilities, lethal autonomous weapon systems, remote sensing, artificial intelligence, and dual-capable C3I systems. Most of these are themselves weapons, or effectors, but others are enablers (remote sensing, artificial intelligence, and dual-capable C3I systems).

During a crisis there will be a lack of clarity whether an incoming hypersonic missile is armed with a conventional or a non-conventional warhead

Hypersonic missiles

Hypersonic missiles affect deterrence stability. Through their compressed time horizons between launch and impact, hypersonic missiles, though not yet a fully employed technology, would allow for little warning, making them highly suited for conventional or non-conventional first strike against the nuclear infrastructure, as well as against conventional targets.[188] Additionally, once their launch by aircraft will be fully mastered, the added potential for flexibility of hypersonic cruise missiles would be particularly destabilizing. Hypersonic missiles also affect crisis stability. The compressed timeline creates an environment of misperception and miscommunication that can contribute to rapid escalation in a crisis. As with ballistic missiles, during a crisis there will be a lack of clarity whether an incoming hypersonic missile is armed with a conventional or a non-conventional warhead.[189]

Anti-satellite weapons

Anti-satellite weapons (ASATs) undermine both deterrence and crisis stability. Space based assets are increasingly important to the uninterrupted functioning of societies. Critical infrastructures rely on positioning, navigation and timing (PNT) functions offered by space-based assets, which are vulnerable to ASATs. If these assets are taken out, entire societies can be paralysed. In today's world, major military powers cannot wage war without access to their space-based assets. In fact, without them, major military powers are "deaf, blind and mute".[190] This in turn is prompting the militarization of space. States are scrambling to secure a foothold in space through the launch of satellites which are used for civilian and military purposes. It is also driving the weaponization of space.[191] In 2019, India showed the world its possession of a direct-ascent anti-satellite (ASAT) capability in a live test, becoming the fourth military power

188 Ian Williams, "Adapting to the Hypersonic Era," *Centre for Strategic and International Studies*, Nuclear Nexus, November 2, 2020, 13, https://nuclearnetwork.csis.org/adapting-to-the-hypersonic-era/; Dean A. Wilkening, "Hypersonic Weapons and Strategic Stability," *Survival* 61, no. 5 (November 2019): 129–48; Robert Haffa and Anand Datla, "Hypersonic Weapons: Appraising the 'Third Offset,'" Research Report (Washington D.C.: American Enterprise Institute, 2017), https://www.jstor.org/stable/resrep03280.

189 Alan Cummings, "Crisis Stability, Ooda Loops, and Hypersonic Weapons," CSIS Porject on Nuclear Issues (Washington D.C.: Center for Strategic and International Studies, February 2021), https://www.csis.org/analysis/horizon-vol-3-collection-papers-next-generation; Eleni Ekmektsioglou, "Hypersonic Weapons and Escalation Control in East Asia," *Strategic Studies Quarterly* 9, no. 2 (2015): 43–68; Wilkening, "Hypersonic Weapons and Strategic Stability."

190 Tim Sweijs and Frans Osinga, "VIII. Maintaining NATO's Technological Edge: Whitehall Papers: Vol 95, No 1," *Whitehall Papers* 95, no. 1 (2019): 104–18.

191 Linda Dawson, *War in Space: The Science and Technology Behind Our Next Theater of Conflict*, 1st ed. (New York: Springer International Publishing, 2019).

to do so after China, Russia and the US.[192] These latter three countries are actively building up their military space capabilities through their development of ASAT missiles, satellite jammers, and directed energy weapons (see below), and major powers such as the US and France, have recently launched military space commands.[193]

ASATs pose a threat to deterrence stability because satellites fulfill both sensing and communication functions in early-warning and are therefore indispensable for a nuclear power's credible second strike capability. They are increasingly under threat from both kinetic and non-kinetic ASATs that can destroy a rival's early-warning satellites, leaving it vulnerable to incoming ballistic missile attacks, which in turn drives efforts to secure a more robust second strike capability.[194] Furthermore, ASATs also affect crisis stability because they pose a threat to space-based nuclear and command control systems, making a decapitating strike feasible.[195] In a similar vein, ASATs affect crisis stability because satellites also fulfill conventional sensing and C3I tasks; during a crisis, nuclear-armed states will be unsure whether an attack on their satellites is part of the conventional phase of the conflict, or a first strike on their nuclear infrastructure.[196] In sum, the development and deployment of ASATs poses a real danger to strategic stability.

Directed energy weapons

DEWs can affect deterrence stability, even if their current applications are mainly defensive. DEWs' speed-of-light delivery, precision engagement, low detectability, and low operational cost per engagement will likely lead to the future inclusion of DEWs in missile defense systems.[197] Enhancing such defensive features through DEWs will have destabilizing consequences due to the "intended or ancillary effect of diminishing a country's second-strike response to a first strike."[198] DEWs will hence contribute to undermine confidence in second-strike capabilities, which can be used as a justification to modernize a country's nuclear arsenal. The potential use of DEWs as anti-satellite weapons poses a further threat

192 Kyle Mizokami, "It Sure Looks Like Russia Just Tested a Space Weapon," Popular Mechanics, December 17, 2020, https://www.popularmechanics.com/military/weapons/a34992366/russia-test-space-weapon-satellite-killing-missile/; Kyle Mizokami, "Meet Russia's Imposing New Satellite-Destroying Missile," *Popular Mechanics* (blog), April 16, 2020, https://www.popularmechanics.com/military/weapons/a32173824/nudol-missile-anti-satellite/; Ashley J. Tellis, "India's ASAT Test: An Incomplete Success," Carnegie Endowment for International Peace, April 15, 2019, https://carnegieendowment.org/2019/04/15/india-s-asat-test-incomplete-success-pub-78884.

193 Todd Harrison et al., "Space Threat Assesment 2021," The CSIS Aerospace Security Project (Washington D.C., US: CSIS, April 2021), https://csis-website-prod.s3.amazonaws.com/s3fs-public/publication/210331_Harrison_SpaceThreatAssessment2021.pdf?gVYhCn79enGCOZtcQnA6MLkeKlcwqqks.

194 Forrest E. Morgan, *Deterrence and First-Strike Stability in Space: A Preliminary Assessment*, RAND Corporation Monograph Series (Santa Monica, CA: RAND, 2010); Christopher Bidwell, Bruce MacDonald, and JD MacDonald, "Emerging Disruptive Technologies and Their Potential Threat to Strategic Stability and National Security" (Federation of American Scientists, September 2018); "Challenges to Security in Space" (Defense Intelligence Agency, January 2019), https://www.dia.mil/Portals/27/Documents/News/Military%20Power%20Publications/Space_Threat_V14_020119_sm.pdf.

195 Matthew Mowthorpe, *The Militarization and Weaponization of Space* (Lexington Books, 2004), 110. ; Kurt Gottfried and Richard Ned Lebow, "Anti-Satellite Weapons: Weighing the Risks," *Daedalus* 114, no. 2 (1985): 147–70, https://www.jstor.org/stable/20024983.

196 Talmadge, "Would China Go Nuclear?"

197 Eric Heginbotham and Jacob L. Heim, "Deterring without Dominance: Discouraging Chinese Adventurism under Austerity," *The Washington Quarterly* 38, no. 1 (January 2, 2015): 193, https://doi.org/10.1080/0163660X.2015.1038189.

198 Marina Favaro, "Weapons of Mass Distortion: A New Approach to Emerging Technologies, Risk Reduction, and the Global Nuclear Order" (London, United Kingdom: Centre for Science and Security Studies, 2021), 19, https://www.kcl.ac.uk/csss/assets/weapons-of-mass-distortion.pdf.

to deterrence stability.[199] In fact, permanent damage to GPS systems and space-based command and control capabilities undermines nuclear powers' capacity to ensure their second-strike.[200] Crisis stability is also affected by DEWs. Their impressive speed of delivery and low detectability of DEWs necessitates of swift countermeasures and, in case of crisis, force operators to take fast decision under pressure. This is conducive to errors of judgement. Investments in DEWs can hence contribute to the creation of 'use it or lose it' dynamics.[201]

Dual capable C3I systems and dual capable missiles

Co-mingling of nuclear and conventional delivery systems, and C3I infrastructure also increases the risk of inadvertent nuclear escalation

The rapid improvements in advanced conventional weapons designed for precision strike, along with infrastructure, also affect strategic stability. They undermine deterrence stability because they create the opportunity to conduct conventional strikes on an adversary's nuclear arsenal without resorting to nuclear weapons. Only nuclear weapons were previously believed to have sufficient destructive capability to destroy launch systems, regardless of whether they managed to score a direct hit. But the increases in precision during the 1990s and 2000s has made conventional weapons and bunker-busting (including EMP) warheads more suited for the task,[202] a development already signaled in the New START Treaty.[203]

The co-mingling of nuclear and conventional delivery systems, and C3I infrastructure also increases the risk of inadvertent nuclear escalation amid a crisis.[204] During such a crisis, an adversary may attack the launchers and infrastructure used for advanced conventional weapons to gain or maintain a conventional advantage in the conflict,[205] yet this can be misunderstood by the party being attacked as an attack on its nuclear launchers and infrastructure. Moreover, the flight profiles of ballistic or cruise missiles do not offer any information on whether the weapon is carrying a conventional or a non-conventional warhead. The potential for a state to mistake the launch of these weapons during a crisis with a nuclear attack is therefore high,[206] and will be shaped by perceptions of the adversary.

Missile Defenses

Missile defenses, as noted in the discussion of Cold War strategic stability, could undermine deterrent stability because they diminish the adversary's confidence in its second strike.[207]

199 Chyba, "New Technologies & Strategic Stability"; Morgan, *Deterrence and First-Strike Stability in Space*, 14–15.

200 Bidwell, MacDonald, and MacDonald, "Emerging Disruptive Technologies and Their Potential Threat to Strategic Stability and National Security"; "Challenges to Security in Space."

201 Favaro, "Weapons of Mass Distortion: A New Approach to Emerging Technologies, Risk Reduction, and the Global Nuclear Order," 20.

202 Altmann and Sauer, "Autonomous Weapon Systems and Strategic Stability," 131.

203 A counterforce ability would be particularly destabilizing if the attacker simultaneously has a missile defense system at its disposal to protect itself against the missiles that had survived a first strike. National Research Council, *U.S. Conventional Prompt Global Strike: Issues for 2008 and Beyond* (The National Academies Press, 2008), https://www.nap.edu/download/12061.,192.

204 Gregory Koblentz, "Strategic Stability in the Second Nuclear Age," Council Special Report No.71 (New York: Council on Foreign Relations, November 2014), 25, https://www.researchgate.net/publication/303345035_Strategic_Stability_in_the_Second_Nuclear_Age.

205 See, for example, the debate on the strategies considered by the United States to counter Chinese A2/AD. Talmadge, "Would China Go Nuclear?"; Joshua Rovner, "Two Kinds of Catastrophe: Nuclear Escalation and Protracted War in Asia," *Journal of Strategic Studies* 40, no. 5 (July 29, 2017): 696–730, https://doi.org/10.1080/01402390.2017.1293532.

206 National Research Council, *U.S. Conventional Prompt Global Strike: Issues for 2008 and Beyond* (Washington D.C., U.S.: The National Academies Press, 2008), https://www.nap.edu/download/12061.

207 Koblentz, "Strategic Stability in the Second Nuclear Age."

This confidence would be further undermined if a state already possesses considerable conventional or non-conventional first strike counterforce capabilities. In response, the state without missile defenses could pursue more, faster, or more destructive nuclear weapons. It could also adopt a launch-under-attack posture to maximize the number of missiles that can survive a first strike and attempt to penetrate the attacker's missile defenses.[208] Beyond the destabilizing effect on first strike stability, missile defenses also undermine crisis stability because they increase the space for technical and human errors of judgment when parts of the decision-making process including targeting and firing decisions are more autonomous (see discussion in AI section as well).[209]

Offensive cyber capabilities

Offensive cyber capabilities undermine deterrent stability because they have created new opportunities for non-kinetic left-of-launch attacks, including a first strike that evades detection.[210] The threat of a first strike with kinetic weapons – whether these are armed with conventional or non-conventional warheads – leaves the attacker uncertain whether they can destroy a sufficient number of missiles and platforms within the short window of opportunity before the adversary detects their first strike and initiates a second strike. This uncertainty has acted as a restraint on nuclear states to avoid attempting second strikes. In contrast, cyberweapons could preemptively infiltrate enemy networks, specifically looking to target the command-and-control systems, and to manipulate data that feeds decision-making processes.[211] They can spoof early warning systems, generate false alarms or suppress real alarms, and perform virtual decapitation strikes by disrupting the communications between national command authorities and nuclear force commanders. Cyberweapons can also target critical civilian infrastructure, possibly to the level of an existential threat to the survival of the state.[212]

Cyberweapons undermine crisis stability, because they make decision-making during a crisis increasingly difficult.[213] Cyber capabilities can both be used to attack an adversary's information systems, and to reconnoiter these to gain intelligence in advance of an attack. Surveillance operations in cyberspace, even if conducted exclusively for defensive purposes, are also difficult to distinguish from offensive operations against nuclear command and control infrastructure.[214] Even if the attacked state is convinced about the purpose of a mission being solely based on espionage purposes, the state might still fear that the

208 Chyba, "New Technologies & Strategic Stability," 156.

209 Altmann and Sauer, "Autonomous Weapon Systems and Strategic Stability," 120. Michael C. Horowitz, "When Speed Kills: Lethal Autonomous Weapon Systems, Deterrence and Stability," *Journal of Strategic Studies*, Emerging Technologies and Strategic Stability, 42, no. 6 (2019): 773.

210 Jesse T. Wasson and Christopher E. Bluesteen, "Taking the Archers for Granted: Emerging Threats to Nuclear Weapon Delivery Systems," *Defence Studies* 18, no. 4 (October 2, 2018): 433–53, https://doi.org/10.1080/14702436.2018.1528137.

211 James M. Acton, "Cyber Warfare & Inadvertent Escalation," *Daedalus* 149, no. 2 (April 1, 2020): 133–49, https://doi.org/10.1162/daed_a_01794.

212 Lu Chuanying, "Forging Stability in Cyberspace," *Survival*, Global Politics and Strategy, 62, no. 2 (March 3, 2020): 125–36, https://doi.org/10.1080/00396338.2020.1739959.

213 Christopher A. Ford (2020) argues that anxieties brought about by emerging technologies, specially, cyber technologies, in combination with the return of great power competition has led to technological competition dynamics. This technological race, he argues, must be tackled with a mix approach encompassing traditional arms control treaties with non-traditional norm development initiatives. Ford, "Strategic Stability and the Global Race for Technology Leadership."

214 William Owens, Kennenth W. Dam, and Herbert S. Lin, *Technology, Policy, Law, and Ethics Regarding U.S. Acquisition and Use of Cyberattack Capabilities* (Washington D.C.: The National Academies Press, 2009), https://www.nap.edu/download/12651; Chuanying, "Forging Stability in Cyberspace."

information being collected could be used to hinder its damage-limitation operations, and it will trigger the state's worries of an imminent attack on its nuclear forces.[215] Decision-makers, when facing an adversary with sophisticated cyber capabilities, could jump the gun in assuming an attack is underway. Worst-case assessments of the adversary's intentions can incentivize states to use nuclear weapons pre-emptively, potentially triggering escalation in a crisis, or to decentralize the nuclear command and control.[216] Finally, the plausible deniability of a cyber-attack makes the enforcement of arms control commitments harder.[217]

Lethal autonomous weapon systems (LAWS)

The robotics revolution is also taking place on land, on sea, and under the latter's surface

Autonomous weapon systems have multiple advantages over manned systems. Unlike humans, autonomous systems do not experience fear, confusion, stress, or fatigue. They can operate in large number, potentially as swarms, and they are largely expendable.[218] Though generally associated with the airborne drones, the robotics revolution is also taking place on land, on sea, and under the latter's surface.

Autonomous systems could undermine deterrent stability by attacking nuclear weapon delivery systems, command and control systems, and sensitive infrastructure components such as antennas, sensors, and air intakes.[219] Unmanned aerial vehicles, specifically medium-altitude long endurance (MALE) and high-altitude long endurance (HALE) drones,[220] allow for persistent sensing of the adversary nuclear infrastructure to facilitate more effective attacks.[221] Autonomous systems present an option to overwhelm an adversary and to offset conventional inferiority,[222] and consequently could trigger conventional arms races as well.[223]

Autonomous systems could undermine crisis stability by limiting human involvement to general oversight and decision-making in instances where communications delays of second and deliberation times of minutes would be unacceptable.[224] The need to fight at machine speed could

215 Acton, "Cyber Warfare & Inadvertent Escalation."

216 Bruce G. Blair, *The Logic of Accidental Nuclear War* (Washington D.C., U.S.: Brookings Institution Press, 1993), https://www.brookings.edu/book/the-logic-of-accidental-nuclear-war/; Koblentz, "Strategic Stability in the Second Nuclear Age"; Richard A. Clarke and Robert Knake, *Cyber War: The Next Threat to National Security and What to Do About It* (USA: HarperCollins Publishers, 2010), https://www.semanticscholar.org/paper/Cyber-War%3A-The-Next-Threat-to-National-Security-and-Clarke-Knake/415a02eed5341991d6f4e3f-0790f43f9f8fa1168; D.A. Fulghum, R. Wall, and A. Butler, "Cyber-Combat's First Shot" 167 (November 26, 2007); Acton, "Cyber Warfare & Inadvertent Escalation."

217 Chuanying, "Forging Stability in Cyberspace."

218 Altmann and Sauer, "Autonomous Weapon Systems and Strategic Stability"; Horowitz, "When Speed Kills."

219 Altmann and Sauer, "Autonomous Weapon Systems and Strategic Stability," 123, 131.

220 Class III (>600 kg) UAVs have a top speed of 600 km/h, a payload capacity of several hundred kg and an endurance of up to 24 hours (with HALE aircraft capable of reaching an endurance up to 32 hours). Depending on the communications equipment used, some Class III models have a range of several thousand km. This class has a maximum operating altitude of up to 65,000 ft.

221 For example, in June 2017, North Korea used a drone for surveillance of the THAAD site in South Korea. Had the drone been armed with an improvised explosive device and destroyed the TPY-2 radar on which the THAAD battery depends, it might have virtually incapacitated the THAAD capability on the Korean peninsula. Tom Karako and Wes Rumbaugh, "Distributed Defense: New Operational Concepts for Integrated Air and Missile Defense" (CSIS, January 25, 2018), https://www.csis.org/analysis/distributed-defense-0.

222 Horowitz, "When Speed Kills," 775.

223 Former US deputy secretary of defense Bob Work argues that delegation to machines will take place, driven by the race for speed where states cannot afford to fall behind rivals. The Washington Post, "David Ignatius and Pentagon's Robert Work Talk about New Technologies to Deter War," March 30, 2016, https://www.washingtonpost.com/video/postlive/david-ignatius-and-pentagons-robert-work-on-efforts-to-defeat-isis-latest-tools-in-defense/2016/03/30/0fd7679e-f68f-11e5-958d-d038dac6e718_video.html.

224 Altmann and Sauer, "Autonomous Weapon Systems and Strategic Stability," 128.

increase unintended escalation.[225] Fears over attacks on the command-and-control capabilities of nuclear states could create incentives for states to adopt stable military postures, such as place strategic weapons on high alert, adopt launch-on-warning postures, and establish pre-delegation mechanisms. In turn, this puts pressure on escalation control mechanisms.[226] As Michael Horowitz notes, imagine the Cuban Missile Crisis with machine-autonomous US naval ships, able to operate independently after activation.[227]

Remote sensing

Strategic stability is undermined by the rapid growth over the past decade in space-based radars, infrared sensors, and persistent monitoring, including by UAVs. This includes the rapid expansion of the role of private commercial actors in space-based sensing. Space-based sensors can undermine deterrent stability by looking for concealed and mobile nuclear launch-platforms, or supporting infrastructure for the nuclear arsenal.[228] As states gain access to a greater number of remote sensing options, through acquiring space-based radar or ISR UAVs (see elsewhere), or combining disparate radar, visual, audio, or other signals, and the quality of sensing improves, the ability to compile and analyze large sets of data becomes increasingly valuable. The interaction with developments in AI is relevant here; operating beyond the cognitive abilities of a human analyst, AI systems can compile these multiple pieces of information to find patterns and generate more complete and accurate targeting information.[229] The improvements in sensing undermine the secure second-strike capability of nuclear powers putting traditional approaches to survivability such as concealment, hardening, and mobility strategies under pressure.[230] Other technological developments were already undermining the effectiveness of traditional survivability measures; however, AI is acting as a multiplier of the possibilities of these other developments. The increasing reliance on remote sensing can also undermine crisis stability due to the dual-use nature of these capabilities; as adversaries attempt to stop conventional attacks, their attacks on satellites could be mistaken for an attack on the nuclear infrastructure.

Artificial Intelligence

Artificial intelligence affects strategic stability; not in isolation,[231] but as an enabler that increases the speed and precision of other technologies beyond that of human operators. AI can undermine deterrent stability because it increases various first strike capabilities, through improved data fusion of disparate sensors that increases precision; the abilities of autonomous systems, including in cyberspace; the in-flight retargeting of guided missiles; and battle management between disparate systems.[232] For the defender, the incorporation of opaque

225 Michael C. Horowitz, Paul Scharre, and Alexander Velez-Green, "A Stable Nuclear Future? The Impact of Autonomous Systems and Artificial Intelligence," *ArXiv:1912.05291 [Cs]*, December 13, 2019, 1–35.

226 Horowitz, "When Speed Kills."

227 Horowitz.

228 Lieber and Press, "The New Era of Counterforce."

229 Johnson, "Artificial Intelligence: A Threat to Strategic Stability," 18.

230 Lieber and Press, "The New Era of Counterforce"; Vincent Boulanin, "The Impact of Artificial Intelligence on Strategic Stability and Nuclear Risk," *Euro-Atlantic Perspectives* 1 (May 2019): 156; Johnson, "Artificial Intelligence: A Threat to Strategic Stability." 18.

231 James S Johnson, "Artificial Intelligence: A Threat to Strategic Stability," *Strategic Studies Quarterly*, 2020, https://www.airuniversity.af.edu/Portals/10/SSQ/documents/Volume-14_Issue-1/Johnson.pdf.

232 Horowitz, "When Speed Kills"; James Johnson, "Artificial Intelligence & Future Warfare: Implications for International Security," *Defense & Security Analysis* 35, no. 2 (April 3, 2019): 147–69, https://doi.org/10.1080/14751798.2019.1600800; Johnson, "Artificial Intelligence: A Threat to Strategic Stability." 19.

Human operators might put excessive trust in an algorithms performance

autonomous systems within the nuclear infrastructure also ensures that different parts are vulnerable to undetected cyberexploitation in the form of capture, hacking, or spoofing.[233]

AI could particularly undermine crisis stability through its effect on decision-making processes. It compresses the decision-making loop and timeframe within the nuclear C3I systems.[234] The potential inaccuracy of machine learning, its high speed, and the opaqueness of its procedures would not allow humans to monitor decision-making steps and correct mistaken assessments,[235] also because human operators might put excessive trust in an algorithms performance as more objective and accurate.[236] False alarms may not be questioned by human operators.[237] Yet, the effects may not all be detrimental; however, it is currently particularly difficult to judge the long-term impact of the incorporation of AI.[238]

Conclusion: consequences of technological trends for strategic stability

In sum, the ten technologies discussed here affect both deterrence and crisis stability. Table 6 summarizes their impact. The speed of hypersonic missiles and directed energy weapons, or the difficult-to-detect nature of cyberweapons, create opportunities for a first strike, specifically when the expansion of remote sensing, UAVs, and AI-driven data fusion increase the ability to find the platforms that carry nuclear weapons and target them with precision-weapons. The precision revolution has also enabled conventional strikes for counterforce purposes. Yet, advanced conventional weapons also fulfill other deterrence tasks below the nuclear spectrum. The entanglement of the conventional and nuclear sensing, command and control, and launcher infrastructures increases the risk of inadvertent nuclear escalation during a crisis. The difficulty to assess adversarial intentions during a cyber-intrusion and to distinguish between reconnaissance or decapitation, has ensured that multiple new crisis escalation paths exist. Finally, the increasing reliance on artificial intelligence, for sensing and for defense, could remove human operators from the loop at critical assessment moments. It is entirely possibly the future nuclear infrastructure lacks a Stanislav Petrov to intervene at the right time.

233 Boulanin, "The Impact of Artificial Intelligence on Strategic Stability and Nuclear Risk."

234 Johnson, "Artificial Intelligence & Future Warfare"; Chuanying, "Forging Stability in Cyberspace."

235 Kenneth Payne, "Artificial Intelligence: A Revolution in Strategic Affairs?," *Survival* 60, no. 5 (September 3, 2018): 7–32, https://doi.org/10.1080/00396338.2018.1518374; Matthijs M. Maas, "How Viable Is International Arms Control for Military Artificial Intelligence? Three Lessons from Nuclear Weapons," *Contemporary Security Policy* 40, no. 3 (July 3, 2019): 285–311, https://doi.org/10.1080/13523260.2019.1576464.

236 Boulanin, "The Impact of Artificial Intelligence on Strategic Stability and Nuclear Risk"; Michael C. Horowitz, "Artificial Intelligence, International Competition, and the Balance of Power," *Texas National Security Review*, Artificial Intelligence, 1, no. 2 (May 2018): 36–57.

237 M.L. Cummings, "Creating Moral Buffers in Weapon Control Interface Design," *IEEE Technology and Society Magazine* 23, no. 3 (Fall 2004): 28–33, https://doi.org/10.1109/MTAS.2004.1337888; M.L. Cummings, "Automation Bias in Intelligent Time Critical Decision Support Systems," in *AIAA 1st Intelligent Systems Technical Conference*, Infotech@Aerospace Conferences (Cambridge, MA: American Institute of Aeronautics and Astronautics, 2004), 6, https://doi.org/10.2514/6.2004-6313; Linda J. Skitka, Kathleen L. Mosier, and Mark Burdick, "Does Automation Bias Decision-Making?," *International Journal of Human-Computer Studies* 51, no. 5 (November 1, 1999): 991–1006, https://doi.org/10.1006/ijhc.1999.0252.

238 It is also possible that AI-augmented weapons will reduce human decision-making errors during crises. Moreover, it is questionable whether military commanders be willing to hand over control, given their self-interest in tightly controlling the escalation ladder. However, competitive pressures might push them to delegate more than they would otherwise. Johnson, "Artificial Intelligence: A Threat to Strategic Stability."

Table 6. Impact of ten emerging technologies on deterrent and crisis stability

Emerging Technology	Deterrence Stability	Crisis Stability
Hypersonic missiles	Compressed timelines increase suitability for conventional or nuclear first strike.	Compressed timelines may create misperception and miscommunication.
		A failure to discriminate between conventional and nuclear warhead during flight could lead to errors of judgement.
Anti-satellite weapons	Disruption of sensing and command and communication can become an opening stage of first strike.	Errors of judgements may occur due to uncertainty about whether attack is directed at conventional or nuclear infrastructure.
Directed energy weapons	Potential use in missile defense and as ASAT undermines confidence in second strike capabilities.	Errors of judgment may occur as a consequence of speed of delivery and low detectability.
Dual-capable C3I and missiles	Dual-capable systems create the opportunity to conduct conventional first strikes on adversary's nuclear arsenal without nuclear weapons.	Risk of inadvertent escalation increases due to inability to distinguish between opening stages of nuclear or conventional attack.
Missile defense	Missile defense decreases adversary's confidence in its second strike.	Need for speed increases potential for technical and human errors of judgement.
	Defenses may incentivize the adoption of launch-under-attack posture.	
Offensive cyber capabilities	Cyber capabilities create new opportunities for non-kinetic left-of-launch attacks on first strike.	Errors of judgment may arise from discrimination problem in cyber intrusion between surveillance and attack.
	Capabilities allow for the manipulation of data to influence, disrupt, or decapitate command and control.	
Lethal autonomous weapons	Attacks on nuclear weapon delivery systems, command and control systems, and sensitive infrastructure components can overwhelm an adversary.	Limited human involvement and the speed of LAWS could increase unintended escalation.
Remote sensing	AI-enabled detection of concealed and mobile nuclear launch-platforms undermines second-strike capabilities.	Attacks on satellites could be mistaken for attacks on the nuclear infrastructure.
Artificial intelligence	Improvements in data analysis and speed can create first strike capabilities.	Compressed timeframes and potential biases in machine learning could lead to errors of judgement.

4. Assessing emerging technologies along the production-proliferation-deployment-employment chain

Key takeaways

- The various phases through which technologies are brought into use can be disentangled into: 1) the feasibility to produce a technology; 2) the likelihood of a technology to proliferate; 3) the ease with which it can be deployed; and 4) the ease with which a technology can be employed.
- The production of most emerging technologies is highly complex, while the assessments for proliferation, deployment and employment generate more mixed results.

Technological trends are fast outpacing the existing arms control and non-proliferation regimes

The military-technological environment is changing rapidly due to the emergence of new technologies as well as the rapid proliferation of existing ones. Technological trends are fast outpacing the existing arms control and non-proliferation regimes, which are additionally under pressure from increased international competition. This section reviews ten technologies that shape this new military-technological environment, focusing on those applications and use of technologies that could undermine strategic stability and contribute to escalation risks.

The emerging technologies include hypersonic missiles, anti-satellite weapons (ASATs), offensive cyber capabilities, artificial intelligence (AI), lethal autonomous weapons systems (LAWS) and directed energy weapons (DEWs). Existing technologies that have become increasingly relevant due to new applications or rapid proliferation include dual-capable missiles as well as command, control, communications and intelligence (C3I) systems, as well as missile defense and remote sensing. In particular, AI, sensing and C3I are enablers that are increasing the effectiveness of the other existing and new weapon systems.

To assess which arms control approaches are best suited for the various technological developments, this chapter looks at the stages through which an emerging weapon technology is being developed and brought into use. Each of these stages has a different logic. *Production* encompasses possession of the technological knowledge, basic skills, and access to materials to indigenously produce a weapon technology. *Proliferation* includes the ability to acquire technologies and materials from other states or non-state actors. *Deployment* refers to what other hard constraints, such as platform technologies or access to specific locations, would allow the weapon technology to put to use. *Employment* covers all the soft constraints such as organizational aptitude and fitness to effectively use the technology. For an overview of the framework with the characteristics of emerging technologies along the production-proliferation-deployment-employment chain, see text box 5. Next, we developed assessment criteria to classify each emerging technology based on: 1) the feasibility to produce it; 2) the likelihood of a technology to proliferate; 3) the ease with which it can be deployed; and 4) the ease with which it can be employed. For an overview of the assessment criteria, see Table 7. The ten emerging technologies were analyzed and evaluated on the basis of desk research, expert interviews and iterative discussions within the project team followed by an independent review of an subject matter expert.

Each of the stages highlight different points where intervention through arms control and non-proliferation measures or deterrence postures might diminish the rapid production, spread, deployment or use of these weapon systems throughout the international system. For example, the ability of states to produce nuclear weapons was monitored and limited by activities of the Nuclear Suppliers Group. For newer technologies that rely less on tangible and unique technologies or materials, other phases of the development of weapons need to be studied to highlight where intervention may be most effective. As such, the assessment offered in this chapter provides the basis for tailored interventions, which is the topic of the next chapter.

Characteristics of emerging technologies along the production-proliferation-deployment-employment chain

1. Production: material inputs, infrastructure, expertise and skills, testing core technology
   a) Are material inputs (raw materials, metals, etc.) accessible (in each country, or is there a broad global market) and affordable? Can material inputs be easily produced domestically?
   b) Can the technology only be produced on the basis of a discrete specialized knowledge base? How widespread is that discrete specialized knowledge base to produce and deploy the new military technology? How effectively can knowledge of the innovation works be shielded from potential adversaries or other states? What are the prospects for future diffusion of technological knowhow?
   c) Can the state weaponize the technology and test it in a relevant environment?
2. Proliferation: dual-use nature, tangibility, distinguishability
   a) Do commercial applications exist? Can they be modified for military use?
   b) How tangible is the technology? Can it be moved (in terms of size etc.) and can it be detected during transport?
   c) How distinguishable is the technology from other military technologies?
3. Deployment: infrastructure, platform requirements, deployment skills
   a) What infrastructure is needed to deploy the technology (including access to location)? (e.g. UAV runways)
   b) What other, prerequisite weapon platforms/systems or enablers are needed to effectively deploy the technology (example: C4ISR for missiles, but also launchers or transport helicopters)? Or can existing technologies be easily updated?
   c) Does the deployment of this technology require highly advanced technical knowledge?
4. Employment: organization, doctrine, norms
   a) Does the technology's implementation require significant organizational changes, including changes in the relative importance of the services, in organizational incentives, recruitment and training?
   b) Does its use require changes in war-fighting doctrine?
   c) Are there other features of the military technology that would disincentivize states to employ these weapons (e.g., norms regarding indiscriminate use towards civilians)?

Table 7. Assessment criteria

Phase		Criteria	
Production	Feasibility of this technology to be produced	High	Material inputs for this technology are accessible and relatively inexpensive. The technology is relatively simple, well-understood and widely shared. Weaponizing and testing the technology in relevant environments is fairly straightforward.
		Medium	Material inputs for this technology are accessible and relatively inexpensive, yet the technology is complex, requiring advanced skills and specialized knowledge that is fairly discrete. Weaponizing and testing the technology in relevant environments can be challenging.
		Low	Material inputs for this technology are rare and expensive. Moreover, the technology is extremely complex, requiring highly advanced skills and discrete specialized knowledge. Weaponizing and testing the technology in relevant environments is highly challenging.
Proliferation	Likelihood of this technology to proliferate	High	Commercial applications of this technology exist and can be modified for military use. The technology is intangible, therefore detectability during transport is low while its movability is generally high. The technology is not necessarily distinguishable from other military technologies.
		Medium	Commercial applications of this technology exist and can be modified for military use. At the same time, the technology is tangible, with detectability during transport being relatively high. Moving the technology is challenging but feasible. The technology is potentially distinguishable from other military technologies.
		Low	Few, if any, commercial applications of this technology exist, complicating their modification for military use. The technology is tangible however, with detectability during transport being relatively high. Moving the technology is challenging. The technology is largely distinguishable from other military technologies.
Deployment	The ease with which this technology can be deployed	High	This technology does not require sophisticated infrastructures, weapon platforms or enablers, or existing technologies can be updated. Deployment does not require highly advanced technical knowledge.
		Medium	This technology requires fairly sophisticated infrastructures, weapon platforms and/or enablers - but potentially modification of existing technologies is possible. Deployment of this technology further requires advanced technical knowledge.
		Low	This technology requires highly sophisticated and novel infrastructures, weapon platforms and/or enablers. Existing technologies cannot be modified. Deployment requires highly advanced technical knowledge.
Employment	The ease with which this technology can be employed	High	Existing organizational structures and warfighting doctrines allow for the employment of this technology. States are not strongly disincentivized to employ this weapon.
		Medium	Employing this technology requires some organizational and/or doctrinal changes. Alternatively, or in addition, states can be disincentivized to employ this weapon.
		Low	Employing this technology requires significant organizational and doctrinal changes. States are strongly disincentivized to employ this weapon.

Hypersonic missiles

Hypersonic missiles are highly maneuverable space vehicles and cruise missiles that fly at speeds of at least Mach 5. They fall into two main categories: unpowered hypersonic glide vehicles (HGVs), which are launched from rockets at the edge of space and glide to target from high altitudes, and hypersonic cruise missiles (HCMs), which are powered by high-speed airbreathing engines after initial launch from a rocket.[239] The key difference between missiles armed with HGVs and missiles armed with ballistic re-entry vehicles is the former's ability to maneuver and change course after release from their rocket boosters. Additionally, HGV boosters launch along a flatter, or more depressed trajectory, and at lower altitudes of flight.[240]

Production: material inputs, infrastructure, expertise and skills, testing core technology

The high temperature and high speed environments combined with hypersonic missiles' small size, delicate contents and thin structures pose distinct challenges to their production. Materials and structures need to integrate thermal barriers, while sensor and communication systems need to survive high temperatures and permit signals without distortion, while also being capable of dealing with the ionized flow resulting from high speeds. Indeed, air vehicle and flight control, propulsion (for hypersonic cruise missiles), as well as testing, modelling and simulation, require highly advanced technical skills.[241] Some of these components, such as the supersonic combustion ramjet (scramjet) engines required for HCMs to fly efficiently at hypersonic speeds, are still in the developmental phase.[242] As a result, deployment of various hypersonic technologies is projected in the early to mid-2020s,[243] and the most complex applications such as scramjets even further away.[244]

Specialized hypersonic test facilities are required to simulate the conditions experienced in hypersonic flight, such as speed, pressure and heating. Wind tunnels that are capable of producing these conditions for several seconds or longer are extremely difficult and expensive to build.[245] In 2019, the US Air Force Scientific Advisory Board assessed the development of tactical range HGVs at Technology Readiness Level (TRL) five out of nine, indicating that components and/or breadboards have been tested in relevant environments. The Board expected the technology to reach TRL six in 2020, indicating the possibility to test the system or subsystem in a relevant environment.[246] Some parts of China's hypersonic missiles

239 Kelley M. Sayler, "Hypersonic Weapons: Background and Issues for Congress," CRS Report (Washington D.C.: Congressional Research Service, July 9, 2021), https://fas.org/sgp/crs/weapons/R45811.pdf.

240 "Hypersonic Weapons" (Science, Technology Assessment, and Analytics), accessed June 2, 2021, https://www.gao.gov/assets/gao-19-705sp.pdf.

241 Richard H. Speier et al., "Hypersonic Missile Nonproliferation: Hindering the Spread of a New Class of Weapons," September 27, 2017, https://www.rand.org/pubs/research_reports/RR2137.html.

242 Fabian Hoffmann, "Cruise Missile Proliferation: Trends, Strategic Implications, and Counterproliferation," Global Security Report, Building Better Security for Wider Europe (European Leadership Network, March 2021), 5–7, https://www.europeanleadershipnetwork.org/wp-content/uploads/2021/03/Fabian_Final-2.pdf.

243 Robert A. Manning, "Emerging Technologies: New Challenges to Global Stability," Issue Brief (Washington D.C.: Atlantic Council: Sowcroft Center for Strategy and Security, May 2020), 14, https://www.jstor.org/stable/resrep26000?seq=1#metadata_info_tab_contents.

244 Interview with TNO.

245 Speier et al., "Hypersonic Missile Nonproliferation."

246 "Hypersonic Weapons."

programs are estimated to have reached TRL levels of between six and eight.[247] A reported test with a dual-capable hypersonic missile in August 2021 in fact suggests that China's hypersonic missile program is far more advanced than was initially thought.[248]

Unsurprisingly, the R&D costs are significant, with the US annual budget for hypersonic-related research for FY2021 reaching approximately $3.2 billion.[249] Countries at earlier stages of development have also allocated tens, or even hundreds, of millions to dual-capable hypersonic missile programs: India spent roughly $30 million on its Hypersonic Technology Demonstrator Vehicle program during the design and development phase and an additional $4.5 million on the prototype development, while Japan's FY2021 budget $218.6.[250]

China's hypersonic missile program is far more advanced than was initially thought

Due to the complexity of the technology and formidable R&D costs, the development and production of hypersonic missile technology is limited to the United States, Russia and China as the frontrunners, and, to a lesser extent, India, France, Japan, Australia and Germany. Programs in India and France are most advanced, with India developing dual-use hypersonic cruise missiles and France developing HCM technology as part of its nuclear arsenal modernization.[251] States that have test facilities for hypersonic flows include Israel and Iran, and several other countries conduct hypersonic research through computational models and theoretical design.[252] Hypersonic knowledge transfer is taking place: states share research results, components, testing facilities, test ranges and other technologies. Frontrunners United States, China and Russia have cooperated with other states, for instance Russia with India or the United States with Australia. Cooperation is also taking place between European, Japanese and Israeli researchers.[253]

The feasibility to produce or acquire hypersonic missiles today is therefore **low** and limited to a select group of countries. Despite cooperation taking place between countries, the development of HGVs and HCMs is highly complex and costly, and testing these weapons in relevant environments is challenging.

247 Peter Wood and Roger Cliff, *A Case Study of the PRC's Hypersonic Systems Development* (Montgomery, AL: China Aerospace Studies Institute, 2020), 27, https://www.airuniversity.af.edu/Portals/10/CASI/documents/Research/Other-Topics/2020-08-25%20CASI_Hypersonic%20Case%20Study_WEB.pdf?ver=2WiFcyY-i1dquXp7kfG_8UA%3d%3d.

248 Demetri Sevastopulo and Kathrin Hille, "China Tests New Space Capability with Hypersonic Missile," *Financial Times*, October 16, 2021, https://www.ft.com/content/ba0a3cde-719b-4040-93cb-a486e1f843fb.

249 Sayler, "Hypersonic Weapons: Background and Issues for Congress."

250 Vivek Raghuvanshi, "Watch India Test Its New Homemade Hypersonic Vehicle," Defense News, September 10, 2020, https://www.defensenews.com/global/asia-pacific/2020/09/09/india-tests-homemade-hypersonic-vehicle/; Defense News, "Japan Reveals Record High Budget Request Eyeing Hypersonic Tech, F-35s and More," *Defense News* (blog), 2021, https://www.defensenews.com/global/asia-pacific/2020/10/01/japan-reveals-record-high-budget-request-supporting-hypersonic-tech-f-35-buys-and-more/.

251 Speier et al., "Hypersonic Missile Nonproliferation," 22.

252 Speier et al., 32–33.

253 Speier et al., 29.

Proliferation: dual-use nature, tangibility, distinguishability

Hypersonic technology is potentially dual-use: non-military purposes include space launch, spacecraft retrieval, and civilian transport of passengers and cargo. Especially efforts in the aerospace industry to develop hypersonic aircraft could be a potential accelerator of this technology. For instance, researchers at the EU-funded Stratofly Project work on scramjet technology for commercial use, with testing in relevant environments foreseen for 2035.[254] That said, countries developing hypersonic technology largely focus on its military application, and no commercial applications exist today or in the near to medium future.[255] Yet, as is the case for ballistic missiles, space-launch technology has a dual-use character, and also the hydrocarbon fuels required are not distinct from fuel used in commercial jets.

Other factors that impact the likelihood of proliferation include tangibility, with effects on detectability, and movability. Scramjets and materials required for thermal protection are indeed tangible and can be detected during transport, with some having unique applications for hypersonic missile technology.

Therefore, the likelihood for hypersonic missiles to spread is **low**. Currently no commercial applications exist, preventing commercial-military modification or transfers. Various parts of the technology are military distinct, while also tangible, even if mobility is not always a given.

States with the capabilities and skills to deploy ballistic missile technology will thus face few challenges

Deployment: infrastructure, platform requirements, deployment skills

Infrastructures required to deploy hypersonic missiles are largely similar to those of regular ballistic and cruise missiles. Typical launch boosters used in HGV tests are MRBMs and IRBMs (and sometimes even SRBMs), including during tests of the Russian Avangard and Chinese DF-DZ. HCMs are deployed from cruisers and submarines using vertical launch systems (VLS), or aircraft. For instance, the Russian Tsirkon hypersonic cruise missile that is currently being developed can be launched from VLS deployed on a variety of sea-based platforms, including cruisers Admiral Nakhimov and Pyotr Veliky, Project 20380 corvettes, Project 22350 frigates, and Project 885 Yasen-class submarines. The Su-34 long-range strike fighters and Tu-22M3 strategic bomber are similarly being tested as potential hypersonic missiles launch platforms. [256]

The deployment of hypersonic technology thus requires complex launching platforms and C4ISR capabilities. Launching HGV requires similar infrastructures to those used for ballistic missile launchers, even if potentially an additional datalink is required when following moving targets. HCM with effective payloads require large and heavy boost systems, too, approximating those of short-range ballistic missiles. States with the capabilities and skills to deploy ballistic missile technology will thus face few challenges, while their use by states and actors who do not yet such capabilities and deployment skills is likely to be limited. Therefore, the ease with which hypersonic missiles can be deployed is assessed to be **medium**.

254 Khaled A. Sallam, "Canada, China, Europe and U.S. Cite Progress in Hypersonic Propulsion," Aerospace America, December 1, 2020, https://aerospaceamerica.aiaa.org/year-in-review/canada-china-europe-and-u-s-cite-progress-in-hypersonic-propulsion/.

255 Manning, "Emerging Technologies: New Challenges to Global Stability."

256 Sayler, "Hypersonic Weapons: Background and Issues for Congress," 13–14.

Employment: organization, doctrine, norms

For major powers, virtually no organizational or doctrinal changes are required for the use of hypersonic missiles. Hypersonic missile technology strengthens countries' ability to seize initiative (through surprise and pre-emption) as well as the capability to surgically strike targets over long-ranges. In the case of US-China competition, these two competences are key elements of both sides' warfighting doctrines, including the American AirSeaBattle doctrine and Conventional Prompt Global Strike program, and Chinese A2/AD strategy. Indeed, through hypersonic developments both powers "appear to have embraced an equally offensive operational thinking that opts for deliberate escalation."[257] Likewise, Russia's battle strategy of active defense is very much conducive to the employment of hypersonic missiles.[258] For countries that have not yet incorporated the use of missiles prominently in their military apparatuses, the employment of hypersonic missile technology could be more problematic. Finally, because of hypersonic missiles' speed and potential use of nuclear warheads, fears exist that the technology heightens the risk of nuclear escalation. This could potentially disincentivize states from using them.

Existing organizational structures and warfighting doctrines thus generally allow for the employment of hypersonic missiles by major powers. Their use is not strongly disincentivized by international norms or other considerations. Even though employment difficulties would rise for countries with little organizational experience employing missiles, the ease with which hypersonic missiles can be employed is assessed to be **high**.

Assessment hypersonic missiles

The production and proliferation of hypersonic missiles are curbed by the high costs and expertise needed in developing this technology, as well as by the absence of commercial applications. Deploying hypersonics requires sophisticated launching infrastructures, albeit similar to those required to launch ballistic missiles. Lastly, employment of hypersonic missiles is allowed by existing organizational structures and warfighting doctrines and it is not disincentivized by international norms. Table 8 sums up the assessment of hypersonics across the production-proliferation-deployment-employment chain, while Figure 4 plots it across a radar chart.

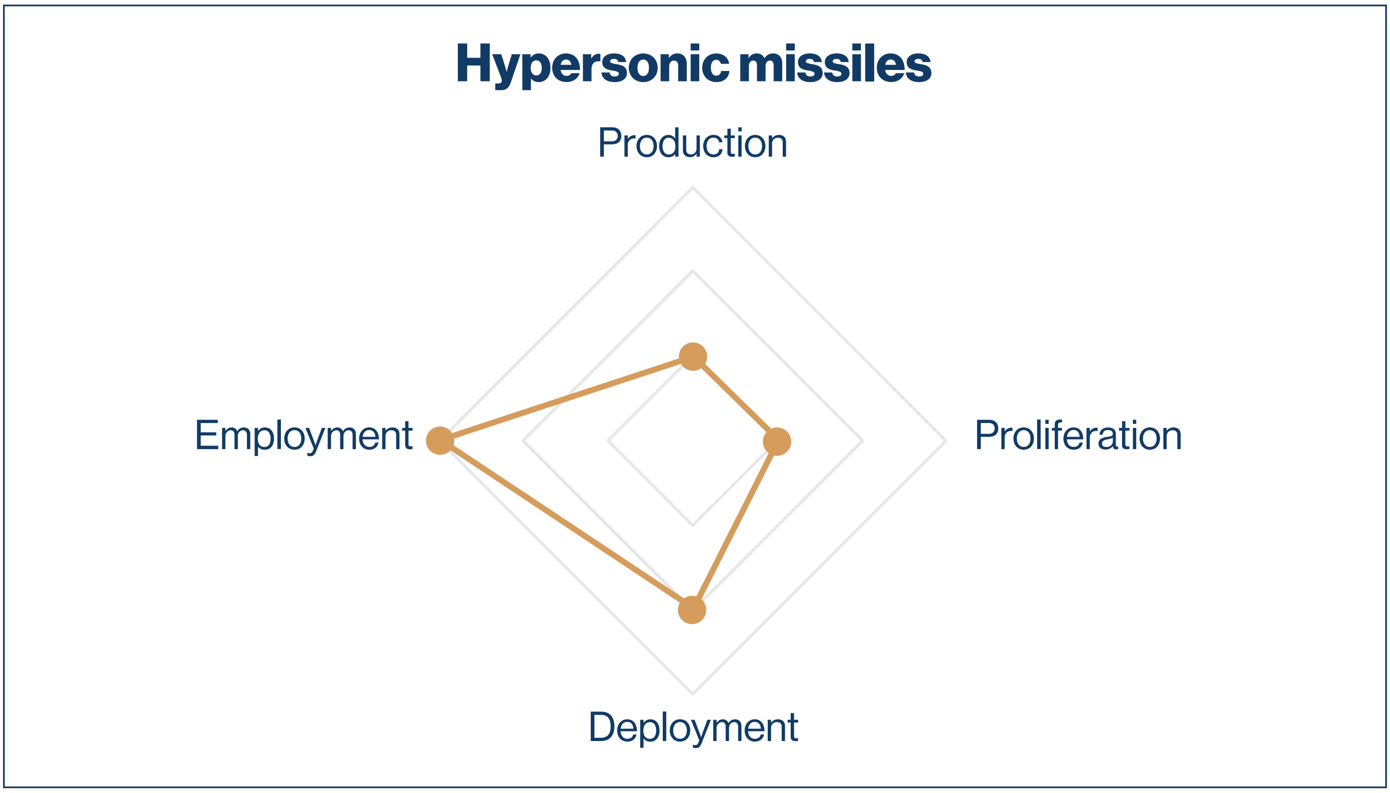
257 Ekmektsioglou, "Hypersonic Weapons and Escalation Control in East Asia," 57.

258 Maren Garberg Bredesen and Karsten Friis, "Missiles, Vessels and Active Defence: What Potential Threat Do the Russian Armed Forces Represent?," *RUSI* 165, no. 5–6 (November 5, 2020): 68–78, https://doi.org/10.1080/03071847.2020.1829991.

Table 8. Assessment of hypersonic missiles across the production-proliferation-deployment-employment chain

Phase		Criteria	
Production	Feasibility of this technology to be produced	Low	Material inputs for hypersonic missiles are rare and expensive. Moreover, the technology extremely complex, requiring highly advanced skills and discrete specialized knowledge. Weaponizing and testing the technology in relevant environments is highly challenging.
Proliferation	Likelihood of this technology to proliferate	Low	Few, if any, commercial applications of this technology exist, complicating their modification for military use. The technology is tangible however, with detectability during transport being relatively high. Moving the technology is challenging. The technology is largely distinguishable from other military technologies.
Deployment	The ease with which this technology can be deployed	Medium	This technology requires fairly sophisticated infrastructures, weapon platforms and/or enablers – but potentially modification of existing technologies is possible. Deployment of this technology further requires advanced technical knowledge.
Employment	The ease with which this technology can be employed	High	Existing organizational structures and warfighting doctrines allow for the employment of this technology. States are not strongly disincentivized to employ this weapon.

Figure 4. Radar chart plotting the assessment of hypersonic missiles



Anti-satellite weapons

Anti-satellite weapons aim to destroy key space-based capabilities needed for military operations and civil use, such as Position-Navigation-timing, observation and sensing and communication. They come in various variants. Kinetic anti-satellite weapons (KE-ASATs) may destroy targets by physically interfering with them or detonating explosives in their proximity. KE-ASATs include direct-ascent weapons (carrying a conventional or nuclear payload), which are ground-based missiles that are launched into space, or co-orbital weapons, which are space-based technologies that could be used to destroy other satellites with lasers, explosives, or by ramming into them or grabbing them with robotic arms. While counterspace capabilities may also involve ground station attacks[259] and non-kinetic weapons such as frequency jamming, directed-energy, or cyber technology[260], this section focuses on direct-ascent and co-orbital KE-ASATs exclusively.

Production: material inputs, infrastructure, expertise and skills, testing core technology

Only fourteen countries are capable of building and launching vehicles beyond the Earth's atmosphere

Kinetic direct-ascent and co-orbital ASATs require highly advanced technical means and expertise, limiting the number of potential users. Space assets' altitude, speed and potential use of countermeasures, as well as orbit's harsh environmental conditions, pose significant technological challenges to an attacker. Accessing material inputs is therefore not straightforward. Specifically, co-orbital ASATs would require hardening to protect against high temperatures and radiation hazards; and may become the target of counterspace capabilities themselves.[261] Today, only fourteen countries are capable of building and launching vehicles beyond the Earth's atmosphere, including the United States, Russia, China, the United Kingdom, France, Canada, Japan, India, Israel, Ukraine, Iran, North and South Korea, and New Zealand.[262]

That said, existing military systems can be modified into direct ascent KE-ASATs. Midcourse missile defense systems, such as the US-made THAAD and Aegis BMD, Chinese-made DN-1, and India's indigenous missile defense system could provide counterspace capabilities. Aegis SM-3 Block IA/Block IB missiles are capable of striking satellites – which typically have low levels of maneuverability – in Low Earth Orbit at or below 600 km altitudes, while SM 3 Block IIA interceptors can reach the majority of LEO satellites, if not all if a burnout speed of 5.5 km/s is reached. The same applies to the American ground-based midcourse (GMD) missile defense systems in Alaska and California.[263] Similarly, various ballistic missiles, if able to reach

259 Nivedita Raju, "A Proposal for a Ban on Destructive Anti-Satellite Testing: A Role for the European Union," Non-Proliferation and Disarmament Papers (EU Non-Proliferation and Disarmament Consortium, April 2021), https://www.nonproliferation.eu/wp-content/uploads/2021/04/EUNPDC_no-74_260421.pdf.

260 The Economic Times, "ASAT: Aimed at Destroying, Disabling Space Assets," *The Economic Times*, March 27, 2019, https://economictimes.indiatimes.com/news/defence/asat-aimed-at-destroying-disabling-space-assets/articleshow/68602915.cms?from=mdr.

261 Clayton K. S. Chun, "Striking Out to Space: Technical Challenges to the Deployment of ASAT Weapons," Research Report, New Challenges in Missile Proliferation, Missile Defense, and Space Security (Monterey, CA: James Martin Center for Nonproliferation Studies (CNS), 2003), 27–28, https://www.jstor.org/stable/resrep09888.7.

262 Dawson, *War in Space*.

263 Laura Grego, "The Anti-Satellite Capability of the Phased Adaptive Approach Missile Defense System," Public Interest Report (Washington D.C.: Federation of American Scientists, 2011), 2–3, https://fas.org/pubs/pir/2011winter/2011Winter-Anti-Satellite.pdf.

space altitudes and with accurate guidance, can be used as direct-ascent ASAT weapons.[264] Currently, only the United States, China, Russia, North Korea, India, Israel, France, and the United Kingdom own operable intercontinental ballistic missiles able to reach space.[265]

A number of state actors, including China, the United States, India and Russia have conducted direct-ascent ASAT tests in space.[266] Russia, for one, has conducted various successful tests of the PL19 Nudol, a direct-ascent ASAT which is a variation of the A-235 anti-ballistic missile system.[267] The United States meanwhile has tested its SM-3 interceptor's antisatellite capacity, intercepting its own USA-13 satellite in low-Earth orbit at a speed of 22,000 miles per hour during Operation Burn Frost in 2008.[268] Given ASATs' various forms, it is difficult to specify their costs of production. Nonetheless, it is safe to assume that their research and development is quite costly, given the skills, technology, and expertise needed to produce them.

The feasibility to produce kinetic ASATs thus somewhat depends on its subtype, with the development and production co-orbital ASATs arguably more complex than direct-ascent ASATs – at least for countries already possessing specific ballistic missile systems. For both types, testing is complex, but not impossible. Because of the highly limited number of countries for which the production of direct-ascent and co-orbital ASAT technology is feasible, both in terms of technological expertise and costs, in the near- to medium term future, the ease with which ASAT technology can be produced is considered **low**.

Proliferation: dual-use nature, tangibility, distinguishability

Both co-orbital and direct-ascent ASATs are generally tangible and detectable. However, problems of distinguishability and dual-use make regulating the proliferation of these technologies harder. Ballistic missiles and extra-atmospheric missile defense systems can be used as direct-ascent ASATs, undermining the distinguishability of ASATs from other military technologies. Additionally, several co-orbital technologies have commercial applications that can be used for military purposes. Satellites, launch vehicles, and active debris removal (ADR) systems all serve civilian purposes, but can also be modified to become co-orbital ASATs.[269] For instance, some reports have suggested that the Chinese Aolong-1 spacecraft, launched in 2016 and officially tasked with cleaning up debris, is simultaneously being used to conduct co-orbital ASAT tests.[270]

To conclude, most kinetic ASAT technologies have commercial applications, and direct-ascent antisatellite technology is not distinct from other military technologies such as missile defense systems. The technology is tangible, however, with detectability levels being high.

264 Kaitlyn Johnson, "A Balance of Instability: Effects of a Direct-Ascent Anti-Satellite Weapons Ban on Nuclear Stability," Nuclear Network (Washington D.C.: Center for Strategic & International Studies, November 17, 2020), https://nuclearnetwork.csis.org/a-balance-of-instability-effects-of-a-direct-ascent-anti-satellite-weapons-ban-on-nuclear-stability/.

265 "Worldwide Ballistic Missile Inventories," Arms Control Association, 2017, http://www.tandfonline.com/doi/abs/10.1080/10736709608436630.

266 Harrison et al., "Space Threat Assesment 2021."

267 Mizokami, "Meet Russia's Imposing New Satellite-Destroying Missile"; Mizokami, "It Sure Looks Like Russia Just Tested a Space Weapon."

268 Mizokami, "It Sure Looks Like Russia Just Tested a Space Weapon."

269 Talia M. Blatt, "Anti-Satellite Weapons and the Emerging Space Arms Race," Harvard International Review, May 26, 2020, https://hir.harvard.edu/anti-satellite-weapons-and-the-emerging-space-arms-race/.

270 Dawson, *War in Space*.

Even if the technology is not necessarily very mobile, the likelihood for anti-satellite weapons to proliferate is therefore **medium**.

Deployment: infrastructure, platform requirements, deployment skills

Deployment challenges vary for different ASAT technologies. Direct-ascent ASATs require a rocket booster with sufficient payload capacity to provide thrust to propel a warhead towards the target. If used to strike an orbital weapon platform, a direct-ascent ASAT additionally needs to have instant readiness to strike the target before it unleashes weapons, requiring extensive maintenance and crew training, as well as exhaustive surface, aerial, and space-based surveillance and tracking systems. Co-orbital ASATs need a booster to be launched into orbit as well as secure and reliable communications system that would allow controllers on the ground to activate and engage the ASAT system. Lastly, depending on the kind of co-orbital ASAT, they might need guidance system and movable weapon housing for projectiles.[271] The deployment of ASAT technology thus requires complex launching platforms, C4ISR capabilities and technical expertise. States that already have the capabilities and skills to deploy commercial applications of space technology, or missile defense systems in the case of direct-ascent KE-ASATs, will face fewer challenges. Therefore, the ease with which kinetic ASATs can be deployed is **medium**.

Employment: organization, doctrine, norms

Changes in war-fighting doctrines are needed for the military use of space

The use of ASATs and space warfare more generally requires serious military transformations and force restructuring. Recently, major powers have implemented changes accordingly. The Chinese People's Liberation Army (PLA) launched the Strategic Support Force, tasked with the development and employment of the army's space-warfare capabilities, including ASATs, while the United States established an independent space force in 2019.[272] That same year, France launched a space command within its air forces and India created a Defence Space Agency.[273] Most recently, the UK formed a space command, jointly staffed by its Royal Navy, British Army, Royal Air Force and Civil Service.[274]

Furthermore, changes in war-fighting doctrines are needed for the military use of space. In recent years, major powers have taken important steps to adjust their national security strategies and defense policies. The US launched a National Security Space Strategy in 2011, Russia has included the space domain in its warfighting doctrine since 2014, and China's 2015

271 Chun, "Striking Out to Space."

272 Kevin Pollpeter, Michael Chase, and Eric Heginbotham, "The Creation of the PLA Strategic Support Force and Its Implications for Chinese Military Space Operations" (Santa Monica, CA: RAND Corporation, 2017), https://doi.org/10.7249/RR2058; Valerie Insinna, "Trump Officially Organizes the Space Force under the Air Force ... for Now," Defense News, February 19, 2019, https://www.defensenews.com/space/2019/02/19/trump-signs-off-on-organizing-the-space-force-under-the-air-forcefor-now/; John Costello and Joe McReynolds, "China's Strategic Support Force," China Strategic Perspectives (INSS, October 2, 2018).

273 Vivek Raghuvanshi, "India to Launch a Defense-Based Space Research Agency," *Defense News* (blog), June 13, 2019, https://www.crows.org/news/455759/India-to-launch-a-defense-based-space-research-agency.htm; Ministry of Defence, "UK Space Command," gov.uk, April 1, 2021, https://www.gov.uk/guidance/uk-space-command; France 24, "Macron Announces Creation of French Space Force," France 24, July 13, 2019, https://www.france24.com/en/20190713-macron-france-space-force.

274 Ministry of Defence, "UK Space Command."

White Paper officially designated space as a military domain.[275] Other states that have taken steps to prepare their militaries for the space domain include India and France, with the latter launching its first French Space Defence Strategy in 2019.

The organizational and doctrinal challenges to the employment of ASATs are further exacerbated by operational concerns including the risk of collateral damage. For instance, the electromagnetic pulse produced by a nuclear ASAT may damage other (unhardened) low-Earth orbiting space assets, and even electrical systems on the Earth's surface, thus complicating attacks for states that rely themselves on such systems. But conventional attacks, too, carry the risk of collateral damage, in the form of debris or when the targeted space asset itself carries nuclear weapons or chemical fuels. These concerns provide strong disincentives to the use (and testing) of ASATs, and are more widely reflected in prevailing international norms for the weaponization of space.[276]

ASAT technology's employment thus requires far-reaching changes in organization and warfighting doctrine. Various widely accepted norms with regard to the weaponization of space and considerations about space debris further discourage this technology's use. As a result, the ease with which anti-satellite weapons can be employed is considered **low**.

Assessment anti-satellite weapons

The ease with which ASATs can be produced is low, given the complexity of testing, high costs of production, and expertise needed. However, proliferation and deployment are somewhat easier, due to the commercial applications of this technology and its launching infrastructures. Employment of ASATs requires far-reaching changes in organization and warfighting doctrine and is further limited by norms regarding the weaponization of space. The assessment of ASATs is summed up in Table 9 and plotted in Figure 5.

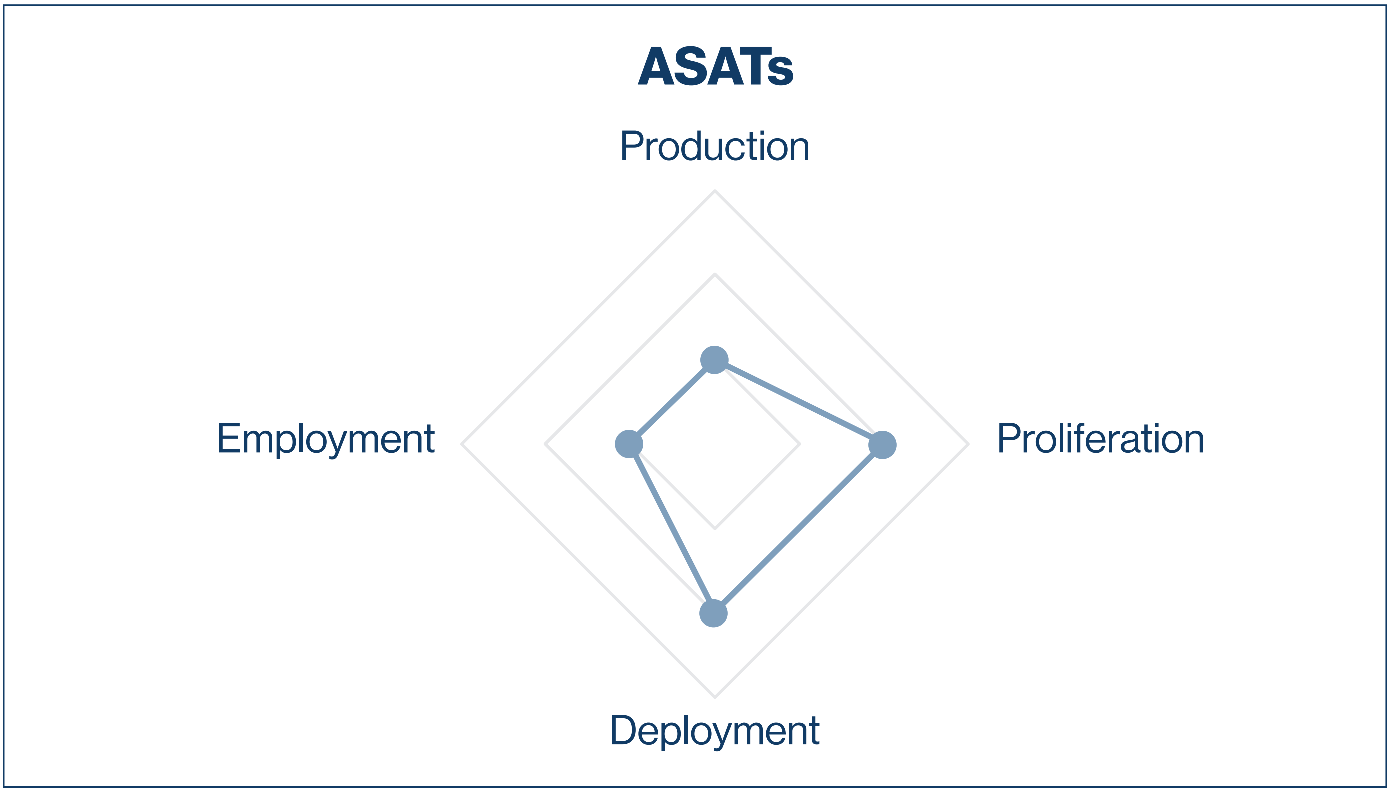
275 "China's Military Strategy" (The State Council of The People's Republic of China, May 27, 2015), http://english.www.gov.cn/archive/white_paper/2015/05/27/content_281475115610833.htm; "The Military Doctrine of the Russian Federation" (The Embassy of the Russian Federation to the United Kingdom of Great Britain and Northern Ireland, June 29, 2021), https://rusemb.org.uk/press/2029; "National Security Space Strategy Unclassified Summary" (Department of Defense, 2011).

276 Chun, "Striking Out to Space," 25–28.

Table 9. Assessment of Anti-Satellite weapons across the production-proliferation-deployment-employment chain

Phase		Criteria	
Production	Feasibility of this technology to be produced	Low	Material inputs for ASAT weapons are rare and expensive. Moreover, the technology extremely complex, requiring highly advanced skills and discrete specialized knowledge. Weaponizing and testing the technology in relevant environments is highly challenging.
Proliferation	Likelihood of this technology to proliferate	Medium	Commercial applications of this technology exist and can be modified for military use. At the same time, the technology is tangible, with detectability during transport being relatively high. Moving the technology is challenging but feasible. The technology is potentially distinguishable from other military technologies.
Deployment	The ease with which this technology can be deployed	Medium	This technology requires fairly sophisticated infrastructures, weapon platforms and/or enablers - but potentially modification of existing technologies is possible. Deployment of this technology further requires advanced technical knowledge.
Employment	The ease with which this technology can be employed	Low	Employing this technology requires significant organizational and doctrinal changes. States are strongly disincentivized to employ this weapon.

Figure 5. Radar chart plotting the assessment of anti-satellite weapons



Directed-energy weapons

Directed energy weapons (DEWs) include a broad spectrum of technologies that transmit concentrated electromagnetic energy to incapacitate, damage, disable, or destroy enemy equipment, facilities, and/or personnel. DEWs take various forms, the most important of which are high-energy lasers (HEL), which direct intensely focused beams of energy, and are powered by a chemical fuel, electric power or a generated stream of electrons;[277] as well as weapons using electromagnetic waves or other wavelengths such as high-power microwaves (HPM).[278]

Here, we focus solely on HEL technology's potential (and future) use in missile defense or as antisatellite capability, since these applications carry implications for strategic stability. (It should be noted, however, that in the near future the most important use of HEL technology will be for defense against drones.) Because laser technology can be used as both a sensor and a weapon, the speed of weapons increases dramatically, limiting the potential for countermeasures such as maneuvering. They can engage multiple targets and offer a flexible results depending on their output power: the spectrum of results goes from non-fatal, disruptive to destructive outcomes.[279] Finally, they present lower operational costs per shot than conventional weapons.[280]

Production: material inputs, infrastructure, expertise and skills, testing core technology

Laser technology has increasingly matured, especially its use against drones

The production of laser technology is costly and requires a high degree of sophistication.[281] Material input challenges include the generation of an appropriate amount of energy/power to military useful levels, their integration into weight sensitive platforms, countering the distortion caused by atmospheric turbulence, and meeting cooling requirements.[282] Indeed, despite billions of dollars invested in the 1990s and early 2000s, "actual directed-energy programs have frequently fallen short of expectations."[283]

In recent years, however, laser technology has increasingly matured, especially its use against drones.[284] Yet, the realization of space-based or airborne applications, to be used for missile defense or as ASATs, requires a different level of sophistication, not least because of storage

277 HELs are classified based on their energy levels: 1) Low: less that 1kW power commonly used in weapon simulation systems for training, communication systems and in antipersonnel mode against the human eye; 2) Medium: 10kW to 100 kW of power. They are employed to destruct optical or optoelectronic systems on the ground or in space; and 3) High: greater than 100 kW. They are used for anti-craft or anti-missile systems.

278 "Joint Publication 3-13.1, Electronic Warfare" (Arlington, VA: U.S. Department of Defense, 2012), 1–16, https://fas.org/irp/doddir/dod/jp3-13-1.pdf.

279 Thair Al-Aish, "Design and Analysis the Fiber Laser Weapon System FLWS," *Advances in Physics Theories and Applications*, Advances in Physics Theories and Applications, 47 (January 1, 2015): 59–68.

280 D.J. van Oorspronk and G.E.A. Franken, "Directed Energy Weapons: An Overview of the Current State of Technology and Systems" (NLR - Royal Netherlands Aerospace Centre, June 2021).

281 Harrison et al., "Space Threat Assesment 2021," 5.

282 Affan Ahmed, Mohsin, and Zubair Ali, 'Survey and Technological Analysis of Laser and Its Defense Applications'; Dussinger, 'Thermal Management for Directed Energy Weapons'; MacRae, 'The Promise and Problem of Laser Weapons'; Robinson, 'Directed Energy Weapons'.

283 Jason D Ellis, "Directed-Energy Weapons: Promise and Prospects," *Center for a New American Security*, 20YY Series, no. April 2015 (2015): 4.

284 Kyle Mizokami, "The Air Force Mobilizes Its Laser and Microwave Weapons Abroad," *Popular Mechanics* (blog), April 9, 2020, https://www.popularmechanics.com/military/weapons/a32083799/laser-microwave-weapons/.

and refueling challenges, but also when it comes to generating appropriate amounts of energy. Given these challenges, the production of laser technology that is capable of permanently disabling space objects or missiles is still a distant future and unlikely to occur beyond a few major powers due to concerns over the affordability, technological feasibility, and operational utility of lasers used for such purposes.[285]

For directed-energy weapons, testing is straightforward, and many countries are currently testing the use of solid state lasers against smaller targets, especially UAVs.[286] Once the technology for such use will have matured, in a couple of years, a next step will be scaling these lasers to even higher powers. Non-destructive laser capabilities reaching into space have already been tested, though: for instance in 2006, China dazzled a US satellite with a ground-based laser.[287] Investments in the development of DEWs are on the rise. The US has noticeably increased its budget for this type of capability, raising from $535 million in fiscal year 2017 to $1.1 billion in fiscal year 2019.[288] India's DRDO has requested a $100 million budget to produce a high-power laser weapon for fiscal year 2021-2022.[289]

Weaponizing and testing the technology in relevant environments also remains challenging

Thus, the development of directed energy weapons technology at the strategic level is highly complex and costly. Particularly when deployed from air or spaceborne platforms, serious doubts remain with regard to the eventual feasibility and affordability of this technology for such use. Weaponizing and testing the technology in relevant environments also remains challenging. As such, the feasibility to produce laser technology that can be applied in missile defense or as ASAT technology is **low**.

Proliferation: dual-use nature, tangibility, distinguishability

Laser technology has a broad variety commercial applications, such as measuring devices, tools for manipulating and shaping materials, and medical spectroscopy. Especially advances in computer controls and computer-aided design and manufacturing, as well as information technology, have enabled the explosive growth in directed-energy applications.[290] Similarly,

285 Aaron Mehta, "Griffin 'Extremely Skeptical' of Airborne Lasers for Missile Defense," *Defense News* (blog), May 20, 2020, https://www.defensenews.com/2020/05/20/griffin-extremely-skeptical-of-airborne-lasers-for-missile-defense/; Justin Doubleday, "Pentagon Punts MDA's Laser Ambitions, Shifts Funding toward OSD-Led 'Laser Scaling,'" Inside Defense, February 19, 2020, https://insidedefense.com/daily-news/pentagon-punts-mdas-laser-ambitions-shifts-funding-toward-osd-led-laser-scaling; Dr James N Miller and Frank Rose, "Bad Idea: Space-Based Interceptors and Space-Based Directed Energy Systems" (Washington D.C.: Center for Strategic & International Studies, December 13, 2018), https://defense360.csis.org/bad-idea-space-based-interceptors-and-space-based-directed-energy-systems/.

286 See for instance: C. Todd López, "With No Bullets, Mobile High-Energy Laser Shoots Drones from Sky," *U.S. Army* (blog), April 14, 2017, https://www.army.mil/article/186025/with_no_bullets_mobile_high_energy_laser_shoots_drones_from_sky; Jared Keller, "The Army Just Test-Fired A Frickin' Laser Beam From An Apache Attack Helicopter," *Task & Purpose* (blog), June 26, 2017, https://taskandpurpose.com/gear-tech/apache-army-laser-weapon/; "China Test-Fires New Laser-Based C-UAS," *UAS Vision* (blog), November 30, 2017, https://www.uasvision.com/2017/11/30/china-test-fires-new-laser-based-c-uas/.

287 Brooke Van Buskirk, "Three Neglected Space Issues: Laser ASATs, Cooperation with China and Russia, and Space Secrecy," Workshop Report (Washington, D.C., U.S.: Nonproliferation Policy Education Center, 2020), https://www.americanbar.org/content/dam/aba/administrative/law_national_security/july-2020-space-report.pdf.

288 "Laser Directed Energy Weapons Likely to Receive the Most Investment," Airforce Technology, July 23, 2021, https://www.airforce-technology.com/news/laser-directed-energy-weapons-likely-to-receive-the-most-investment-in-future-poll/.

289 Mike Yeo Martin Nigel Pittaway, Usman Ansari, Vivek Raghuvanshi and Chris, "Hypersonic and Directed-Energy Weapons: Who Has Them, and Who's Winning the Race in the Asia-Pacific?," Defense News, March 15, 2021, https://www.defensenews.com/global/asia-pacific/2021/03/15/hypersonic-and-directed-energy-weapons-who-has-them-and-whos-winning-the-race-in-the-asia-pacific/.

290 Thompson and Gouré, 'Directed-Energy Weapons: Technologies, Applications and Implications'.

technological developments in the areas of thermal control and power management subsystems in the electric car industry have been applied to help tackle thermal management and power supply issues in the development of DEWs.[291] In the future, this dual-use nature of laser technology can thus spur their proliferation, but it should be noted that laser technology's military applications alluded to here – missile defense and ASAT capacity – are an entirely different order of magnitude.

Further, laser technology is tangible, and can be detected during transport. While it is largely distinct from other technologies, it does have lower level military applications, such as defense against drones.

The likelihood for laser technology to proliferate is therefore considered **medium**. Commercial applications exist, yet the technology is tangible, with detectability during transport being relatively high. Moving the technology is challenging but not impossible.

Deployment: infrastructure, platform requirements, deployment skills

Laser weapons can be deployed from ground- or ship-based sites, airborne platforms, or other satellites. Ground-based HEL DEWs would make use of ground vehicles equipped with radar, network and fire-control equipment, and would require various space-based high altitude relay mirrors to increase their transmission and detection range, which is otherwise hampered by atmospheric turbulence, absorption, and the Earth's curvature.[292] Airborne platforms make use of a ground-based section with heavier components, including a generator, cooling system, accumulators, pump diodes, beam coupler, control station and operator; as well as a space- or air-based section with lighter components, including the active laser, focusing drivers, telescope, and sensors.[293]

In addition, compared to fixed systems, the mobile use of ground-based technology is even more complex given DEW systems size, weight, and sensitivity to shock and vibration, complicating laser systems transport.[294] This underlines the complexity of weaponizing laser technology.

The complexity of many DEW systems requires highly skilled operators and maintenance crews to keep the systems operational. Implementation requirements on training, people, infrastructure, organization, information and logistics will need to be considered in parallel to the development of the technology.

The deployment of DEWs would thus require large amounts of support personnel, advanced technical knowledge, extensive infrastructures such as launch platforms and mobile ground units, and sophisticated automated support systems including C4ISR. Hence, the ease of deploying laser weapons is **low**.

291 Henry Obering, "Directed Energy Weapons Are Real...And Disruptive," *PRISM* 8, no. 3 (2019): 37–46.

292 Syed Affan Ahmed, Mujahid Mohsin, and Syed Muhammad Zubair Ali, "Survey and Technological Analysis of Laser and Its Defense Applications," *Defence Technology* 17, no. 2 (April 2021): 583–92, https://doi.org/10.1016/j.dt.2020.02.012.

293 Affan Ahmed, Mohsin, and Zubair Ali, 590.

294 Elihu Zimet and Christopher Mann, "Directed Energy Weapons - Are We There Yet? The Future of DEW Systems and Barriers to Success" (Fort Belvoir, VA: Defense Technical Information Center, May 2009), 9, https://doi.org/10.21236/ADA501628.

Employment: organization, doctrine, norms

The employment of DEWs necessitates some considerations. First, lasers' potential for devastation at the speed of light will accelerate the pace of warfare, spurring the automatization of countermeasures.[295] Moreover, the utility of pre-emptive strikes could be reconsidered.[296] In addition, the employment of DEWs, which are less-than-lethal capabilities, risks increasing their use in environments where lethal weapons would not be considered. Especially the latter may undermine battlefield acceptance of the technology.[297] Also at the operational level, such questions are currently unresolved, as US former Undersecretary of Defense Michael Griffin pointed out: "We've not invested enough in the operational studies that, you know, if I gave a war fighter a weapon of X number of kilowatts, you know, how and in what circumstances could you use it, and where is it better than a kinetic weapon and where is it not? The operational assessments just have not received as much attention as they should."[298]

The deployment of weapons in space is still largely taboo

Finally, as was mentioned in the ASAT section, the deployment of weapons in space is still largely taboo.[299] The use of space-based laser technology may therefore also be frowned upon given its potential impact on civilian infrastructures. Moreover, if used against satellites, lasers could potentially be considered weapons of mass destruction.

Given the operational and organizational challenges complicating the use of laser technology for missile defense or in its potential ASAT capacity, and taking into account the norms cautioning against the weaponization of space, the ease of employment of strategic laser technology is considered **low**.

Assessment directed-energy weapons

DEWs are extremely costly and complex to produce and, while commercial applications exist, DEWs are not likely to proliferate easily. Advanced technical knowledge and extensive infrastructures make it hard for DEWs to be deployed. Employment is also complicated by operational and organizational challenges. Table 10 sums up the assessment of DEWs across the production-proliferation-deployment-employment chain, while Figure 6 plots the assessment on a radar chart.

295 David Hayes and Elizabeth Quintana, "When Will Directed Energy Weapons See The Light?," *The RUSI Journal* 156, no. 3 (June 2011): 68.

296 John P. Geis, *Directed Energy Weapons on the Battlefield: A New Vision for 2025* (Alabama: Center for Strategy and Technology, Air War College, Air University, 2003), 37, https://books.google.es/books?hl=en&lr=&id=Lq-DeFsTzQoYC&oi=fnd&pg=PP11&dq=materials+involved+in+high+energy+weapons&ots=YoKZMl-Qi5O&sig=vv7YqlF1FQZK-aFHROxezefn4jg&redir_esc=y#v=onepage&q&f=false.

297 Hayes and Quintana, "When Will Directed Energy Weapons See The Light?"

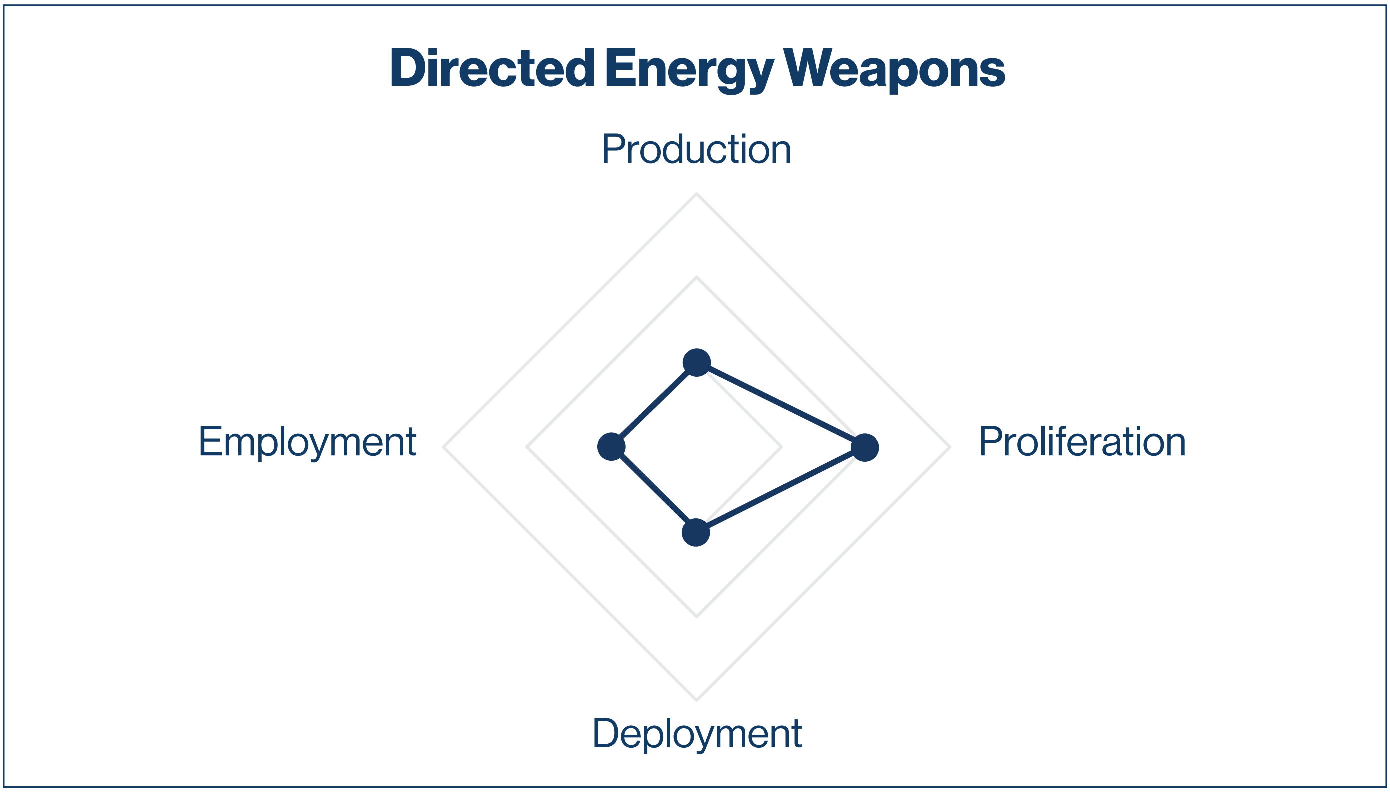
298 Mehta, "Griffin 'Extremely Skeptical' of Airborne Lasers for Missile Defense."

299 Thompson and Gouré, "Directed-Energy Weapons: Technologies, Applications and Implications," 43.

Table 10. Assessment of directed energy weapons across the production-proliferation-deployment-employment chain

Phase		Criteria	
Production	Feasibility of this technology to be produced	Low	Material inputs for DEW are rare and expensive. Moreover, the technology extremely complex, requiring highly advanced skills and discrete specialized knowledge. Weaponizing and testing the technology in relevant environments is highly challenging.
Proliferation	Likelihood of this technology to proliferate	Medium	Commercial applications of this technology exist and can be modified for military use. At the same time, the technology is tangible, with detectability during transport being relatively high. Moving the technology is challenging but feasible. The technology is potentially distinguishable from other military technologies.
Deployment	The ease with which this technology can be deployed	Low	This technology requires highly sophisticated and novel infrastructures, weapon platforms and/or enablers. Existing technologies cannot be modified. Deployment requires highly advanced technical knowledge.
Employment	The ease with which this technology can be employed	Low	Employing this technology requires significant organizational and doctrinal changes. States are strongly disincentivized to employ this weapon.

Figure 6. Radar chart plotting the assessment of directed energy weapons



Dual-capable missiles

Dual-capable missiles can deliver nuclear and conventional warheads, entangling mainly tactical nuclear weapons with non-nuclear weapons. While again not a 'new' technology, entanglement of missiles has been occurring progressively due to a variety of technological and geopolitical trends, with important implications for strategic stability.

Production: material inputs, infrastructure, expertise and skills, testing core technology

The production of dual-capable missiles is complex. Dual-capable missiles, like their conventional counterparts, need to be accurate. As ranges increase, so does production complexity. One could therefore assume that producing short-range dual-capable missiles is somewhat more straightforward – given that nuclear warheads are sufficiently small and light – while those with ranges of approximately 3,000 kilometers is not.[300]

Despite testing difficulties related to the strict restrictions on nuclear weapons, dual-capable missiles have been produced by a number of countries. The Russian ground-launched SS-26 Iskander and SS-21 Tochka short-range ballistic missiles, as well as the intermediate range SSC-8 ground-launched cruise missile (GLCM), are reportedly-dual capable. Meanwhile, the Russian Navy operates the dual-capable Kalibr sea-launched cruise missiles (SLCM) and the potentially dual-capable SS-N-26 on its nuclear powered attack submarines.[301] While China's DF-21 missile is fielded in both nuclear and conventional variants (hence not strictly dual-capable), its intermediate range ballistic missile DF-26 and the HGV DF-17 are reportedly true dual-capable missiles.[302] In 2017, the US Air Force National Air and Space Intelligence Centre (NASIC) did not designate any of China's cruise missiles dual-capable, contrary to its 2013 assessment when it marked the ground-launched DH-10 as dual-capable.[303]

Dual-capable missiles are also being fielded by smaller nuclear powers. Pakistan is developing the Ra'ad II system, an allegedly dual-capable air-launched cruise missile.[304] In fact, all Pakistan's missiles, including its NASR (Hatf-9) land-based ballistic missile, are thought to be dual-capable, even though not all bases may have a nuclear role nor do all missile launchers have assigned nuclear warheads.[305] India's Nirbhay GLCM is also reported to be dual-capable.[306] Finally, it is unclear to what extent North Korea has dual-capable missiles. Its longer-range ground-missiles are almost certainly loaded with nuclear warheads only, given their inaccuracy, and missiles in the shortest range are expected to be exclusively conventional

300 In the 1950s the United States and Soviet Union already deployed dual-capable missiles with ranges up to a few hundred kilometers. However, given missiles' inaccuracy at the time, the advantage of deploying conventional payloads on ballistic missiles was highly limited. As accuracy increased throughout the 1970s-80s, dual-capable missiles with longer ranges were fielded in the Soviet Union, including the SS-12 Mod 2.

301 Kristensen and Norris, "Russian Nuclear Forces, 2018."

302 Kristensen, 'China's New DF-26 Missile Shows Up At Base In Eastern China'; Panda, 'Introducing the DF-17'.

303 "SIPRI Yearbook: Armaments, Disarmament and International Security," SIPRI, 2021, https://www.sipri.org/yearbook.

304 Nasima Khatoon, "The Maiden Test of Pakistan's Ra'ad II Cruise Missile: An Overview," CAPS in Focus (Centre for Air Power Studies - Forum for National Security Studies, March 24, 2020), http://www.capsindia.org/files/documents/882329cf-997a-48ca-a86f-c9a3db5f74e0.pdf.

305 Kristensen Kristensen Hans M., "Pakistan's Evolving Nuclear Weapons Infrastructure," *Federation Of American Scientists* (blog), November 16, 2016, https://fas.org/blogs/security/2016/11/pakistan-nuclear-infrastructure/; Hans M. Kristensen, Robert S. Norris, and Julia Diamond, "Pakistani Nuclear Forces, 2018," *Bulletin of the Atomic Scientists* 74, no. 5 (August 31, 2018): 348–58, https://doi.org/10.1080/00963402.2018.1507796.

306 Kristensen and Korda, "Indian Nuclear Forces, 2020."

given a lack of small nuclear warheads. It may, however, be the case that missiles with ranges between 300 to 1,500 kilometers have dual warhead capabilities.[307]

Altogether, the feasibility to produce dual-capable missiles is assessed to be **medium**. Long-range missiles need to be accurate enough for conventional payloads, while nuclear warheads need to be small enough to be mounted on short-range missiles. As a result, the development and production of dual-capable missiles is limited to a select group of major military (nuclear) powers, even if the production of dual-capable missile does not require additional material inputs or high levels of technological advancement. In fact, dual-capable missile systems may be more cost-effective.

Proliferation: dual-use nature, tangibility, distinguishability

Long-range missiles need to be accurate enough for conventional payloads, while nuclear warheads need to be small enough to be mounted on short-range missiles

Dual-capable missiles are a strictly military technology, even if some missile technology is being used in the civilian space sector. Detectability during transport is high given that the technology is tangible. Moving the technology is challenging, however, with the spread of dual-capable missiles further limited to nuclear powers only. As a result, the likelihood of dual-capable missile systems to proliferate is **medium**.

Deployment: infrastructure, platform requirements, deployment skills

The deployment of dual-capable missile systems is moderately similar to that of missiles designed for one type of warhead, at least when comparing missiles with similar ranges.[308] Missile launchers and platforms are largely the same, and no additional deployment skills are required. That said, when compared to infrastructures required for conventional missiles, dual-capable missiles loaded with nuclear warheads have additional (safety and security) requirements such as a Permissive Action Link (PAL) in the United States that prevents unauthorized arming or detonation. In China, nuclear units come with special warhead handling units or security detachments.[309] Moreover, reload capabilities, transport capacity, and support brigades may differ for nuclear and conventional missile brigades. In China, for instance, conventional missile units could require additional missile transport vehicles because of their reload capacity. Conventional missile brigades may include technical and communication missile brigades that are absent from nuclear ones.[310]

Thus, while the feasibility to deploy dual-capable missiles can be argued to be low, if a state already deploys nuclear and conventional missiles, the adaptations required in infrastructure, platform requirements and deployment skills are fairly limited. Therefore, the ease with which dual-capable missiles can be deployed is assessed to be **medium**.

Employment: organization, doctrine, norms

The employment of dual-capable C3I necessitates some adjustments because doctrines, personnel management policies, and organization structures tend to differ for nuclear and

307 James M. Acton, "Appendix: France, India, Pakistan and North Korea," in *Is It a Nuke? Pre-Launch Ambiguity and Inadvertent Escalation* (Washington D.C.: Carnegie Endowment for International Peace, 2020), 55–57, https://carnegieendowment.org/files/Acton_NukeorNot_final.pdf.

308 Amy F. Woolf, "Conventional Warheads for Long-Range Ballistic Missiles: Background and Issues for Congress" (Washington D.C.: Congressional Research Service, January 26, 2009), https://fas.org/sgp/crs/nuke/RL33067.pdf.

309 David C. Logan, "Are They Reading Schelling in Beijing? The Dimensions, Drivers, and Risks of Nuclear-Conventional Entanglement in China," *Journal of Strategic Studies*, November 12, 2020, 24, https://doi.org/10.1080/01402390.2020.1844671.

310 Logan, 23.

conventional forces. The employment of dual-capable missiles could require significant efforts in the training of brigades, who need to be proficient in both nuclear and conventional operational postures, and which have traditionally often been separate.[311] In the case of China's People's Liberation Army Rocket Force (PLARF), for instance, nuclear and conventional forces differ operationally, with differences in the size, structure and number of missiles assigned for nuclear and conventional units.[312] Reload capabilities and transport capacity for conventional missiles could be absent for nuclear arsenals; and conventional missile brigades may include technical and communication missile brigades that are absent from nuclear ones. That said, dual-capable missiles will progressively erode these differences.[313] Similar differences and separations in terms of training and organization traditionally exist in the United States, where personnel performing nuclear C3I and launch activities need to complete training specific to Nuclear and Missile Operations and the Personnel Reliability Program (PRP).[314] That said, dual-capable systems (e.g., aircraft) are in use much longer in various countries, and challenges are not insurmountable.

Furthermore, the tactical component of nuclear-conventional integration at the theater level needs to be thought through as well: "Closely tied with integrating nuclear forces with regional forces and plans is how to synchronize and de-conflict dual-capable systems and supporting assets needed to implement regional deterrence architectures."[315] Thus, dual-capable assets spur the need to balance leveraging nuclear deterrence during a conventional campaign with regular warfighting efforts.

Dual-capable assets spur the need to balance leveraging nuclear deterrence with regular warfighting efforts

Various other considerations could be taken into account when deploying dual-capable missiles. The risk of inadvertent escalation is perhaps the strongest disincentive. While states may deploy and employ these capabilities with the right distinctions, adversaries may not see the differences, raising the risk of escalation. Finally, for countries like the United States, the limitations of basing nuclear-armed mobile missiles on overseas bases may discourage the country from employing dual-capable missile systems.[316]

The employment of dual-capable missiles thus requires various changes to organization and warfighting doctrine to make sure that they work effectively separately. While no international norms strongly discourage the use of dual-capable missiles, further disincentives such as the risk of escalation may temper their use. The ease of dual-capable missile employment is therefore **medium**.

Assessment dual-capable missiles

For countries that already produce nuclear and (precise) conventional missiles, dual-capable missile technology is fairly straightforward. Nonetheless, the proliferation of this technology is limited by challenges related to moveability and detectability. Deployment and employment are feasible, but somewhat constricted by technical and organizational challenges, respectively. The assessment of dual-capable missiles across the production-proliferation-deployment-employment chain is summarized in Table 11 and visualized in Figure 7.

311 P.W. Singer and Ma Xiu, "China's Ambiguous Missile Strategy Is Risky," *Popular Science* (blog), May 11, 2020, https://www.popsci.com/story/blog-network/eastern-arsenal/china-nuclear-conventional-missiles/.

312 Logan, "Are They Reading Schelling in Beijing?," 24.

313 Logan, 23.

314 U.S. Air Force, "Nuclear and Missile Operations Officer," U.S. Air Force, accessed June 10, 2021, https://www.airforce.com/careers/detail/nuclear-and-missile-operations-officer.

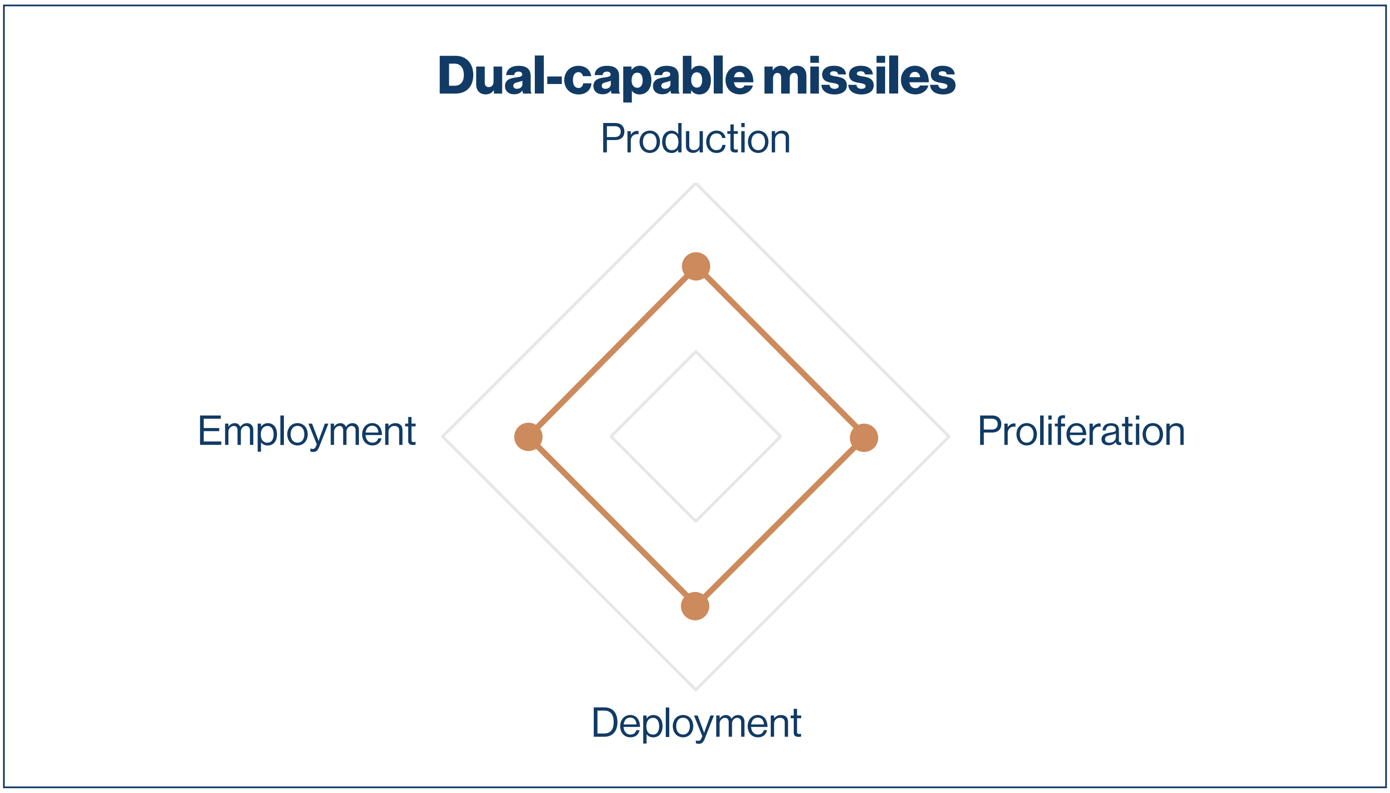
315 Robert Peters, Justin Anderson, and Harrison Menke, "Deterrence in the 21st Century: Integrating Nuclear and Conventional Force," *Strategic Studies Quarterly* 12, no. 4 (2018): 29.

316 James M. Acton, "Is It a Nuke?: Pre-Launch Ambiguity and Inadvertent Escalation" (Carnegie Endowment for International Peace, April 9, 2020), 23, https://carnegieendowment.org/2020/04/09/is-it-nuke-pre-launch-ambiguity-and-inadvertent-escalation-pub-81446.

Table 11. Assessment of dual-capable missiles across the production-proliferation-deployment-employment chain

Phase		Criteria	
Production	Feasibility of this technology to be produced	Medium	Material inputs for dual-capable missiles are accessible and relatively inexpensive, yet the technology is complex, requiring advanced skills and specialized knowledge that is fairly discrete. Weaponizing and testing the technology in relevant environments can be challenging.
Proliferation	Likelihood of this technology to proliferate	Medium	Commercial applications of this technology exist and can be modified for military use. At the same time, the technology is tangible, with detectability during transport being relatively high. Moving the technology is challenging but feasible. The technology is potentially distinguishable from other military technologies.
Deployment	The ease with which this technology can be deployed	Medium	This technology requires fairly sophisticated infrastructures, weapon platforms and/or enablers - but potentially modification of existing technologies is possible. Deployment of this technology further requires advanced technical knowledge.
Employment	The ease with which this technology can be employed	Medium	Employing this technology requires some organizational and/or doctrinal changes. Alternatively, or in addition, states can be disincentivized to employ this weapon.

Figure 7. Radar chart plotting the assessment of dual-capable missiles



Missile defense

This section considers missile defense systems that defend against strategic and theater missile threats, such as the US Ground-Based Midcourse Defense system and Russian A-135 system defending against ICBMs; and the US Aegis SM-3 interceptors and THAAD, Russian S-400, and Israeli Arrow systems defending against medium-range missiles. As with dual-capable C3I and missiles, missile defense is not an emerging technology, yet the current geopolitical context renders these systems increasingly relevant for strategic stability.

Production: material inputs, infrastructure, expertise and skills, testing core technology

The development of missile defense systems requires highly advanced expertise and skills, with key challenges including discrimination and optimal communication between radars and interceptors. Testing of the US Aegis Ballistic Missile Defense – a system in an advanced stage of development – is exemplary: five tests conducted in 2019 successfully intercepted ballistic missile and cruise missile targets, but also demonstrated the need to improve inter-element coordination and interoperability. Moreover, not all threats were addressed in flight testing and models and simulations: a lack of validation data from live fire raid engagements and a lack of post-intercept debris modeling have stalled raid performance tests.[317] Other threats, such as hypersonic missiles and swarming techniques, similarly pose obstacles to effective missile defense systems. Developments to counter such threats are in full swing. For instance, Russia is currently working on the S-500 to protect strategic nuclear sites from hypersonic missiles. Meanwhile, the modernization of the A-135 missile defense system, as well as the S-400, is to protect Russian military and political leadership from ballistic missiles and non-nuclear boost-glide vehicles.[318] Finally, researching and developing missile defense capabilities is extremely expensive. For instance, the requested US budget to bolster its missile defense capabilities is $20.4 billion for fiscal year 2022 and costs are set to rise over the next few years.[319]

Given the sophisticated skills, vast material inputs, and enormous costs associated with the development of missile defense systems, the likelihood of such systems to be produced is assessed to be **low**.

317 Ronald O'Rourke, "Navy Aegis Ballistic Missile Defense (BMD) Program: Background and Issues for Congress" (Washington D.C.: Congressional Research Service, August 23, 2021), 20–21, https://fas.org/sgp/crs/weapons/RL33745.pdf.

318 Alexey Arbatov et al., "Entanglement: Chinese and Russian Perspectives on Non-Nuclear Weapons and Nuclear Risks" (Washington D.C.: Carnegie Endowment for International Peace, November 8, 2017), 30, https://carnegieendowment.org/2017/11/08/entanglement-chinese-and-russian-perspectives-on-non-nuclear-weapons-and-nuclear-risks-pub-73162.

319 John Harper, "Pentagon Requesting Boost in R&D Funding to Compete with China," National Defense, May 28, 2021, https://www.nationaldefensemagazine.org/articles/2021/5/28/pentagon-requesting-boost-in-rd-funding-to-compete-with-china.

Proliferation: dual-use nature, tangibility, distinguishability

Missile defense is a strictly military technology with very few dual-use components. Most of its crucial components are tangible, with some exceptions such as discrimination and interception algorithms. While moving missile defense technology is complex, given its size, most of its components are thus detectable. Finally, missile defense hardware overlaps with offensive missile technologies. Altogether, the likelihood of missile defense systems to proliferate is **low.**

Deployment: infrastructure, platform requirements, deployment skills

The deployment of missile defense systems requires a globally-integrated network of sensors, interceptors, and command and control centers. For example, the American GMD system deployed in Alaska and California relies on ground- and space-based sensors for detection, tracking and discrimination, including launch detection satellites, the COBRA DANE radar in Alaska, early-warning radars in California, Greenland and the United Kingdom, forward-based X-band radars in Japan, Aegis BMD destroyers, and a Sea-Based X-band radar in the Pacific Ocean.[320]

Missile defense systems that target medium-range missiles (theater missile defense) also rely on complex support infrastructures and platforms. Systems like the S-400 have limited fire control radars; hence they need to be placed on high masts or, better, airborne warning and control aircraft systems (AWACS) or aerostats. The fuel and maintenance costs of an AWACS fleet is significant, while also networking the information acquired by radars to missile interceptors is complex, susceptible to failure and very costly. In fact, "the total systems cost of deploying an effective integrated aerospace defense is likely to be many times the procurement and maintenance costs of the S-400 system."[321]

Strong international norms cautioning against their use are also absent

Finally, the deployment of missile defense systems is complex and requires specialized skills. Therefore, when countries such as India buy S-400 systems from Russia, a team from the Indian Air Force is being trained in Moscow.[322]

The effective use of missile defense systems hence requires highly sophisticated infrastructures and enablers, such as early warning satellites or AWACS. The deployment of this technology further requires highly advanced technical knowledge. As a result, the ease with which missile defense systems can be deployed is considered **low**.

320 U.S. Department of Defense, "Missile Defense Review" (Washington D.C.: Department of Defense, 2019), 42, https://www.defense.gov/Portals/1/Interactive/2018/11-2019-Missile-Defense-Review/The%202019%20MDR_Executive%20Summary.pdf.

321 Peter A. Wilson and John V. Parachini, "Russian S-400 Surface-to-Air Missile System: Is It Worth the Sticker Price?," The RAND Blog, May 6, 2020, https://www.rand.org/blog/2020/05/russian-s-400-surface-to-air-missile-system-is-it-worth.html.

322 Peter Suciu, "India Wants Russia's Killer S-400 Air Defense System ASAP," *The National Interest* (blog) (The Center for the National Interest, April 29, 2021), https://nationalinterest.org/blog/buzz/india-wants-russias-killer-s-400-air-defense-system-asap-183986.

Employment: organization, doctrine, norms

No significant organizational changes or adjustments in war-fighting doctrines are required to employ missile defense. Today, strong international norms cautioning against their use are also absent, even if this has not always been the case. In the past, limiting missile defense was thought to be instrumental in "restraining the nuclear arms race,"[323] because such systems would undermine the stabilizing logic of mutual assured destruction.[324] Nowadays, such normative and strategic concerns are largely absent (even if slowing coming back) and missile defense is often seen as contributing to arms control.[325] Without the need for significant organizational or doctrinal changes, and absent broadly-shared disincentives, the ease with which missile defense systems can be employed is thus considered **high**.

Assessment missile defense

Missile defense requires significant material inputs, high levels of technical expertise, extensive financing, sophisticated infrastructures, and advanced enablers, which make it unlikely for this technology to be easily produced and deployed. The difficulties in transportation as well as the overlap with offensive missile technology contribute significantly to curb its risk of proliferation. Nonetheless, virtually no obstacles related to organizational and doctrinal changes or international norms currently prevent the employment of missile defense. Table 12 summarizes the assessment, while Figure 8 plots it across a radar chart.

323 "Missile Defense and the ABM Treaty" (SIPRI, June 2001), https://www.sipri.org/sites/default/files/files/FS/SIPRIFS0106.pdf.

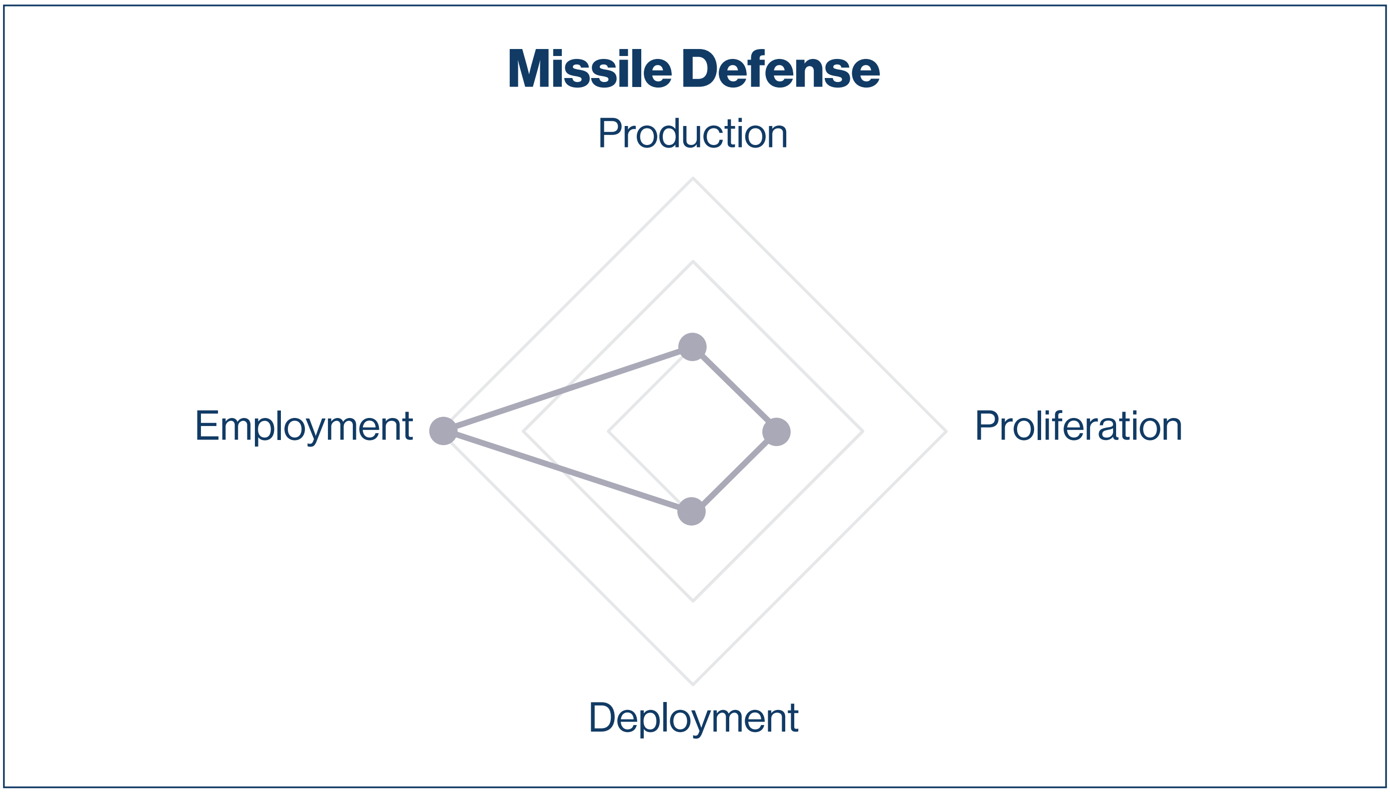
324 Igor Ivanov, "The Missile-Defense Mistake: Undermining Strategic Stability and the ABM Treaty," *Foreign Affairs* 79, no. 5 (2000): 15–20, https://doi.org/10.2307/20049885.

325 Robert Soofer, "Missile Defense Is Compatible with Arms Control," War on the Rocks, April 29, 2021, http://warontherocks.com/2021/04/missile-defense-is-compatible-with-arms-control/.

Table 12. Assessment of missile defense across the production-proliferation-deployment-employment chain

Phase		Criteria	
Production	Feasibility of this technology to be produced	Low	Material inputs for missile defense are rare and expensive. Moreover, the technology extremely complex, requiring highly advanced skills and discrete specialized knowledge. Weaponizing and testing the technology in relevant environments is highly challenging.
Proliferation	Likelihood of this technology to proliferate	Low	Few if any commercial applications of this technology exist, complicating their modification for military use. The technology is tangible however, with detectability during transport being relatively high. Moving the technology is challenging. The technology is largely distinguishable from other military technologies.
Deployment	The ease with which this technology can be deployed	Low	This technology requires highly sophisticated and novel infrastructures, weapon platforms and/or enablers. Existing technologies cannot be modified. Deployment requires highly advanced technical knowledge.
Employment	The ease with which this technology can be employed	High	Existing organizational structures and warfighting doctrines allow for the employment of this technology. States are not strongly disincentivized to employ this weapon.

Figure 8. Radar chart plotting the assessment of missile defense



Offensive cyber capabilities

Offensive cyber capabilities with a potential impact on strategic stability may target either critical national infrastructure (CNI)[326] or high-value military and operational infrastructures, with the targeting of nuclear assets (such as satellites used for nuclear communication) particularly relevant for strategic stability. The second category includes a counterspace capability (which has not been discussed in the section on ASATs), whereby cyber operations may target satellites.

Production: material inputs, infrastructure, expertise and skills, testing core technology

Off-the-shelf exploits can be accessed relatively easily

The preparation and conduct of offensive cyber operations which could potentially trigger nuclear escalation involves "painstaking work that involves identifying a platform in another country, gaining access, and then remaining undetected, often for years, inside the system."[327] These operations include advanced evasion and persistence techniques, and may take years of preparation, as is demonstrated by the operation against the Natanz nuclear facility in 2010. The development of the Stuxnet weapon, for which the planning began in the early 2000s, was a joint effort by the NSA and Israeli 8200 unit. Testing involved Libyan P-1 centrifuges confiscated in 2003 and the Israeli Dimona complex, while Siemens and the Idaho National Laboratory identified ICS vulnerabilities.[328] Moreover, the malware was even tested "against mock-ups of the next generation of centrifuges the Iranians were expected to deploy, called IR-2s, and successor models, including some the Iranians still are struggling to construct."[329]

Cyber operations against CNI are typically more straightforward. Many CNI include older technology while knowledge of the systems typically used in CNIs – such as Industrial Control Systems (ICS) and Supervisory Control and Data Acquisition (SCADA) – has spread widely in recent years. CNI vulnerabilities and off-the-shelf exploits can be accessed relatively easily.[330] That said, the utility of offensive cyber capabilities drastically decreases after they are being put to use, hampering their spread.[331] In fact, the need for constant reinvestment – in case a vulnerability is patched - and continuous development and testing significantly limits the number of actors capable (and willing) of producing these weapons against CNI. Cooperation between countries, but also among national organizations, is contingent on a

326 Defined as the physical or virtual systems, assets, facilities, processes and networks, "the loss or compromise of which could result in major detrimental impact on the availability, integrity or delivery of essential services and/or significant impact on national security, national defense, or the functioning of the state," Centre for the Protection of National Infrastructure, "Critical National Infrastructure," Centre for the Protection of National Infrastructure, April 20, 2021, https://www.cpni.gov.uk/critical-national-infrastructure-0.

327 Sue Halpern, "How Cyber Weapons Are Changing the Landscape of Modern Warfare," The New Yorker, July 18, 2019, https://www.newyorker.com/tech/annals-of-technology/how-cyber-weapons-are-changing-the-landscape-of-modern-warfare.

328 Jon R. Lindsay, "Stuxnet and the Limits of Cyber Warfare," *Security Studies* 22, no. 3 (2013): 365–404, https://doi.org/10.1080/09636412.2013.816122.

329 David E. Sanger, *Confront and Conceal: Obama's Secret Wars and Surprising Use of American Power* (New York: Random House, Inc., 2012), 198, https://www.belfercenter.org/publication/confront-and-conceal-obamas-secret-wars-and-surprising-use-american-power.

330 Hamid Jahankhani et al., eds., *Cyber Defence in the Age of AI, Smart Societies and Augmented Humanity*, Advanced Sciences and Technologies for Security Applications (Cham: Springer International Publishing, 2020), 9, https://doi.org/10.1007/978-3-030-35746-7.

331 Max Smeets, "A Matter of Time: On the Transitory Nature of Cyberweapons," *Journal of Strategic Studies* 41, no. 1–2 (February 23, 2018): 6–32, https://doi.org/10.1080/01402390.2017.1288107.

mutual understanding of timing, target, and proportionality. Indeed, "the paradox of cyber-weapons is that, although technically they can be (relatively) effortlessly replicated, their transitoriness changes the incentive structure of actors and turns weapons into indivisible goods."[332] Nonetheless, investments in military cyberspace activities, including offensive ones, are constantly increasing and several states pour substantial amount of money in this field every year. For instance, the US plans to invest $10.4 billion in military cyberspace activities in fiscal year 2022.[333]

When it comes to offensive cyber operations against nuclear military assets, there is no singular assessment of the technological feasibility.[334] At one end of the spectrum, it has been argued that these systems are hackable, with some even contending that unauthorized launches can be conducted.[335] At the other end of the range, it has been said that nuclear systems are virtually impenetrable.[336] More nuanced assessments would likely agree that while nuclear C3I systems "are likely secure against less capable actors with limited capabilities (e.g., non-state actors and states that rely on off-the-shelf malware), their capacity to defend themselves against a determined and well-resourced state actor is more uncertain."[337] When it comes to cyberattacks against nuclear delivery systems, it is again hard to pinpoint the exact technological feasibility. Yet, the joint US-Israeli Stuxnet virus directed at the Iranian Nuclear program in 2010, as well as reported efforts against North Korean missiles, reveal that such attacks against military assets are possible.[338]

Conducting large-scale offensive cyber operations against CNI or high-value military infrastructures thus requires vast resources and a highly skilled team of engineers and IT security experts, with the need for material inputs contingent upon the target. As a rule of thumb, production complexity increases as the attack becomes more sophisticated – assuming advanced states present targets that are continually updating their defenses.[339] The feasibility to produce an offensive cyberattack capability is therefore estimated to be **medium**, with the most sophisticated attacks against well-guarded infrastructure likely limited to a very small set of states.

332 Smeets, 26–27.

333 Harper, "Pentagon Requesting Boost in R&D Funding to Compete with China."

334 Wasson and Bluesteen, "Taking the Archers for Granted."

335 Julian Borger, "Nuclear Weapons Risk Greater than in Cold War, Says Ex-Pentagon Chief," The Guardian, January 7, 2016, http://www.theguardian.com/world/2016/jan/07/nuclear-weapons-risk-greater-than-in-cold-war-says-ex-pentagon-chief; Andrew Futter, "Hacking the Bomb: Cyber Threats and Nuclear Weapons," accessed June 21, 2021, https://www.amazon.com/Hacking-Bomb-Threats-Nuclear-Weapons/dp/1626165645; Robert Burns, "Former US Commander: Take Nuclear Missiles off High Alert," *AP NEWS*, April 29, 2015, sec. Archive, https://apnews.com/article/2ae0a33fa1c7402999afb6d55046e2cc.

336 Matt Caylor, "The Cyber Threat to Nuclear Deterrence," War on the Rocks, February 1, 2016, https://warontherocks.com/2016/02/the-cyber-threat-to-nuclear-deterrence/; John Reed, "Keeping Nukes Safe from Cyber Attack," *Foreign Policy* (blog), September 25, 2012, https://foreignpolicy.com/2012/09/25/keeping-nukes-safe-from-cyber-attack/.

337 Wasson and Bluesteen, "Taking the Archers for Granted," 345; "Resilient Military Systems and the Advanced Cyber Threat," Task Force Report (Washington D.C., U.S.: Department of Defense, January 2013), https://nsarchive2.gwu.edu/NSAEBB/NSAEBB424/docs/Cyber-081.pdf.

338 David E. Sanger and William J. Broad, "Trump Inherits a Secret Cyberwar Against North Korean Missiles," *The New York Times*, March 4, 2017, sec. World, https://www.nytimes.com/2017/03/04/world/asia/north-korea-missile-program-sabotage.html; Martin Chulov, "Israel Appears to Confirm It Carried out Cyberattack on Iran Nuclear Facility," *The Guardian*, April 11, 2021, sec. World news, http://www.theguardian.com/world/2021/apr/11/israel-appears-confirm-cyberattack-iran-nuclear-facility.

339 Dale Peterson, "Offensive Cyber Weapons: Construction, Development, and Employment" 36, no. 1 (2013): 120–24.

Proliferation: dual-use nature, tangibility, distinguishability

Crucially, cyber is an omni-use (even more so than a dual-use) technology, meaning that it "could be used for a range of purposes simultaneously, from improvements in healthcare and infrastructure to exceptionally efficient surveillance and military operations".[340] Distinguishing between legitimate activities such pentesting and offensive operations is therefore complex. To illustrate, the addition of intrusion software in the Wassenaar Arrangement in 2013 fell short because it hampered the sharing of vulnerabilities among security researchers.[341] Furthermore, cyber technology's intangibility and movability further complicates efforts to control their proliferation. The likelihood of offensive cyber capabilities to proliferate is therefore considered **high**.

Deployment: infrastructure, platform requirements, deployment skills

Cyber technology's intangibility and movability further complicates efforts to control their proliferation

Deploying offensive cyber capabilities poses a range of challenges, such as developing the means to deliver the weapon to the target, potentially through human agents,[342] and maintaining communication with a deployed cyber weapon.[343] Indeed, at times malware is only activated months or years after entering the systems. The intelligence requirements cannot be overemphasized.[344] As a result, it can be said that the effective deployment of offensive cyber capabilities of a level and time scale relevant for strategic stability is highly contingent upon support infrastructures, including intelligence and delivery mechanisms, such as human agents. The years-long preparation of the Stuxnet operation included planners with expertise in computer science, ICS and nuclear engineering; highly skilled program managers, operational planners, and commanders overseeing the planning, financing, and monitoring; and finally human agents to insert the malware.[345] Therefore, though the costs are probably lower than for most physical systems, the ease of deployment is assessed to be **low**.

Employment: organization, doctrine, norms

Executing a highly complex offensive cyber operation against high-value civilian or military targets necessitates some doctrinal and organizational changes. Over the last decade, countries have taken significant steps to include the cyber domain into their military structures. Military doctrines and rules of engagement have been adopted to govern the use of offensive cyber capabilities, with various countries including the United States, the United Kingdom, Canada, Australia, France, Germany and the Netherlands developing the tools and legislations to enable offensive cyber operations.[346] Moreover, restrictions to their use have been eased. While cyberattacks in the United States first needed approval from the president, these requirements have been eased (the specificities of which are unknown) amid concerns over crucial delays undermining the effectiveness of operations.[347] Finally, the use of offen-

340 Brigitte Dekker and Maaike Okano-Heijmans, "The US–China Trade–Tech Stand-Off," n.d., 9.

341 Adam Segal, "Using Incentives to Shape the Zero-Day Market," Cyber Brief (Council on Foreign Relations, September 2016), https://www.cfr.org/report/using-incentives-shape-zero-day-market.

342 Christian Leuprecht, Joseph Szeman, and David B. Skillicorn, "The Damoclean Sword of Offensive Cyber: Policy Uncertainty and Collective Insecurity," *Contemporary Security Policy* 40, no. 3 (2019): 382–407, https://doi.org/10.1080/13523260.2019.1590960.

343 Peterson, "Offensive Cyber Weapons: Construction, Development, and Employment."

344 Lindsay, "Stuxnet and the Limits of Cyber Warfare."

345 Lindsay, 385.

346 Leuprecht, Szeman, and Skillicorn, "The Damoclean Sword of Offensive Cyber."

347 Halpern, "How Cyber Weapons Are Changing the Landscape of Modern Warfare."

sive cyber operations could be discouraged due to its potential for indiscriminate effects for civilians if aimed at CNI or nuclear infrastructure.[348]

The institutional infrastructure required to conduct offensive cyberattacks is thus substantive, and largely novel. Military doctrines similarly need adjustments to include cyber warfare, while normative disincentives – though still in the early stages compared to more established technologies - may further complicate use. The ease of employing strategic offensive cyber capabilities is thus **medium**.

Assessment cyber operations

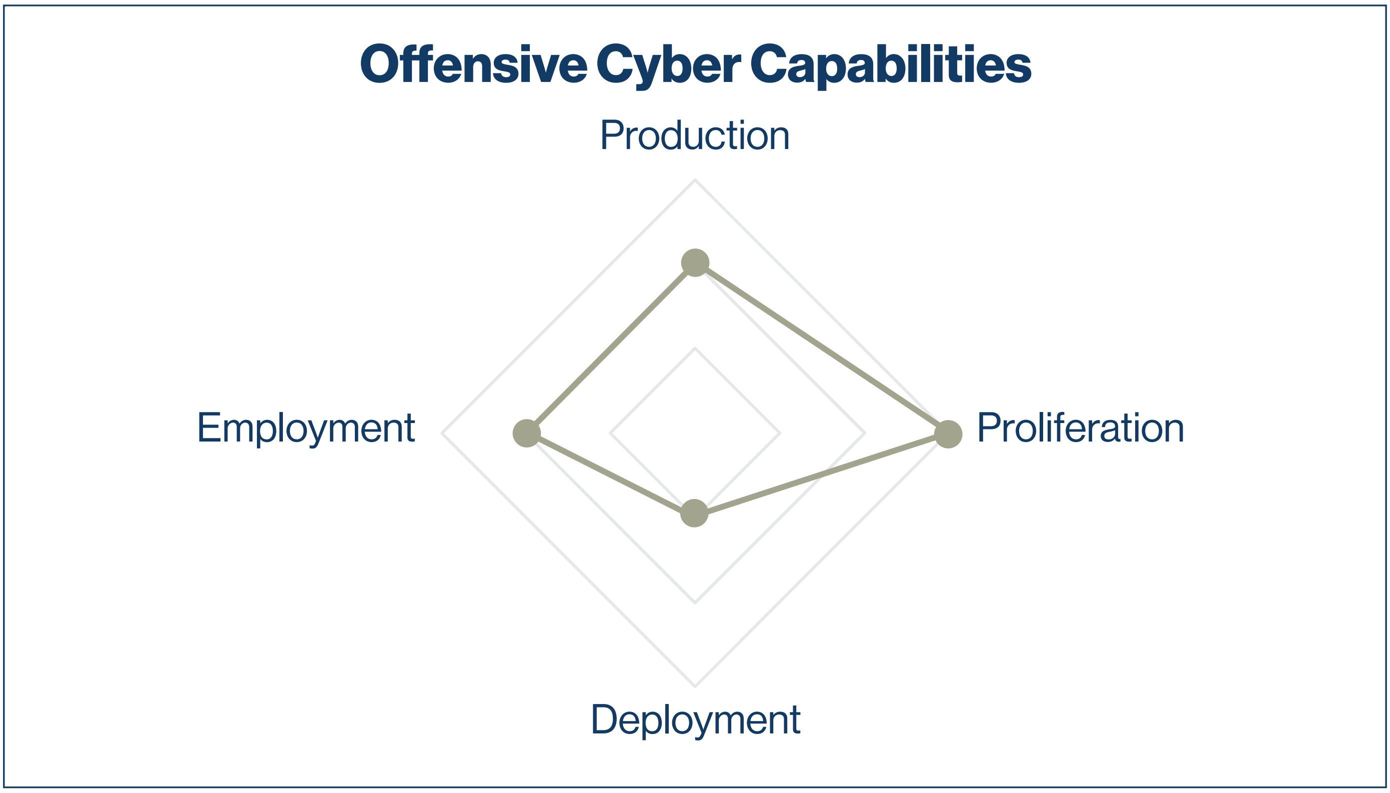
While producing, deploying, and employing offensive cyber capabilities is not easy, their proliferation is likely. Highly sophisticated skills and infrastructures are involved in the production and deployment of cyber capabilities, and military doctrines and organizations require significant changes to adapt to the use of cyber capabilities. Meanwhile, the dual-use nature, intangibility, and high moveability of this technology contribute to make proliferation extremely likely, as shown in Table 13 and plotted in Figure 9.

348 Max Smeets, "Integrating Offensive Cyber Capabilities: Meaning, Dilemmas, and Assessment," *Defence Studies* 18, no. 4 (October 2, 2018): 395–410, https://doi.org/10.1080/14702436.2018.1508349.

Table 13. Assessment of offensive cyber capabilities across the production-proliferation-deployment-employment chain

Phase		Criteria	
Production	Feasibility of this technology to be produced	Medium	Material inputs for offensive cyber capabilities are accessible and relatively inexpensive, yet the technology is complex, requiring advanced skills and specialized knowledge that is fairly discrete. Weaponizing and testing the technology in relevant environments can be challenging.
Proliferation	Likelihood of this technology to proliferate	High	Commercial applications of this technology exist and can be modified for military use. The technology is intangible, therefore detectability during transport is low while its movability is generally high. The technology is not necessarily distinguishable from other military technologies.
Deployment	The ease with which this technology can be deployed	Low	This technology requires highly sophisticated and novel infrastructures, weapon platforms and/or enablers. Existing technologies cannot be modified. Deployment requires highly advanced technical knowledge.
Employment	The ease with which this technology can be employed	Medium	Employing this technology requires significant organizational and doctrinal changes. States are strongly disincentivized to employ this weapon.

Figure 9. Radar chart plotting the assessment of offensive cyber operations



Lethal autonomous weapon systems

Lethal autonomous weapon systems (LAWS) are autonomy-enhanced weapons capable of identifying, selecting, and engaging targets without human interference. This can be of particular use in operating environments where communications are severed or limited, and where traditional weapons systems struggle to operate.[349] There are various ways in which LAWS are expected to undermine strategic and crisis stability. First, autonomy allows for resilient and simultaneous attacks that are overwhelming and difficult to defend against.[350] Such systems' potential use against adversaries' retaliatory capabilities, including nuclear C3I and nuclear-weapon delivery systems, could incentivise states to attack pre-emptively.[351] Additionally, LAWS can be used in leadership decapitation maneuvers. While targeted killings have been carried out mainly in counterterrorism efforts, LAWS could significantly facilitate these operations, potentially expanding leadership decapitation strategies to target state actors.[352] Second, LAWS attacks would require extremely rapid, AI-enabled responses, spurring risks of unintended escalation as outcomes of algorithm interactions, especially if human control is removed, are unforeseeable.[353]

Production: material inputs, infrastructure, expertise and skills, testing core technology

Raw materials used in LAWS are fairly inexpensive and accessible.[354] Moreover, autonomy-relevant technology can be acquired in the commercial sector, rendering military research associated to these weapons less costly than for other technologies.[355] For instance, the price of light detection and ranging (LIDAR) systems used in the automotive sector for automated systems has dropped dramatically.[356]

Despite these cost-related advantages, the production of LAWS is complex due to the need for highly advanced algorithms and onboard computational efficiency. Autonomous targeting requires various capabilities that need to work seamlessly, including pattern recognition, label matching, data classification and the training routines that ultimately guide action based on sensed inputs.[357] Interpretation of battlefield complexity, with significant differences in

349 Kelley M. Sayler, "International Discussions Concerning Lethal Autonomous Weapon Systems" (Washington D.C.: Congressional Research Service, 2021), https://fas.org/sgp/crs/weapons/IF11294.pdf.

350 Altmann and Sauer, 'Autonomous Weapon Systems and Strategic Stability,' 130-131.

351 Burgess Laird, "The Risks of Autonomous Weapons Systems for Crisis Stability and Conflict Escalation in Future U.S.-Russia Confrontations," June 3, 2020, https://www.rand.org/blog/2020/06/the-risks-of-autonomous-weapons-systems-for-crisis.html.

352 Michael Carl Haas and Sophie-Charlotte Fischer, "The Evolution of Targeted Killing Practices: Autonomous Weapons, Future Conflict, and the International Order," *Contemporary Security Policy* 38, no. 2 (May 4, 2017): 281–306, https://doi.org/10.1080/13523260.2017.1336407.

353 Altmann and Sauer, "Autonomous Weapon Systems and Strategic Stability."

354 Coley Felt, "Autonomous Weaponry: Are Killer Robots in Our Future?," *The Henry M. Jackson School of International Studies* (blog), February 14, 2020, https://jsis.washington.edu/news/autonomous-weaponry-are-killer-robots-in-our-future/.

355 Thomas E. Ricks, "Weapons Autonomy Is Rocketing," *Foreign Policy* (blog), September 28, 2016, https://foreignpolicy.com/2016/09/28/weapons-autonomy-is-rocketing/.

356 "Velodyne Lidar Introduces Solid State Sensor for Autonomous Mobile Robotics and Last-Mile Delivery," *Velodyne Lidar* (blog), December 10, 2020, https://investors.velodynelidar.com/news-releases/news-release-details/velodyne-lidar-introduces-solid-state-sensor-autonomous-mobile/.

357 Paddy Walker, "Leadership Challenges from the Deployment of Lethal Autonomous Weapon Systems," *RUSI* 166, no. 1 (2021): 10–21, https://doi.org/10.1080/03071847.2021.1915702.

operational environments, is still extremely challenging.[358] Algorithms rely on data input, extensive expertise and computing power (see the AI section). Access to relevant data, both in quantitative and qualitative terms, is limited to major military powers with extensive information technology infrastructures. Expertise is scarce, with commercial industries typically outbidding military ones.[359] Moreover, the semiconductor chips that are used to run computation and training algorithms are extremely capital-intensive, requiring highly specialized machinery.[360] It should be noted that LAWS still face issues with hardware, including heavy power sources and batteries of short durability.[361] Finally, due to the lower acceptance of risks when it comes to autonomous systems, technological barriers including operational malfunctioning or countermeasures, such as hacking and spoofing efforts, need to be solved.[362]

Expertise is scarce, with commercial industries typically outbidding military ones

As the section on AI will further highlight, barriers to testing further complicate the production of LAWS. Military operational environments are hard to predict and adversarial, while slight changes in settings can already vastly undermine a system's effectiveness.[363] For instance, commercial LIDAR sensors need to be adjusted to operate under highly unfavorable conditions and to achieve signature reduction.[364] That said, simple LAWS can be built and tested with relative ease using commercial applications of machine learning: "A determined militant group or nation-state could mount a machine gun on a tracked vehicle, connect a heat sensor and write software code such that the machine gun will fire at anything that has the heat signature of a human being. While such a system would be indiscriminate and violate the Law of War in nearly all use cases, it is buildable today."[365] These systems are, however, unlikely to be of significance to crisis or strategic stability.

Although no state has officially developed a LAWS yet, developments are gathering pace.[366] The United States and Israel are frontrunners in LAWS research and development[367] but Chinese and Russian manufacturers have also been developing systems capable of autonomous target identification and possibly engagement.[368]

358 Stephanie Carvin, "Normal Autonomous Accidents: What Happens When Killer Robots Fail?," Working Paper (Ontario: Carleton University, March 1, 2017), https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3161446.

359 M.L. Cummings, "Artificial Intelligence and the Future of Warfare," Research Paper (London: Chatham House: The Royal Institute of International Affairs, January 2017), https://www.chathamhouse.org/sites/default/files/publications/research/2017-01-26-artificial-intelligence-future-warfare-cummings-final.pdf.

360 Michaela D Platzer, John F Sargent Jr, and Karen M Sutter, "Semiconductors: U.S. Industry, Global Competition, and Federal Policy," CRS Report (Washington D.C., US: Congressional Research Service, October 26, 2020), https://fas.org/sgp/crs/misc/R46581.pdf.

361 Vincent Boulanin and Maaike Verbruggen, "Mapping the Development of Autonomy in Weapon Systems" (Solna, Sweden: Stockholm International Peace Research Institute, November 2017), https://www.sipri.org/sites/default/files/2017-11/siprireport_mapping_the_development_of_autonomy_in_weapon_systems_1117_1.pdf.

362 Paul Scharre, *Army of None* (W.W. Norton & Company, 2018), https://wwnorton.com/books/Army-of-None/; Carvin, "Normal Autonomous Accidents: What Happens When Killer Robots Fail?"

363 Lucas Perry, "AI Alignment Podcast: On Lethal Autonomous Weapons with Paul Scharre," Future of Life Institute, accessed September 9, 2021, https://futureoflife.org/2020/03/16/on-lethal-autonomous-weapons-with-paul-scharre/; Altmann and Sauer, "Autonomous Weapon Systems and Strategic Stability."

364 Altmann and Sauer, "Autonomous Weapon Systems and Strategic Stability."

365 Horowitz, "When Speed Kills," 778.

366 Some experts have argued that the Israeli-produced Harpy, which has been described as an anti-radiation loitering munition system, is fully autonomous. Harpy has been exported by Israel to Chile, China, India, South Korea, and Turkey. Sayler, "International Discussions Concerning Lethal Autonomous Weapon Systems"; Scharre, *Army of None*; "Harpy Autonomous Weapon for All Weather," IAI, 2017, https://www.iai.co.il/p/harpy.

367 Altmann and Sauer, "Autonomous Weapon Systems and Strategic Stability."

368 Kelley M. Sayler, "Emerging Military Technologies: Background and Issues for Congress" (Washington D.C.: Congressional Research Service, November 10, 2020), https://fas.org/sgp/crs/natsec/R46458.pdf; Kyle Mizokami, "Kalashnikov Will Make an A.I.-Powered Killer Robot," Popular Mechanics, July 19, 2017, https://www.popularmechanics.com/military/weapons/news/a27393/kalashnikov-to-make-ai-directed-machine-guns/; Patrick Tucker, "SecDef: China Is Exporting Killer Robots to the Mideast," *Defense One* (blog), November 5, 2019, https://www.defenseone.com/technology/2019/11/secdef-china-exporting-killer-robots-mideast/161100/.

Altogether, it can be argued that the feasibility to produce long endurance strategic LAWS is **low,** at least for the foreseeable future. Even if raw materials are relatively cheap and developments in the commercial sector reduce costs, semiconductor chips are scarce and costly, while access to a vast body of high-quality data is equally challenging. Software algorithms extremely complex, requiring highly advanced skills and discrete specialized knowledge. Crucially, testing the technology in relevant environments is highly challenging.

Proliferation: dual-use nature, tangibility, distinguishability

LAWS technology includes both the platforms and the components that allow for autonomous targeting functions, such as hardware (actuators, sensors, processors), software programs and algorithms, and data.[369] With few exceptions, LAWS technology is dual-use. Hardware like sensors and electronics have been increasingly miniaturized to facilitate the transport of autonomous systems.[370] Yet, even if miniaturization increases the moveability, these hardware items, including processors, are very much tangible. Other enablers, such as software and training data are however intangible and easy to move.[371] Detectability and movability of LAWS components thus varies. Lastly, distinguishing LAWS from other military technology is extremely challenging, considering that "an outside observer cannot tell whether the weapon operates under predesigned rules or is being controlled remotely."[372]

Taking into account LAWS' reliance on dual-use hard- and software, the different levels of moveability and tangibility of LAWS components, and the challenges related to distinguishing LAWS from other military technologies, the likelihood of LAWS to proliferate is estimated to be **medium**.

Deployment: infrastructure, platform requirements, deployment skills

LAWS require the integration of a mobile combat platform, such as an unmanned aircraft, ship or ground vehicle; advanced sensors; processing systems to classify objects; and algorithms that direct an attack when a target has been discovered and classified as such.[373] Deployment requirements are dependent on the size of the platform: middle- and large-sized unmanned weapons systems require significant infrastructure and skills to be operated, limiting their deployment to major militaries, even if existing infrastructures and platforms can be adjusted.[374]

The ease with which LAWS can be deployed is thus **medium**. Depending on size, autonomous weapons systems require sophisticated weapon platforms and advanced technical knowledge, yet all LAWS are contingent on advanced enablers including sensors.

369 "LAWS and Export Control Regimes: Fit for Purpose?," Working Paper (Berlin: International Panel on the Regulation of Autonomous Weapons, April 2020), https://www.ipraw.org/wp-content/uploads/2020/04/iPRAW_WP_ExportControls.pdf.

370 Altmann and Sauer, "Autonomous Weapon Systems and Strategic Stability."

371 "LAWS and Export Control Regimes: Fit for Purpose?"

372 Zachary Kallenborn, "A Partial Ban on Autonomous Weapons Would Make Everyone Safer," *Foreign Policy* (blog), October 14, 2020, https://foreignpolicy.com/2020/10/14/ai-drones-swarms-killer-robots-partial-ban-on-autonomous-weapons-would-make-everyone-safer/.

373 Michael T. Klare, "Autonomous Weapons Systems and the Laws of War," *Arms Control Association* (blog), March 2019, https://www.armscontrol.org/act/2019-03/features/autonomous-weapons-systems-laws-war.

374 Boulanin and Verbruggen, "Mapping the Development of Autonomy in Weapon Systems," 79.

Employment: organization, doctrine, norms

The adoption of autonomy requires significant organizational and personnel changes in militaries, most dramatically because fully autonomous systems push humans out of the loop. Unsurprisingly, this requires large-scale organizational changes, notably in terms of personnel policies. Given that positions at the decision-making level are likely to be impacted, opposition from military elites can be expected.[375] Indeed, resistance is likely due to the loss of organizational autonomy that LAWS bring along. Military organizations strive to achieve and preserve autonomy and are thus unlikely to welcome systems which may jeopardize this.[376]

Military organizations strive to achieve and preserve autonomy and are thus unlikely to welcome systems which may jeopardize this

Legal and ethical constraints further complicate the use of LAWS. Beyond questions of responsibility and accountability,[377] adherence to principles of distinction, proportionality and precaution – set under international humanitarian law – is particularly complex, if not impossible, when militarizing autonomous systems. For instance, while the Israeli Harpy can identify a radar, it cannot determine whether it would be surrounded by civilians. Moreover, an autonomous system may find it hard to establish whether the collateral damage or civilian loss of life is excessive in relation the military advantage anticipated. When it comes to precaution, again "the type of assessments required to comply (…) are highly complex and very difficult to translate into an algorithmic form."[378] Finally, operational issues such as the potential for fratricide discourage the use of LAWS.[379]

Unsurprisingly, the ease with which LAWS can be employed is **low**. Employing autonomous weapons platforms requires significant organizational changes, and legal and ethical constraints further disincentivize their use.

Assessment LAWS

The feasibility to produce LAWS that are of strategic importance is low, thanks to constraints including the need for advanced algorithms, onboard computational efficiency and testing difficulties. The likelihood for LAWS to proliferate, and the ease with which they can be deployed, vary considerably according to different types of LAWS. Deployment difficulties similarly vary, with baseline requirements applying to all systems. Lastly, significant organizational and doctrinal changes hinder the employment of LAWS. Table 14 sums up the assessment of LAWS across the production-proliferation-deployment-employment chain, while Figure 10 plots it across a radar chart.

375 Boulanin and Verbruggen, 70–73.

376 Barry R. Posen, *The Sources of Military Doctrine : France, Britain, and Germany Between the World Wars* (Ithaca: Cornell University Press, 1984), 44–45, https://web-b-ebscohost-com.ezproxy.leidenuniv.nl/ehost/ebookviewer/ebook/ZTAwMHh3d19fODQzNzMxX19BTg2?sid=8542c7f7-2320-40a6-839f-c1a85f60638f@sessionmgr103&vid=0&format=EB&rid=1.

377 Ilse Verdiesen, Filippo Santoni de Sio, and Virginia Dignum, "Accountability and Control Over Autonomous Weapon Systems: A Framework for Comprehensive Human Oversight," *Minds and Machines* 31, no. 1 (March 1, 2021): 137–63, https://doi.org/10.1007/s11023-020-09532-9.

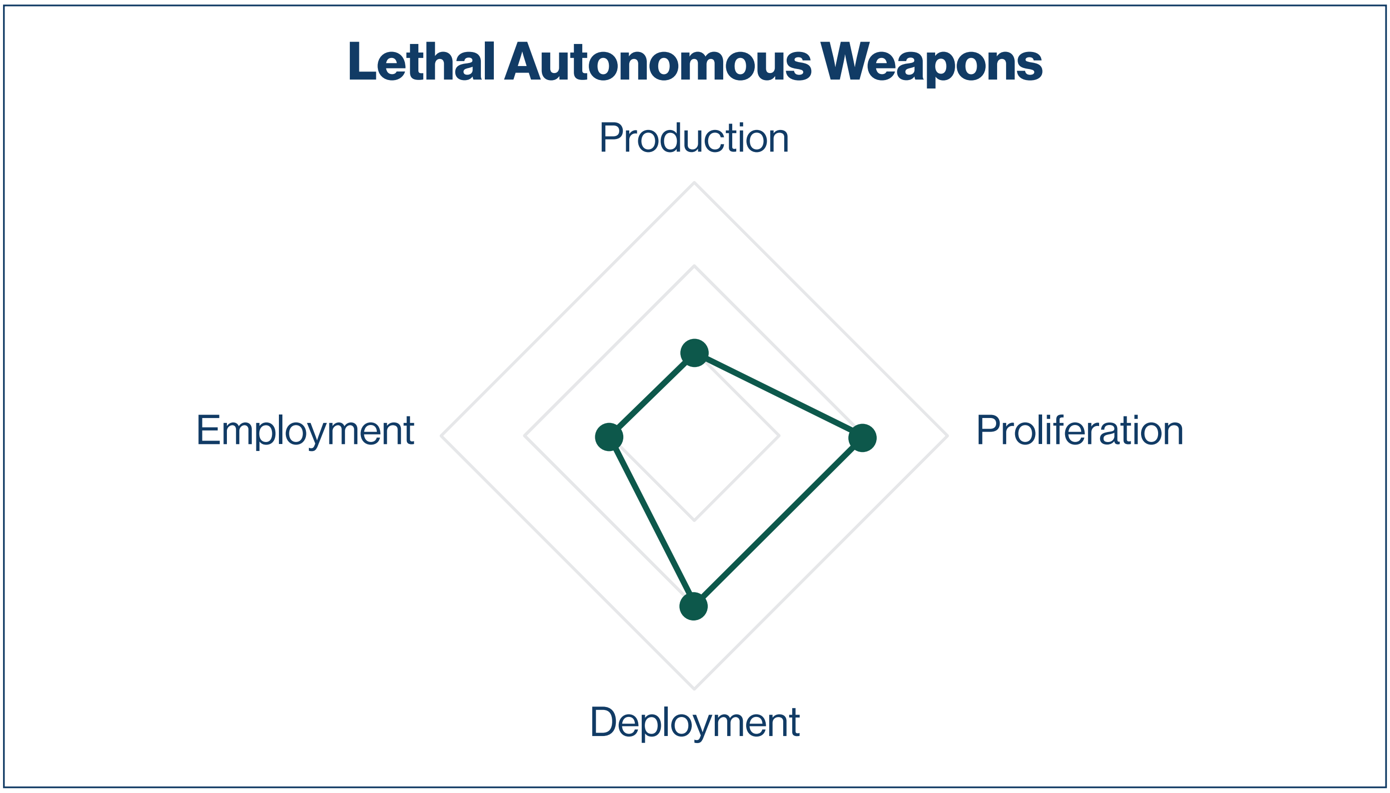
378 Boulanin and Verbruggen, "Mapping the Development of Autonomy in Weapon Systems," 74.

379 Altmann and Sauer, "Autonomous Weapon Systems and Strategic Stability."

Table 14. Assessment of lethal autonomous weapons across the production-proliferation-deployment-employment chain

Phase		Criteria	
Production	Feasibility of this technology to be produced	Low	Material inputs for LAWS are rare and expensive. Moreover, the technology extremely complex, requiring highly advanced skills and discrete specialized knowledge. Weaponizing and testing the technology in relevant environments is highly challenging.
Proliferation	Likelihood of this technology to proliferate	Medium	Commercial applications of this technology exist and can be modified for military use. At the same time, the technology is tangible, with detectability during transport being relatively high. Moving the technology is challenging but feasible. The technology is potentially distinguishable from other military technologies.
Deployment	The ease with which this technology can be deployed	Medium	This technology requires fairly sophisticated infrastructures, weapon platforms and/or enablers - but potentially modification of existing technologies is possible. Deployment of this technology further requires advanced technical knowledge.
Employment	The ease with which this technology can be employed	Low	Employing this technology requires significant organizational and doctrinal changes. States are strongly disincentivized to employ this weapon.

Figure 10. Radar chart plotting the assessment of lethal autonomous weapons



Remote sensing

Space-based remote sensing technologies include satellite automatic identification system (AIS), synthetic aperture radar (SAR), multispectral (MSP) and hyper-spectral (HSP) optical sensors, and global navigation satellite system reflectometry (GNSS-R). While not strictly an emerging technology, advances in the technology and rapid proliferation have far-reaching consequences, including the improved ability to find nuclear and conventional forces, increasing their potential effects on strategic stability.

Production: material inputs, infrastructure, expertise and skills, testing core technology

The production of various sensors, including hyperspectral, LIDAR, multispectral, thermal infrared and visual, are fairly advanced and increasingly well understood. Developing and testing remote sensing capabilities is relatively cheap, if compared to launching one's own satellite in space. Indeed, the data central to remote sensing are more accessible and less expensive than launching technologies. Some challenges remain, however. Despite enhanced capabilities of imaging systems enabled by multi-dimensional sensors, these systems still face obstacles such as target detection in complex environments that may cause recognition algorithms to mistake ground objects for target objects.[380] Remote sensing technology also faces the issue of preprocessing. The problem of low resolution presented by different remote sensing systems could however be solved by hyperspectral remote sensing data. Finally, the complexity of producing persistent remote sensing capacity lies with the integration into air- or space-based platform, the most important of which are small satellites and unmanned aerial vehicles (UAVs). Given these remaining challenges, and the need to produce the most sophisticated sensors and algorithms when using remote sensing for strategic purposes, the ease with which they can be produced is estimated to be **medium**.

Proliferation: dual-use nature, tangibility, distinguishability

Civilian or commercial applications of remote sensing are numerous, and include weather forecasting, terrestrial monitoring and natural research management (e.g. crop monitoring), or tracking changes in the earth's physical, biological and human environments (e.g. monitoring changes in sea ice).[381]

Space-based remote sensing capabilities that are particularly useful for ISR include optical imaging (visible light pictures), synthetic aperture radar (SAR, or 3D radar imagery) and electronic intelligence (ELINT, the monitoring of radio frequency signals). Indeed, while previously limited to larger powers, today a broad spectrum of smaller countries can acquire commercially available space-based optical, SAR and ELINT capabilities, or even

380 Z. Wu et al., "Rapid Target Detection in High Resolution Remote Sensing Images Using Yolo Model," *Space Engineering University* XLII–3 (2018): 1015–1920, https://doi.org/10.5194/isprs-archives-XLII-3-1915-2018.

381 "Enabling Wide Area Persistent Remote Sensing for Agriculture Applications by Developing and Coordinating Multiple Heterogeneous Platforms," UK Research and Innovation, accessed September 13, 2021, https://gtr.ukri.org/projects?ref=ST%2FN006852%2F1.; 940305.Pdf'

satellites.[382] Examples of commercially available remote sensing capabilities include optical sensors Pleiades and Worldview, and SAR sensors TerraSAR-X, TanDEM-X, COSMOS-Skymed, Radarset and Sentinel-1.[383] Similar to LAWS, the tangibility and moveability of remote sensing varies according to its components. Hardware components such as sensors and satellites are tangible, while software and data processing are intangible.

Given remote sensing's dual-use nature, its varying levels of tangibility and therein moveability and detectability during transport, the likelihood of this technology to proliferate is assessed to be **medium**.

Deployment: infrastructure, platform requirements, deployment skills

Various challenges remain unresolved, including battery life, limited area coverage, data processing and storage space

The effective deployment of remote sensors requires platforms, data processing capabilities and fairly advanced skills. The small satellites used for remote sensing are increasingly available to a rapidly growing number of countries and organizations. These small satellites are ever more capable, while also increasingly affordable, thanks to advances in the miniaturization of these platforms' technology and the availability of less costly commercial off-the-shelf parts.[384] Indeed, the miniaturization of electronics, optics and sensors has spurred the technological feasibility of small satellites, encouraging venture capital and defense industry investments.[385] Similarly, the costs of ground stations and launch services have fallen, the capabilities of signal processing have improved, while the omnipresent GPS allows for persistent location and attitude determination. UAVs too are an increasingly attractive platform for remote sensing capabilities, again thanks to advances in sensor miniaturization and other technological developments. That said, various challenges remain unresolved, including battery life, limited area coverage, data processing and storage space, among others.[386]

Due to SAR sensors' complex data structure, more sophisticated processing and training is required, especially when compared to optical sensors. Further, large image images sizes may cause some data exchange and storage issues, but solutions such as image compression are at hand.[387]

While platforms are increasingly available, remote sensing still requires fairly advanced skills and supporting infrastructures. Therefore, the ease with which remote sensing can be deployed is **medium**.

382 Jason Wang and Mark Matossian, "David vs Goliath: How Space-Based Assets Can Give Taiwan an Edge," *The Diplomat*, March 27, 2021, https://thediplomat.com/2021/03/david-vs-goliath-how-space-based-assets-can-give-taiwan-an-edge/.

383 Irmgard Niemeyer, Mona Dreicer, and Gotthard Stein, eds., *Nuclear Non-Proliferation and Arms Control Verification: Innovative Systems Concepts* (Cham: Springer International Publishing, 2020), 341, https://doi.org/10.1007/978-3-030-29537-0.

384 Jonathan R. Behrens and Bhavya Lal, "Exploring Trends in the Global Small Satellite Ecosystem," *New Space* 7, no. 3 (2019): 126, https://doi.org/10.1089/space.2018.0017.

385 Alyssa K King, "Small Satellite Boom Poses Challenges for Regulators" (Washington D.C., US: Congressional Research Service, January 7, 2020), https://fas.org/sgp/crs/space/IF11382.pdf.

386 Norzailawati Mohd Noor, Alias Abdullah, and Mazlan Hashim, "Remote Sensing UAV/Drones and Its Applications for Urban Areas: A Review," IOP Conference Series: Earth and Environmental Science (IOP Publishing, July 31, 2018), https://iopscience.iop.org/article/10.1088/1755-1315/169/1/012003/pdf.

387 Niemeyer, Dreicer, and Stein, *Nuclear Non-Proliferation and Arms Control Verification*.

Employment: organization, doctrine, norms

No significant changes in organizational structures and warfighting doctrines are required for the employment of remote sensing, nor are states strongly disincentivized to employ it. The ease with which remote sensing can be employed is therefore **high**.

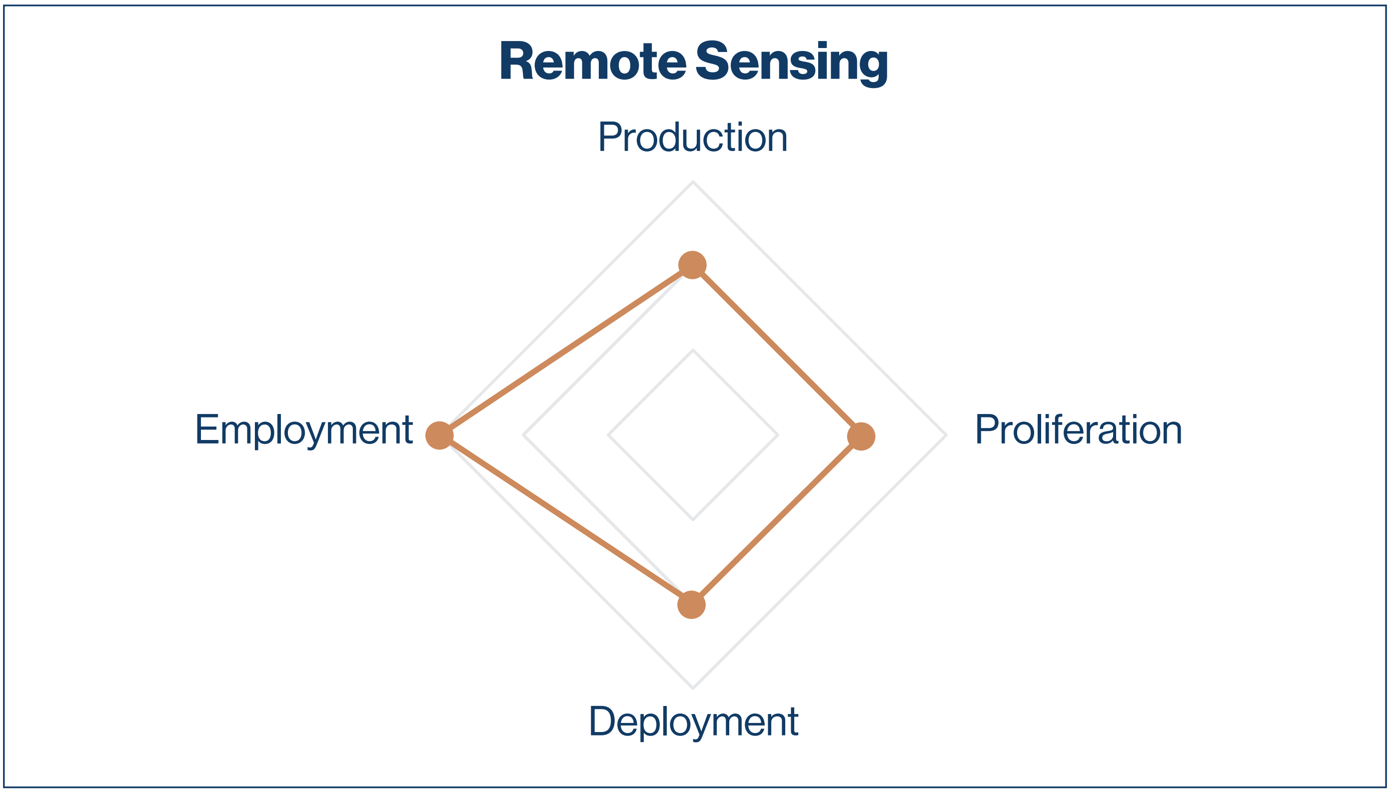
Assessment remote sensing

Remote sensing technologies can be produced quite easily, albeit with some difficulties related to preprocessing, low resolution, and integration into air- or space-based platforms. While remote sensing tools are likely to proliferate, moveability and detectability somewhat limit the proliferation of these technologies. Deployment is made easy by the availability of platforms but constricted by the need for advanced skills and supporting infrastructures. Existing organizational structures, warfighting doctrines, and international norms allow for this technology to be employed with ease. The assessment of remote sensing across the production-proliferation-deployment-employment chain is summarized in Table 15 and visualized in Figure 11.

Table 15. Assessment of remote sensing across the production-proliferation-deployment-employment chain

Phase		Criteria	
Production	Feasibility of this technology to be produced	Medium	Material inputs for persistent remote sensing are accessible and relatively inexpensive, yet the technology is complex, requiring advanced skills and specialized knowledge that is fairly discrete. Weaponizing and testing the technology in relevant environments can be challenging.
Proliferation	Likelihood of this technology to proliferate	Medium	Commercial applications of this technology exist and can be modified for military use. At the same time, the technology is tangible, with detectability during transport being relatively high. Moving the technology is challenging but feasible. The technology is potentially distinguishable from other military technologies.
Deployment	The ease with which this technology can be deployed	Medium	This technology requires fairly sophisticated infrastructures, weapon platforms and/or enablers - but potentially modification of existing technologies is possible. Deployment of this technology further requires advanced technical knowledge.
Employment	The ease with which this technology can be employed	High	Existing organizational structures and warfighting doctrines allow for the employment of this technology. States are not strongly disincentivized to employ this weapon.

Figure 11. Radar chart plotting the assessment of remote sensing



Artificial intelligence

Artificial intelligence (AI) is an enabling technology with a variety of military applications: it enables autonomy in military platforms such as tanks, planes and ships; it enhances data processing and interpretation processes; or it can optimize command and control, including battle management, whereby data is analyzed and used to direct human action or action by algorithms.[388] While states, for now, are generally reluctant to use AI-enabled autonomous systems carrying nuclear weapons, there are other ways in which AI could potentially undermine strategic stability. First strikes may be encouraged as AI-enabled disinformation undermines trust in intelligence.[389] Meanwhile, second-strike capabilities could be compromised as AI may potentially improve the tracking and targeting of submarines and enhance defense against nuclear attacks.[390] Finally, the machine speed of autonomous weapons systems could create crisis instability.[391]

Production: material inputs, infrastructure, expertise and skills, testing core technology

First strikes may be encouraged as AI-enabled disinformation undermines trust in intelligence

The production of AI relies on three key inputs: data, talent and computing power.[392] Machine learning is contingent on both the quantity and quality of data it is fed. Indeed, machine learning algorithms "are only as good as the data on which they are trained."[393] As a result, major military powers that maintain large arsenals of advanced sensors have a clear advantage. Talent is scarce, in some regions more than others, as the limited number of engineers with both solid software and hardware expertise is often drawn to the commercial sector.[394] Finally, AI requires hardware with advanced semiconductor chips at its core to run its computation and train algorithms. Competition in the semiconductor industry has been rising steeply, with countries ramping up efforts to secure supply.[395] Developing semiconductors requires highly specialized machinery, with distinct challenges in their design, production, and testing phases.[396] The costs are high: tens of billions of dollars are poured into R&D, while new semiconductor fabrication plants costs between $7 and $14 billion.[397] The research and development of American AI-related capabilities will be assigned $874 million in fiscal year 2022, if the budget is approved. While China also conspicuously invests in military AI venues, Russia has

388 Horowitz, "Artificial Intelligence, International Competition, and the Balance of Power," 22.

389 Favaro, "Weapons of Mass Distortion: A New Approach to Emerging Technologies, Risk Reduction, and the Global Nuclear Order."

390 Boulanin, "The Impact of Artificial Intelligence on Strategic Stability and Nuclear Risk"; Horowitz, "When Speed Kills"; Ulrike Franke, "Artificial Intelligence Diplomacy: Artificial Intelligence Governance as a New European Union External Policy Tool" (Luxembourg: European Parliament, June 2021), https://www.europarl.europa.eu/RegData/etudes/STUD/2021/662926/IPOL_STU(2021)662926_EN.pdf.

391 Horowitz, "When Speed Kills," 782.

392 Franke, "Artificial Intelligence Diplomacy: Artificial Intelligence Governance as a New European Union External Policy Tool."

393 Boulanin, "The Impact of Artificial Intelligence on Strategic Stability and Nuclear Risk," 12.

394 Cummings, "Artificial Intelligence and the Future of Warfare."

395 Leonardo Dinic, "US-China Competition – Semiconductors and the Future of Tech Supremacy," *China-US Focus* (blog), February 2, 2021, https://www.chinausfocus.com/foreign-policy/us-china-competition-semiconductors-and-the-future-of-tech-supremacy.

396 Platzer, Sargent Jr, and Sutter, "Semiconductors: U.S. Industry, Global Competition, and Federal Policy."

397 James A. Lewis, "Learning the Superior Techniques of the Barbarians: China's Pursuit of Semiconductor Independence," China Innovation Policy Series (Washington D.C.: Center for Strategic & International Studies, February 27, 2019), https://www.csis.org/analysis/chinas-pursuit-semiconductor-independence.

a military spending of only $12.5 million annually for AI-related projects.[398] The feasibility of testing AI capabilities varies according to the type of AI application.

Testing AI-enabled weapons is particularly challenging. Systems are not very robust to changes in environmental conditions, and changes in settings either undermine their effectiveness, or worse, cause unintended results such as civilian harm. While AI-enabled cars can be tested in both real life and through simulations, militaries do not get to test their weapons in actual operational environments. Besides, military operating conditions are hardly predictable, limiting simulation possibilities. A further layer of complexity is added because military contexts are necessarily antagonistic, with adversaries willfully undermining and manipulating one another's AI-enabled weapons systems. These factors render testing, and therefore production, especially challenging.[399]

Clearly, not all AI applications in the security and defense realm are equally challenging technologically speaking. Simple LAWS can be relatively easily built and improving military logistics should be fairly straightforward. AI applications with significant implications for strategic and crisis stability, such as the tracking and targeting of submarines, certainly require extensive resources and a high degree of technological expertise.[400] Testing AI-enabled weapons systems is particularly challenging. The feasibility to produce AI applications with effects for strategic stability is thus **low**.

Proliferation: dual-use nature, tangibility, distinguishability

Despite its variety in components, AI technology is without exception dual-use

Despite its variety in components – including hardware such sensors and processors (GPU, chips), software programs and algorithms, and data used for training and testing machine learning algorithms – AI technology is without exception dual-use. Crucially, civilian developments currently outpace military ones. The proliferation of AI is however limited by the large amount of computational power needed to develop cutting-edge technology in this field.[401] While AI can be overall described as "discreet and discrete,"[402] tangibility differs for its various subparts. Although algorithms are intangible and can proliferate quickly, this is not the case for processing power (GPU, chips) and the datasets necessary to develop algorithms. Clearly, detectability of these latter components is higher. Moveability similarly varies, depending on the components of AI taken into account. Considered altogether, the likelihood of AI to proliferate is therefore **medium**.

Deployment: infrastructure, platform requirements, deployment skills

The ease with which military AI can be deployed is highly dependent on its military applications, varying from logistics, cyber operations, and disinformation to autonomous weapons systems, swarming, and command and control.[403] Supporting military logistics through AI-enabled prediction of maintenance or AI-enhanced supply chains is fairly straightforward, requiring a limited set of sensory inputs. More complicated AI applications, including cyber

398 Haner and Garcia, 'The Artificial Intelligence Arms Race,' 333-334.

399 Perry, "AI Alignment Podcast: On Lethal Autonomous Weapons with Paul Scharre."

400 Horowitz, "When Speed Kills," 782.

401 Maas, "How Viable Is International Arms Control for Military Artificial Intelligence?," 6.

402 Maas, "How Viable Is International Arms Control for Military Artificial Intelligence?"

403 Franke, "Artificial Intelligence Diplomacy: Artificial Intelligence Governance as a New European Union External Policy Tool."

warfare and LAWS, are more dependent on highly sophisticated enablers, platforms and equally advanced deployment skills.[404] It should be added that for some deployment requirements, such as weapon launch platforms, existing systems can be adjusted.[405]

As a result, the ease with which AI can be deployed is considered **medium**. While varying broadly per military application, AI requires highly advanced sensors, potentially sophisticated infrastructures and weapon platforms, but occasionally modification of existing technologies is possible. Deployment of this technology further requires advanced and specialized technical knowledge.

Employment: organization, doctrine, norms

The extent to which AI will change military organizations will be significant, even if the specificities are still uncertain. Planning, doctrine, recruitment, and force structure will need readjusting. As Horowitz puts it: "What happens as militaries increasingly need soldiers who have training in coding and who understand how algorithms work? Or if swarming, uninhabited systems make large conventional military platforms seem costly and obsolete?"[406] Indeed, if fully implemented, AI is highly likely to be an organizationally disruptive innovation.

When it comes to specific applications of machine learning, such as AI-enabled autonomy, legal and ethical considerations pose significant barriers to employment (see the LAWS section for a more in-depth discussion). AI's use for the spread of disinformation equally faces moral barriers.[407]

The ease with which AI can be employed is assessed to be **low**. Employing AI-enabled weapons or other applications of AI that may undermine strategic stability such as disinformation require significant organizational changes, while legal and ethical constraints strongly disincentivise their use.

Assessment artificial intelligence

As summarized in Table 16 and Figure 12, the need for extensive resources and technological expertise limits the production of AI-enabled technologies that have significant effects on strategic stability. Commercial applications of AI do however render proliferation likely. Deploying AI weapons calls for fairly sophisticated infrastructures. Lastly, the employment of AI-enabled weapons that may undermine strategic stability requires significant organizational changes and raises several ethical concerns and it is thus not easily achievable.

404 Klare, "Autonomous Weapons Systems and the Laws of War."

405 Boulanin and Verbruggen, "Mapping the Development of Autonomy in Weapon Systems," 79.

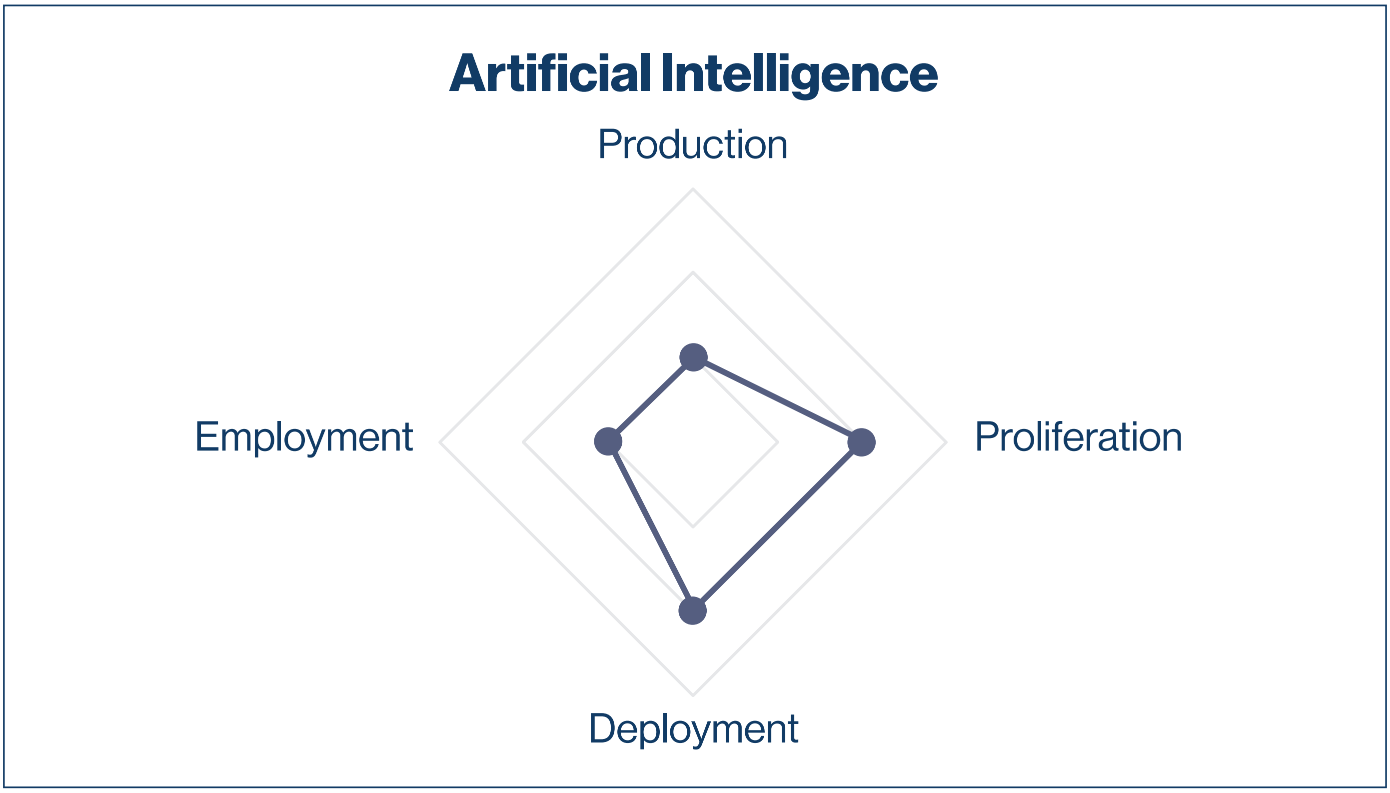
406 Horowitz, "Artificial Intelligence, International Competition, and the Balance of Power," 39.

407 Alex Hern, "New AI Fake Text Generator May Be Too Dangerous to Release, Say Creators," The Guardian, February 14, 2019, http://www.theguardian.com/technology/2019/feb/14/elon-musk-backed-ai-writes-convincing-news-fiction.

Table 16. Assessment of artificial intelligence across the production-proliferation-deployment-employment chain

Phase		Criteria	
Production	Feasibility of this technology to be produced	Low	Material inputs for AI are rare and expensive. Moreover, the technology extremely complex, requiring highly advanced skills and discrete specialized knowledge. Weaponizing and testing the technology in relevant environments is highly challenging.
Proliferation	Likelihood of this technology to proliferate	Medium	Commercial applications of this technology exist and can be modified for military use. At the same time, the technology is tangible, with detectability during transport being relatively high. Moving the technology is challenging but feasible. The technology is potentially distinguishable from other military technologies.
Deployment	The ease with which this technology can be deployed	Medium	This technology requires fairly sophisticated infrastructures, weapon platforms and/or enablers - but potentially modification of existing technologies is possible. Deployment of this technology further requires advanced technical knowledge.
Employment	The ease with which this technology can be employed	Low	Employing this technology requires significant organizational and doctrinal changes. States are strongly disincentivized to employ this weapon.

Figure 12. Radar chart plotting the assessment of artificial intelligence



Dual-capable C3I systems

Older and newer nuclear powers alike appear to increasingly rely on the integration of dual-capable command, control, communications and intelligence (C3I) assets, including satellites used for communication, early warning, and intelligence (ISR), ground-based radars and transmitters, and aircraft used for communication.[408] Crucially, entangling nuclear and conventional C3I capabilities increases the risk of inadvertent escalation. Conventional attacks against C3I assets may be wrongly interpreted and responded to with nuclear force, or incidental attacks against C3I assets may raise adversary's fears of losing it nuclear forces unless it used them.[409]

Production: material inputs, infrastructure, expertise and skills, testing core technology

Integrating nuclear and conventional C3I does not pose formidable production obstacles. Instead, entangling nuclear and conventional command, control, communications and intelligence assets is highly cost-effective. As conventional C3I capabilities have grown increasingly advanced, and because the skills and technologies required for nuclear command and control overlap with conventional assets, countries have chosen to entangle parts of their nuclear and conventional C3I structures.

Every C3I asset listed in the Nuclear Posture Review is dual-capable

In the United States, entanglement has occurred progressively. While nuclear forces never had separate communication satellites (the DSCS, Milstar and AEHF communication systems have always been used for both nuclear and conventional forces), until the mid-1980s, early warning satellites provided information exclusively about the launch of nuclear missiles. Today, these systems are additionally tasked with providing cueing information for missile defense systems against conventional ballistic missiles. Similarly, the United States dismantled various land-based nuclear-only communication capabilities, such as the Emergency Rocket Communications System in the 1990s and the Survivable Low Frequency Communications Systems in the early 2000s. Today, every C3I asset listed in the Nuclear Posture Review is dual-capable, with the exception of nuclear-weapon control capabilities directly associated with delivery system and potentially the system for detecting nuclear explosions – even though some of these are hosted by the GPS satellites.[410]

Satellites part of Russia's Unified Satellite Communication System reportedly likewise communicate with both nuclear and non-nuclear forces, and so do various Russian radars. Newly acquired command and control aircraft also reportedly work with both nuclear and conventional forces, while new early-warning satellites are expected to detect current and potential future US non-nuclear weapons. While debate exists as to the extent of Chinese C3I entanglement, recent deployment of the dual-capable DF-26 ballistic missile suggests

408 James M. Acton, "For Better or for Worse: The Future of C3I Entanglement" (Washington D.C.: Carnegie Endowment for International Peace, 2019), https://carnegieendowment.org/2019/11/21/for-better-or-for-worse-future-of-c3i-entanglement-pub-80405.

409 Acton; James M. Acton, "Command and Control in the Nuclear Posture Review: Right Problem, Wrong Solution," War on the Rocks, February 5, 2018, https://warontherocks.com/2018/02/command-and-control-in-the-nuclear-posture-review-right-problem-wrong-solution/.

410 James M. Acton, "Escalation through Entanglement: How the Vulnerability of Command-and-Control Systems Raises the Risks of an Inadvertent Nuclear War," *International Security* 43, no. 1 (August 2018): 64–65, https://doi.org/10.1162/isec_a_00320.

significant overlap in communication infrastructures. Moreover, various Chinese early-warning satellites can detect both nuclear and conventional forces.[411] This suggests that today, Chinese C3I is moderately entangled, with future entanglement likely to increase. The PLA National Defense University's *Science of Military Strategy* has apparently been urging for further integration of nuclear counterattack capabilities and conventional strike capabilities.[412] Finally, the Rocket Force's conventional missile units are being integrated into the Theatre Commands, reducing entanglement.[413]

For nuclear powers such as India, it is likely that new or modernized nuclear command and control structures build off existing conventional C3I structures as information sharing, skills and technologies overlap. The technology used in nuclear and conventional C3I assets is largely similar, and produced by the same industrial base. It has been suggested that India's nuclear command and control system overlaps with conventional systems and will further integrate in the future.[414]

The increasing number of dual-capable missile capabilities makes C3I entanglement even more desirable

The feasibility for nuclear powers to produce dual-capable C3I assets is therefore assessed to be **high**. Entanglement does not require additional material inputs, and since technological features of nuclear and conventional C3I are similar, with defense industrial bases often producing both, integration is technologically speaking not an issue. In fact, the opposite could be said to be true: dual-capable C3I enables modernization and increases efficiency and redundancy. Moreover, modern early warning sensors will have the inherent capability to detect conventional weapons, rendering entanglement in certain domains no longer a choice. Finally, the increasing number of dual-capable missile capabilities makes C3I entanglement even more desirable.

Proliferation: dual-use nature, tangibility, distinguishability

Many C3I technologies, such as satellites, are dual-use – and assets may indeed be of both military and civilian use simultaneously[415] – and this is no different for dual-capable versions.[416] The technology is tangible (at least its hardware components), and can be detected during transport. The ease of moving varies per component. One factor particularly spurring the ability to proliferate, however, is the fact that dual-capable 3CI technology is not distinct from conventional- and nuclear-only C3I systems. These factors, considered with the fact that 3CI entanglement is limited to nuclear powers, render the likelihood of dual-capable C3I to proliferate **medium**.

411 Acton, "Escalation through Entanglement."

412 Logan, "Are They Reading Schelling in Beijing?"

413 Logan, 26.

414 Lauren J. Borja and M.V. Ramana, "Command and Control of India's Nuclear Arsenal," *Journal for Peace and Nuclear Disarmament* 3, no. 1 (2020): 1–20, https://doi.org/10.1080/25751654.2020.1760021.

415 Yasmin Afina, Calum Inverarity, and Beyza Unal, "Ensuring Cyber Resilience in NATO's Command, Control and Communications Systems" (London: Chatham House, July 2020), https://www.chathamhouse.org/sites/default/files/2020-07-17-cyber-resilience-nato-command-control-communication-afina-inverarity-unal_0.pdf.

416 Note that dual-use in this paper refers to civilian/military, while dual-capable refers to nuclear/conventional.

Deployment: infrastructure, platform requirements, deployment skills

The deployment of dual-capable C3I systems does not pose significant challenges. The need for, and complexity of, dual-capable 3CI infrastructures and enablers does not differ from dedicated conventional or nuclear C3I systems – at least if modernized. The needed technical expertise neither rises above the level already required for conventional or nuclear C3I systems. The ease of dual-C3I deployment is thus estimated to be **high**.

Employment: organization, doctrine, norms

The employment of dual-capable C3I requires very limited adjusting of doctrine and organization structures. Naturally, the military bases and capabilities used for both conventional and nuclear command and control require both a conventional and nuclear mission.[417] Meanwhile, command principles and authority lines may differ for conventional and nuclear units, as has indeed been the case for the Second Artillery, the China's Rocket Force's predecessor. C3I integration also requires some changes in warfighting doctrine. For instance, the 2018 US Nuclear Posture Review warns that the United States could respond to conventional attacks against nuclear-related C3I assets with nuclear means.[418] (See the section on employing dual-capable missiles.) Considered altogether, the ease of dual-capable C3I employment is still assessed to be **high**, though of course this only applies to nuclear powers.

Assessment dual-capable C3I

Dual-capable C3I is easily produced and deployed, since it simply entails the entanglement of already existing technologies. While its proliferation and deployment are somewhat more difficult, there are no insurmountable obstacles to the propagation and use of C3I, as is visible from the assessment summarized in Table 17 and plotted in Figure 13.

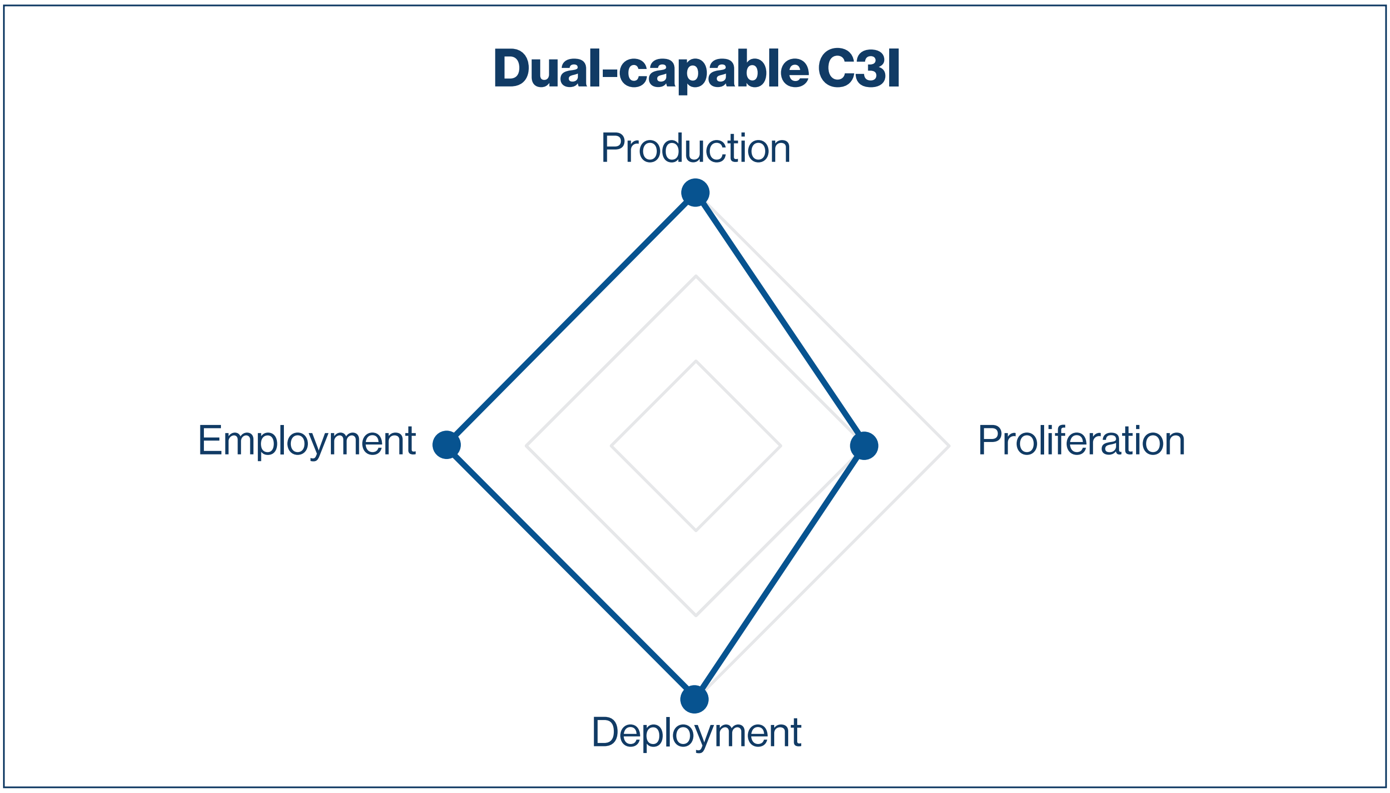
417 Borja and Ramana, "Command and Control of India's Nuclear Arsenal."

418 Office of the Secretary of Defense, "Nuclear Posture Review," 21.

Table 17. Assessment of dual-capable C3I across the production-proliferation-deployment-employment chain

Phase		Criteria	
Production	Feasibility of this technology to be produced	High	Material inputs for this technology are accessible and relatively inexpensive. The technology is relatively simple, well-understood and widely shared. Weaponizing and testing the technology in relevant environments is fairly straightforward.
Proliferation	Likelihood of this technology to proliferate	Medium	Commercial applications of this technology exist and can be modified for military use. At the same time, the technology is tangible, with detectability during transport being relatively high. Moving the technology is challenging but feasible. The technology is potentially distinguishable from other military technologies.
Deployment	The ease with which this technology can be deployed	High	This technology does not require sophisticated infrastructures, weapon platforms or enablers, or existing technologies can be updated. Deployment does not require highly advanced technical knowledge.
Employment	The ease with which this technology can be employed	High	Existing organizational structures and warfighting doctrines allow for the employment of this technology. States are not strongly disincentivized to employ this weapon.

Figure 13. Radar chart plotting the assessment of dual-capable C3I



Conclusion: Identifying key trends

The assessment of technologies along the production-proliferation-deployment-employment chain offers a number of insights. First, the production of many emerging technologies is still highly complex and will thus be restricted to major military powers. As was mentioned, and crucially, only those applications of relevance to strategic stability are considered: cyber attacks on critical national infrastructure or high-value military infrastructures for sustained periods of time and antisatellite weapons taking out nuclear communication assets are therefore considered; simple LAWS or anti-drone laser systems are not. With the exception of hypersonic missiles and missile technology, the proliferation of all discussed technologies scores at least medium if not high: emerging technologies' dual-use nature is most often to blame for this. Offensive cyber capabilities spread most rapidly, as the technology is not merely dual-use but even omni-use, in addition to being largely intangible. When it comes to deployment, the majority of technologies require fairly or very sophisticated infrastructures, weapon platforms and enablers, with at times modification of existing technologies possible. Only the deployment of dual-capable C3I is supposedly straightforward, even if strictly limited to nuclear powers. Finally, the assessment reveals that more "traditional" technologies such as offensive and defensive missile capabilities are most easily employable. For more novel ones, such as ASATs, DEWs, cyber and AI, various organizational, doctrinal and normative constraints hinder their use.

Table 18. Assessments for all weapon technologies and stages

	Production	Proliferation	Deployment	Employment
Hypersonic missiles	Low	Low	Medium	High
ASATs	Low	Medium	Medium	Low
DEWs	Low	Medium	Low	Low
Dual-capable missiles	Medium	Medium	Medium	Medium
Missile defense	Low	Low	Low	High
Cyber	Medium	High	Low	Medium
LAWS	Low	Medium	Medium	Low
Remote sensing	Medium	Medium	Medium	High
AI	Low	Medium	Medium	Low
Dual-capable C3I	High	Medium	High	High

5. Towards a comprehensive policy agenda for arms control, non-proliferation, and deterrence

Key takeaways

- Emerging technologies lend themselves to a variety of arms control, non-proliferation and deterrence measures along the PPDE chain. These include both time-tested methods and newer ones.
- Four types of measures emerge:
  - The first type of measures focus on curbing production and proliferation; whereby the production of more traditional technologies can be countered through test bans; while tailored and creative export control methods need to hamper the spread of new and complex technologies.
  - The second type of efforts focus on risk reduction in the deployment and employment phases through technical and political means, including crossverification, hotlines, situational awareness, and unilateral declaratory statements.
  - The third type of measures aim at regulating the production, deployment and employment of technologies by setting norms and rules, such as frameworks for human control that may be translated into industry codes of conduct and securityover-efficiency rules .
  - The fourth type of measures seeks to complement risk reduction efforts through adjusting deterrence postures, whether by denial, punishment, or entanglement.

The previous chapter assessed the level of difficulty with which ten weapon technologies can be produced, proliferated, deployed and employed. This chapter builds on the insights provided in the previous chapter and suggests a set of policy measures in the realm of arms control, non-proliferation and deterrence to reduce the risks to strategic stability. The goal of this chapter is twofold: first, to identify and evaluate specific policy recommendations; second, to offer a more generic overview of the balance of policy mixes that should be part of a more comprehensive policy portfolio of the Netherlands and its partners to address risks posed to strategic stability by emerging technologies in the years to come. Each of the technology sections offer a concise write up of the principle thrust of the proposed policy measures follows by reflections on the effectiveness of these policy measures along the production-proliferation-deployment-employment chain with specific recommendations signposted with the symbol ❖. The final section reflects on the overall balance of policy mixes as the sum total of the suggested measures. The insights offered by this chapter are based on desk research, interviews with policymakers, and the independent expert judgment of experts who are not part of the principal research team.

Hypersonic missiles

Key takeaways

Even if highly complex, the development and production of hypersonic missiles appears inevitable due to political and technical reasons; yet transparency measures such as pre-launch notifications could be adopted to enhance trust. Main arms control efforts will need to be undertaken by major military powers and focus on limiting their proliferation and reducing escalation risks. Containing hypersonic missile deployment is likely to be feasible for nuclear-tipped versions only.

Production

Fears of a perceived hypersonic missile gap further reduce the likelihood of controlling the production

Due to hypersonic missile technology's complexity and immaturity, as well as the formidable costs associated with R&D programs, the production of hypersonic missiles is limited to great powers. The low feasibility to produce this technology suggests that arms control measures could be implemented at the production phase provided that the great powers are willing cooperate. Proposals for stalling or halting the development of hypersonic missile technology have indeed been put forward, including negotiating a new arms control agreement that limits the development of hypersonic missiles, such as a test ban.[419] Both technical and political factors limit the effectiveness of these efforts, however. Experts are skeptical of the technical feasibility to impose and verify limitations, as "no clear technical distinction can be made between hypersonic missiles and other conventional capabilities that are less prompt, have shorter ranges, and also have the potential to undermine nuclear deterrence."[420] In addition, political considerations including fears of a perceived hypersonic missile gap further reduce the likelihood of controlling the production of hypersonic missiles.

Instead, progress could be made through transparency measures such as data exchanges and notifications. The Hague Code of Conduct (HCoC), which prescribes pre-launch notifications (PLNs) on ballistic missile and space-launch vehicle launches and test flights, covers ballistic missile boosters used in boost-glide systems, but not the boost-glide systems themselves; nor does it specify whether PLN obligations apply to hypersonic missile flight tests.[421] There is thus potential room for expansion here to include PLN obligations for hypersonic non-ballistic systems.

❖ Expand the HCoC to including pre-launch notification obligations for hypersonic missile tests

419 Mark Gubrud, Rajaram Nagappa, and Zhao Tong, "Test Ban for Hypersonic Missiles?," *Bulletin of the Atomic Scientists* (blog), August 6, 2015, https://thebulletin.org/roundtable/test-ban-for-hypersonic-missiles/.

420 Tong Zhao, "Banning Hypersonics: Too Much to Hope For," *Bulletin of the Atomic Scientists* (blog), June 26, 2015, https://carnegietsinghua.org/2015/06/26/banning-hypersonics-too-much-to-hope-for-pub-60520.

421 Kolja Brockmann, "Controlling ballistic missile proliferation Assessing complementarity between the HCoC, MTCR and UNSCR 1540" (The Hague Code of Conduct, June 15, 2020), https://www.nonproliferation.eu/hcoc/controlling-ballistic-missile-proliferation-assessing-complementarity-between-the-hcoc-mtcr-and-unscr-1540/.

Proliferation

The complexity of developing and producing hypersonic missile technology and lack of dual-use applications suggests that there are venues to prevent horizontal proliferation. Agreeing on proliferation measures should be feasible, since major powers would benefit from limiting the technology to a selected group of states, both from a security and prestige perspective. Existing non-proliferation instruments for missile technologies partially cover hypersonic missile technology, with potential room for expanding coverage. For one, the Missile Technology Control Regime (MTCR) regulates missile technology and delivery vehicles, irrespective of their payloads, including various components of hypersonic systems, such as scramjets, hydrocarbon fuels, and materials required for thermal protection.[422] Yet, not all hypersonic technologies are covered by the MTCR, suggesting room for expansion.[423] Furthermore, conventional-tipped hypersonic missiles are currently not covered under UNSCR 1540. Including hypersonic missile technology into this binding treaty focused on countering the proliferation of chemical, biological and nuclear weapons to non-state actors is thus an option worth exploring.

❖ Expand coverage of existing export regimes, notably MTCR and UNSCR 1540

Deployment

Prospects of concluding a trilateral or multilateral treaty are bleak

In the past, the INF Treaty banned all land-based ballistic and cruise missiles as well as their launchers within certain ranges regardless of them carrying nuclear or conventional warheads; INF would therefore have also limited the deployment of hypersonic missiles. Today, New START only covers weapons that fly on a ballistic trajectory “over most of its flight path”, therefore excluding most hypersonic missiles – though not the Russian Avangard.[424] The effect of expanding New START to include hypersonic missiles, or reinvigorate previous arms control treaties such as INF, is limited though, given the treaty’s expiration date and the fact that only two of the major military powers are involved.[425] Prospects of concluding a trilateral or multilateral treaty are bleak, especially due to political obstacles including diverging arsenal sizes and general reluctance to limit deployment of conventional warheads.[426] Technologically speaking, setting limits to the deployment of hypersonic missiles could be feasible, especially for nuclear-tipped versions, for which verification measures exist (see the section on dual-capable missiles).[427]

❖ Limit sites where nuclear-tipped (hypersonic) missiles may be deployed

422 “Missile Technology Control Regime (MTCR): Annex Handbook,” Annex Handbook 2017 (Bureau of International Security and Nonproliferation, 2017), https://mtcr.info/wordpress/wp-content/uploads/2017/10/MTCR-Handbook-2017-INDEXED-FINAL-Digital.pdf.

423 Kelsey Davenport and Sang-Min Kim, “Missile Proliferation Poses Global Risk,” *Arms Control Association* (blog), June 2021, https://www.armscontrol.org/act/2021-06/news/missile-proliferation-poses-global-risk.

424 Cameron Tracy, “Fitting Hypersonic Weapons into the Nuclear Arms Control Regime,” All Things Nuclear, April 1, 2020, https://allthingsnuclear.org/ctracy/fitting-hypersonic-weapons-into-the-nuclear-arms-control-regime/.

425 Sayler, “Hypersonic Weapons: Background and Issues for Congress.”

426 Wu Riqiang, “Trilateral Arms Control Initiative: A Chinese Perspective,” *Bulletin of the Atomic Scientists* (blog), September 4, 2019, https://thebulletin.org/2019/09/trilateral-arms-control-initiative-a-chinese-perspective/; Ulrich Kühn et al., “Trilateral Arms Control? Perspectives from Washington, Moscow, and Beijing,” IFSH Research Report (Hamburg: Institute for Peace Research and Security Policy, March 2020), http://rgdoi.net/10.13140/RG.2.2.18656.43526.

427 Pavel Podvig, Ryan Snyder, and Wilfred Wan, “Evidence of Absence: Verifying the Removal of Nuclear Weapons” (Geneva: United Nations Institute for Disarmament Research, 2018), https://unidir.org/publication/evidence-absence-verifying-removal-nuclear-weapons.

Employment

Because the employment of hypersonic missiles does not face insurmountable barriers in terms of organization, doctrines, or international norms, efforts need to focus on limiting risks of escalation that result from hypersonic missiles' warhead ambiguity and strike capacity against nuclear assets. Promoting transparency through confidence-building measures such as data exchanges, also regarding testing, are key. States could also take unilateral steps by specifying that hypersonic missile technology will be used for conventional use only,[428] and exclude the use of hypersonic missiles against strategic targets.[429] Risk reduction could also be furthered through separating nuclear and conventional assets to the largest extent possible:[430] "choosing separate, distinctive launch locations for tests of hypersonic missiles and placing restraints on sea-based tests."[431] Declaratory policies could further outline responses to hypersonic missile attacks against nuclear-related assets, highlighting this specific escalation risk (see the section on dual-capable 3CI assets). In addition to such punishment-based deterrence strategies, deterrence by denial tools, such as bolstering missile defenses, are worth considering.[432]

- Promote data exchanges including advance test notifications
- Restrain sea-based tests
- Separate launch locations as well as nuclear and conventional assets
- Publicly specify that hypersonic missiles will be conventionally-tipped only and used against conventional targets only
- Explore both punishment- and denial-based deterrence options

Anti-satellite weapons

Key takeaways

Halting the production and proliferation of ASATs will prove challenging due to the technology's dual-use nature, use in missile defense, and difficulties related to test bans including verification issues. Co-orbital ASATs need to be countered in the deployment phase; for instance, through limiting the proximity of space objects whereby verification can be achieved through broad-casting obligations for space systems. Furthermore, efforts to create a rules-based space order need to continue, ideally with internationally-enforced verification and enforcement mechanisms.

Production

Given the complexity to produce ASATs, space-faring nations could double down on efforts to halt the production of ASATs. Crucially, efforts could focus on limiting ASAT tests, which are currently not indisputably banned. The Outer Space Treaty (OST) bans the placement,

428 Rajaram Nagappa, "New Technology, Familiar Risks," *Bulletin of the Atomic Scientists* (blog), June 25, 2015, https://thebulletin.org/roundtable_entry/new-technology-familiar-risks/.

429 Zhao, "Banning Hypersonics: Too Much to Hope For."

430 Acton, "Escalation through Entanglement."

431 Nagappa, "New Technology, Familiar Risks"; James M. Acton, "Silver Bullet? Asking the Right Questions About Conventional Prompt Global Strike" (Washington, DC: Carnegie Endowment for International Peace, 2013), https://carnegieendowment.org/files/cpgs.pdf.

432 Benjamin Hautecouverture, Emmanuelle Maitre, and Bruno Tertrais, "The Future of Strategic Stability" (Fondation pour la Recherche Strategique, March 2021), https://www.frstrategie.org/en/publications/recherches-et-documents/future-strategic-stability-2021.

instalment and stationing of nuclear weapons and other weapons of mass destruction (WMD), including testing, in space. Because of its emphasis on "placement, instalment and stationing", the OST arguably does not pertain to direct-ascent nuclear and other types of WMD ASATs. Further discussions have arisen with regard to Article IV of the Treaty, which sets that space shall be used "exclusively for peaceful purposes." Yet, "peaceful" in this context has been commonly interpreted as non-aggressive rather than non-military.[433] Therefore, testing ASATs against one's own space assets does not necessarily violate the treaty (at least if tests are not conducted on or near celestial bodies).[434] However, some have pointed out that ASAT tests can be prohibited under Article III, which mandates adherence to IHL, whereby, unless framed as self-defense, states cannot conduct ASAT tests. Moreover, under Article IX, international consultations before ASATs tests are mandatory if activities would potentially cause harm to the activities of other parties to the treaty.[435] Because of debris, many ASAT tests, even if conducted against a state's own space assets, can be reasoned to be in violation of the treaty – but it should be noted that degrees of debris have recently become more limited.[436] Finally, it should be added that testing of nuclear-armed ASATs in outer space is prohibited under the Partial Test Ban Treaty (PTBT).[437] Taken together, the legality to test ASATs is not undisputed, and multilateral processes to clear inconsistencies and introduce further regulation are necessary.

The legality to test ASATs is not undisputed

If testing cannot be banned, confidence-building and transparency measures could be implemented. The HCoC prescribes pre-launch notifications on space-launch vehicle launches and test flights. Options to extend the HCoC to include PLNs for space-based conventional ASATs could be considered.

- ❖ Clear inconsistencies in the OST and further control ASAT tests
- ❖ Promote pre-launch notifications for ASATs tests under existing regimes such as the HCoC

Proliferation

While many of ASAT components are of dual-use nature, the technology's tangibility suggests opportunities to halt the proliferation of ASAT technology. Efforts to prevent ASAT proliferation could focus on increased verification and implementation of existing regimes. The Wassenaar Arrangement, to which many space faring nations are party, can play a role in countering the spread of co-orbital ASATs (even if non-binding). Several space and satellite technologies are listed as sensitive or very sensitive goods and their transfer or denial must be notified accordingly. Furthermore, the MTCR addresses rocket systems including space launch vehicles and sounding rockets. Another option to consider is expanding UNSCR 1540, which is binding, to restrict the export of satellite technology to non-state actors. Many ASAT technologies are on the US Commerce Control List (CCL), including but not limited to launch vehicles, missiles, rockets and other military explosive devices (Category IV); spacecraft and related articles (Category XV); and Directed energy weapons

433 Kumar Abhijeet, "Arms Control in Outer Space: ASAT Weapons," in *Recent Developments in Space Law*, ed. R. Venkata Rao, V. Gopalakrishnan, and Kumar Abhijeet (Singapore: Springer Singapore, 2017), 129–40, https://doi.org/10.1007/978-981-10-4926-2_10.

434 Raju, "A Proposal for a Ban on Destructive Anti-Satellite Testing: A Role for the European Union."

435 United Nations Office for Outer Space Affairs, "The Outer Space Treaty," United Nations Office for Outer Space Affairs, 2021, https://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/introouterspacetreaty.html.

436 Raju, "A Proposal for a Ban on Destructive Anti-Satellite Testing: A Role for the European Union"; Daniel Porras, "Towards ASAT Test Guidelines," Space Dossier, Space (Geneva: United Nations Institute for Disarmament Research, 2018), https://www.unidir.org/files/publications/pdfs/-en-703.pdf.

437 It is signed by the United States, Russia, UK, India, but not China and France. Johnson, "A Balance of Instability."

(Category XVIII).[438] Anti-satellite or space-based weapons are also listed as an item in the United States Munitions List (USML). The USML is part of an export control regime named International Traffic in Arms Regulations (ITAR) administered by the US State Department, Directorate of Defense and Trade Controls. Through the licensing process, the Defense Department can review transactions of regulated technologies.[439] In Europe, the newly updated EU Council Regulation (EC) No 2021/821 regulates the exports of several technologies needed in the development of ASAT weapons, including space launch vehicles, spacecraft, spacecraft payloads, as well as sounding rockets.[440]

❖ Expand coverage and increase verification of existing export regimes, such as MTCR and UNSCR 1540

Deployment

Active debris removal (ADR) and on-orbital servicing (OOS) add complexity since these can be converted into weapons

The OST bans the placement and stationing of weapons of mass destruction and nuclear weapons in orbit, meaning that any ASAT that only transits in orbit can be employed. Moreover, because "peaceful" is interpreted as non-aggressive rather than non-military, the deployment of ASATs in space is not banned. Other treaties related to the weaponization of outer space, such as the Moon Agreement and the Registration Convention, do not specifically cover ASATs.[441] A proposal in 2008 by Russia and China for a Prevention of the Placement of Weapons in Outer Space Treaty (PPWT), supposed to ban the use of force in space altogether, was rejected by the United States because it was short of a verification mechanism, lacked clarity about the definition of "space weapon", did not include the possession, testing, production and stockpiling of such weapons, and failed to address ground-based ASATs.[442] Moreover, active debris removal (ADR) and on-orbital servicing (OOS) add complexity since these can be converted into weapons, which call into question the feasibility of banning the deployment (or verification thereof) of ASATs in space altogether. Instead, limits could be placed on the proximity of space objects.[443] Verification is a key concern, as is illustrated by American objections to the PPWT, but could be achieved through imposing broadcasting obligation on ADR and OOS. International space situational awareness capabilities would help here. Limiting the deployment of direct-ascent ASATs is likely less feasible, thanks to challenges related to distinguishing direct-ascent ASATs from missile defense systems.[444]

❖ Clear inconsistencies in the OST and (further) limit the deployment of ASATs
❖ Place limits on the proximity of space objects
❖ Enhance verification through broadcasting obligations and potentially shared space situational awareness capabilities

438 Ian F Fergusson and Paul K Kerr, "The U.S. Export Control System and the Export Control Reform Initiative" (Congressional Research Service, 2020), 13–14, https://fas.org/sgp/crs/natsec/R41916.pdf.

439 Botwin, "U.S. Space Industry 'Deep Dive' Assessment: Impact of U.S. Exports Controls on the Space Industrial Base."

440 "Regulation (EU) 2021/821 of the European Parliament and of the Council of 20 May 2021" (n.d.).

441 Abhijeet, "Arms Control in Outer Space."

442 Brian G. Chow, "Space Arms Control: A Hybrid Approach," *Strategic Studies Quarterly* 12, no. 2 (2018): 107–32; Porras, "Towards ASAT Test Guidelines."

443 Chow, "Space Arms Control."

444 See for example Defence News India, "The S-500 Air Defense System Can Shoot down Military Satellites," *Defence News India* (blog), August 2, 2021, https://www.defenceaviationpost.com/2021/08/the-s-500-air-defense-system-can-shoot-down-military-satellites/.

Employment

Given the significant organizational, doctrinal and normative barriers that prevent or impede the employment of anti-satellite capabilities, opportunities arise to counter the use of ASATs for larger and smaller space players alike. Currently, no rules-based order for space exists, and important steps should be made to define, internationally, which types of behavior in space are acceptable and which are not.[445] Previous efforts such as undertaken by the EU to create an International Code of Conduct for Outer Space Activities need to be continued. An important step is the UN resolution A/RES/75/36, proposed by the United Kingdom, seeks to reinvigorate these discussions and broker international consensus.

In tandem to creating (and jointly adopting) an international code of conduct for space, ideally internationally-enforced space situational awareness (SSA) and space traffic management (STM) systems need to be put in place to monitor states' behavior in space.[446] If efforts to agree on a space code of conduct and enforcement mechanism continue to fail, national SSA capabilities can help reduce "uncertainty surrounding counterspace activities" and "minimize the chance of miscalculation and increase crisis stability."[447]

International dialogue on the escalation risks associated with ASATs could help to increase awareness and limit potentially dangerous behavior. Finally, states need to explore both punishment- and denial-based deterrence options. While both pathways face a variety of constraints, the first may center around punitive strikes against counterspace architectures, while the second includes active defenses and the creation of redundancies.[448]

- ❖ Work towards an international code of conduct for space, building on existing efforts such as the UK-sponsored UN resolution A/RES/75/36
- ❖ Implement national and international space situational awareness systems to monitor and enforce space activities
- ❖ Explicitly include the risks associated with ASATs in bilateral and multilateral strategic dialogues concerning nuclear weapons
- ❖ Examine the possibilities and constraints associated with space deterrence

Directed energy weapons

Key takeaways

Discussions to limit the deployment of ground-based DEWs should be held in tandem with those on missile defense systems, but expectations should be realistic given limited political appetite to set limits on these systems. Initiatives aimed at creating a space code of conduct that includes DEWs (whether deployed in space or used against assets in space) could be more promising.

445 Patricia Lewis, "Create a Global Code of Conduct for Outer Space," Chatham House, June 12, 2019, https://www.chathamhouse.org/2019/06/create-global-code-conduct-outer-space.

446 Bruce McClintock et al., "Responsible Space Behavior for the New Space Era: Preserving the Province of Humanity," 2021, 50.

447 Favaro, "Weapons of Mass Distortion: A New Approach to Emerging Technologies, Risk Reduction, and the Global Nuclear Order," 19.

448 Morgan, *Deterrence and First-Strike Stability in Space*, 30–33.

Production

Even if the production of strategic laser weapons is highly complex and years away – and its ultimate feasibility questioned by some – efforts to halt their production could commence. Currently, the testing of DEWs is not explicitly prohibited under the Outer Space Treaty (OST), which prohibits testing of nuclear weapons and weapons of mass destruction in space. Yet, if used to disable satellites, DEWs could potentially be regulated under the OST as they can be argued to be weapons of mass destruction if used as such.[449] To eliminate the risk of diverging interpretations, extending the OST to explicitly refer to the testing of DEWs and ramping up verification options (see ASAT section) could be considered. Even if caveats apply, curbing the testing of space-based DEWs may prove challenging because of their potential use for missile defense, which major military states may be keen to develop.

- ❖ Clear inconsistencies in the OST and further regulate the testing of space-based DEWs
- ❖ Step up verification, potentially through shared situational awareness capabilities

Proliferation

Curbing the testing of space-based DEWs may prove challenging because of their potential use for missile defense

Given their seminal stage of development, the proliferation of DEWs is hardly regulated even if some of its technologies appear in export control lists. The Arms Trade Treaty (ATT) does not include them in its list of weapons but Article 5.3 encourages States Parties to "apply the ATT provisions to all additional categories of weapons," including DEWs.[450] The Wassenaar Arrangement does explicitly cover laser technology in its Section 6.A but without specific references to DEWs. Guidelines in the ATT and Wassenaar Arrangement are useful, albeit not legally binding. In Europe, the Council Common Position 2008/944/CFSP defines rules governing the control of exports of military technology and equipment.[451] Within this guide, the Council follows the Common Military List of the European Union, which includes laser technology.[452] In the United States, DEWs are regulated through the Commerce Control List, under the jurisdiction of the Export Administration Regulations (EAR), which imposes license requirements on exports and reexports.[453]

- ❖ Refine and reinforce existing arms control regimes, including the Arms Trade Treaty and the Wassenaar Arrangement

Deployment

Even if maturation of strategic DEW technology is years away, efforts to limit the potential deployment of laser weapons could start already. Given their potential use in missile defense, these discussions could take place in conjunction with those on limiting missile defense systems. That said, prospects for setting limits on the number of deployed missile defense systems, including those using laser technology, are bleak. Indeed, during the two

449 Thompson and Gouré, "Directed-Energy Weapons: Technologies, Applications and Implications," 43.

450 "ATT Monitor 2016," 83.

451 Council of the European Union, "Council Common Position 2008/944/CFSP," EUR-Lex, 2008, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32008E0944.

452 Council of the European Union, "Common Military List of the European Union Adopted by the Council on 26 February 2018" (Brussels: Official Journal of the European Union, March 15, 2018), https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:C:2018:098:FULL&from=EN.

453 Industry and Security Bureau, "Commerce Control List: Addition of Items Determined to No Longer Warrant Control Under United States Munitions List Category XIV (Toxicological Agents) or Category XVIII (Directed Energy Weapons)," Federal Register, June 17, 2015, https://www.federalregister.gov/documents/2015/06/17/2015-14474/commerce-control-list-addition-of-items-determined-to-no-longer-warrant-control-under-united-states.

Appetite for setting limits on the deployment of missile defense systems has been low

decades following the breakdown of the Anti-Ballistic Missile Treaty in 2002, appetite for setting limits on the deployment of missile defense systems has been low, especially in the United States.[454] Changes in defense postures, notably by Russia, may shift calculations and increase momentum for reopening talks on missile defense. In any case, starting talks about the limitation of DEWs deployment could be beneficial to future developments in this field.[455]

- Start the discussion of international rules limiting the number of DEWs that can be deployed through formal gov-to-gov talks (track 1) and expert-to-expert (track 2) meetings

Employment

The complexity to employ DEWs suggests room to limit such weapons' use, even if legal considerations do not yet fully cover laser technology. Apart from the prohibition of blinding laser weapons under Protocol IV to the CCW, which also prohibits the use of laser weapons that inflict "excessively injurious" casualties,[456] DEWs are not defined under international law or on the agenda of existing multilateral mechanisms.[457] Yet, various legal regimes ranging from national civilian-use regulations and guidelines to international humanitarian law (IHL) and human rights law could hinder their use. Examples include the 1990 UN Basic Principles on the Use of Force and Firearms by Law Enforcement Officials (BPUFF), which states that "the development and deployment of non-lethal incapacitating weapons should be carefully evaluated in order to minimize the risk of endangering uninvolved persons, and the use of such weapons should be carefully controlled."[458] Further, IHL limits the right to choose methods of warfare and obliges states to assess all new weapons.[459] Additional concerns may arise from IHL given some of DEWs potential effects, such as burning, radiation sickness, and their impact on civilian infrastructures when deployed in space.[460] Generally, collateral damage by a laser weapon is unchartered judicial terrain that could be further explored.

Limiting the specific (eventual) use of laser technology as counterspace capability offers additional possibilities for regulation. Currently, as indicated, potential space-based laser weapons, whether used for offensive purposes or missile defense, do not fall under current space treaties and regimes, unless they would be defined as weapons of mass destruction – which is not unthinkable if used to destroy satellites.[461] Arms control efforts could focus on setting norms against the use of DEWs in space (see section on ASATs).

- Establish a working group of legal experts to reflect on the legal implications of collateral damage of DEW
- Include the use of DEWs in the efforts to set norms for behavior in space

454 Amy F Woolf, Paul K Kerr, and Mary Beth D Nikitin, "Arms Control and Nonproliferation: A Catalog of Treaties and Agreements" (Congressional Research Service, March 11, 2021).

455 Favaro, "Weapons of Mass Distortion: A New Approach to Emerging Technologies, Risk Reduction, and the Global Nuclear Order," 20.

456 Andrew Feickert, "U.S. Army Weapons-Related Directed Energy (DE) Programs: Background and Potential Issues for Congress" (Congressional Research Service, 2018), 4–5.

457 Protocol on Blinding Laser Weapons (1995), annexed to the framework Convention on Prohibitions or Restrictions on the Use of Certain Conventional Weapons (CCW).

458 Principle 3, 1990 Basic Principles on the Use of Force and Firearms by Law Enforcement Officials.

459 Article 35(1) and Article 36 of Protocol I to the CCW respectively.

460 Art 35(2) API; ICRC, Customary IHL study, Rule 70.

461 Feickert, "U.S. Army Weapons-Related Directed Energy (DE) Programs: Background and Potential Issues for Congress," 5; Thompson and Gouré, "Directed-Energy Weapons: Technologies, Applications and Implications."

Dual-capable missiles

Key takeaways

Nuclear powers do not face any technological or budgetary barriers to produce missiles that are capable of carrying both nuclear and conventional warheads, and the proliferation of dual-capable missiles among nuclear states cannot be prevented due to the absence of a specific technology to be regulated. Arms control measures could instead focus on the deployment and employment of these weapons. Limiting the deployment of nuclear warheads appears most feasible.

Proliferation

While the MTCR does not refer to dual-capable missile systems explicitly, it does pertain to dual-capable missile systems with a range of 300 kilometers or more, including their warheads, launchers and platforms, as well as software, which all fall under Category I. Export regulations thus restrict the transfer of dual-capable missiles, even if monitoring is challenging. As such, non-proliferation efforts could focus on implementing and monitoring these regulations.

❖ Reinforce the implementation and verification of MTCR

Deployment

Verification is crucial, but also feasible

Historically, formal treaties such as INF addressed the issue of dual-capable missiles by banning all land-based ballistic and cruise missiles as well as their launchers within certain ranges regardless of them carrying nuclear or conventional warheads. The New START Treaty limits the deployment of intercontinental ballistic missiles and submarine-launched ballistic missiles regardless of their re-entry vehicles, too, while setting a cap on strategic bombers dedicated for nuclear use.[462] This latter provision illustrates the possibility to limit or prohibit one type of re-entry vehicle only, which can prove particularly valuable if attempts to control delivery systems fail. Because states generally oppose verification measures on the deployment of conventional weapons – as was illustrated by the decision to exclude cruise missiles from the HCoC – arms control efforts could focus on nuclear re-entry vehicles. Indeed, states may want to consider "banning the deployment of nuclear versions at a number of sites."[463]

Other options include banning ground-based nuclear-tipped intermediate-range missiles or limiting the number of nuclear-armed missiles.[464] Verification is crucial, but also feasible, as was suggested by a study conducted by UNIDIR outlining the possibility of verifying the absence of nuclear weapons from storage facilities and bases through inspection arrangements and radiation detection techniques.[465] It should be noted that verification of bans

462 Amy F. Woolf, "The New START Treaty: Central Limits and Key Provisions" (Congressional Research Service, July 30, 2021).

463 Emmanuelle Maitre, "What Prospects for Arms and Missile Control after the End of the INF Treaty?" (Paris: Fondation pour la Recherche Stratégique, February 2020), 7, https://www.frstrategie.org/sites/default/files/documents/publications/recherches-et-documents/2020/202003.pdf.

464 Rose Gottemoeller, "Rethinking Nuclear Arms Control," *The Washington Quarterly* 43, no. 3 (July 2, 2020): 139–59, https://doi.org/10.1080/0163660X.2020.1813382.

465 Podvig, Snyder, and Wan, "Evidence of Absence: Verifying the Removal of Nuclear Weapons."

is more straightforward than arsenal limitations.[466] Proposals to prohibit the use of nuclear-tipped cruise-missiles have similarly been made, even if various states have recently ramped up their nuclear-armed cruise missile arsenals.[467]

❖ Limit the deployment of nuclear-tipped missiles, e.g. by banning nuclear weapons from sites

Employment

No international treaties specifically refer to dual-capable missiles. However, the INF Treaty (1986-2019), which banned all types of ground-launched ballistic and cruise missiles with a range between 500 and 5,500 kilometers, long stalled the development of dual-capable missiles in the United States and the Soviet Union/Russia.[468] Today, dual-capable missiles fall within the scope of the New START Treaty concluded between the United States and Russia in 2010, which inter alia limits nuclear-armed ICBMs and SLBMs, as well as their launchers.[469]

Beyond multilateral treaties, which take years to negotiate and include many hurdles, states could take unilateral measures to reduce dual-capable missile arsenals, by reducing nuclear warheads as was done by the United States and the Soviet Union through the Presidential Nuclear Initiatives (PNIs) in the early 1990s as well as other unilateral decisions by nuclear states such as France and the United Kingdom. It should be noted that verification however is absent in unilateral initiatives.

Efforts in these directions are further complicated as countries such as China may pursue a strategy of ambiguity,[470] or rely on nuclear and conventional entanglement for more practical reasons.[471] What is more, addressing these issues in trilateral or multilateral frameworks is highly complex, given the wide variety in stockpile sizes and differences in on- or off-alert practices.[472]

That said, various confidence-building measures remain, such as no-first-use statements (either individually, bilaterally or multilaterally), or the development of multilateral pre-notification protocols.[473]

❖ Publicly commit to no-first-use
❖ Work internationally to create pre-launch notification protocols

466 Gottemoeller, “Rethinking Nuclear Arms Control.”

467 Honorable Andy Weber and Christine Parthemore, “Cruise Control: The Logical Next Step in Nuclear Arms Control?,” *Journal for Peace and Nuclear Disarmament* 2, no. 2 (July 3, 2019): 453–67, https://doi.org/10.1080/25751654.2019.1681886.

468 Acton, “Is It a Nuke?”

469 U.S. Department of State, “New START Treaty,” *U.S. Department of State* (blog), June 24, 2021, https://www.state.gov/new-start/.

470 Arbatov et al., “Entanglement: Chinese and Russian Perspectives on Non-Nuclear Weapons and Nuclear Risks.”

471 Logan, “Are They Reading Schelling in Beijing?”

472 Riqiang, “Trilateral Arms Control Initiative.”

473 Frank O’Donnell, “Launching an Expanded Missile Flight-Test Notification Regime,” *Stimson Center* (blog), March 23, 2017, https://www.stimson.org/2017/launching-expanded-missile-flight-test-notification-regime/.

Missile defense

Since the breakdown of the ABM Treaty in 2002, arms control discussions for missile defense have been avoided by the United States. Recently, however, momentum has been building over the prospect of reinstating missile defense. When it comes to capping deployment, discussions could be linked to those on offensive systems. Specifying missile defense policy and clearly separating strategic from regional systems could help build trust.

Proliferation

Reinforcing existing export control regimes, while important, will be of limited use

Missile defense systems are regulated under the Missile Technology Control Regime (MTCR). THAAD falls just below MTCR's "strong presumption to deny" threshold, the SM-3 interceptor and Israeli Arrow system fall just above it, and the ground-based interceptors deployed in Alaska and California far exceed the threshold. Because vertical rather than horizontal proliferation is the issue here, reinforcing existing export control regimes, while important, will be of limited use.

Deployment

For almost two decades, missile defense has largely been off the table for the United States in arms control discussions. Yet, new openings to bring the issue back in seems to be rising, whether fed by fears over adversaries' missile defense build-up or a growing sense that missile defense could be used to increase leverage in broader arms control conversations that also include offensive weapon systems.[474] Including missile defense in broader arms control discussions that focus on offensive weapons could prove fruitful.

❖ Reflect on the utility of missile defense as a bargaining chip to facilitate further arms control discussions, also including offensive weapons

Employment

It is crucial to ensure and communicate that strategic missile defenses do not undermine adversaries' nuclear deterrents, even if such policy remains unchanged for decades, as the Arms Control Association stated: "it is worth clarifying because it has been clouded by declaratory statements (Trump in 2019) and by the exploration of approaches that could be integrated to provide an expandable, global defense, such as space-based missile defense systems and the incorporation of the regional Aegis missile defense system into homeland defense."[475] While communication efforts between the US and Russia have existed for decades, and should continue, dialogue between other nuclear dyads, such as the US and China, need to be effectively started. Separating strategic from regional missile defense and limiting efforts to increase or develop the former, including space-based systems, which would bolster countries' first-strike capabilities, would thus be key to build trust and avoid

474 "Reconsidering Arms Control Orthodoxy," War on the Rocks, March 26, 2021, https://warontherocks.com/2021/03/reconsidering-arms-control-orthodoxy/; Jeffrey Lewis, "The Nuclear Option," February 22, 2021, https://www.foreignaffairs.com/articles/china/2021-02-22/nuclear-option; "A Better Missile Defense Strategy | Arms Control Association," accessed September 14, 2021, https://www.armscontrol.org/act/2020-12/features/better-missile-defense-strategy.

475 "A Better Missile Defense Strategy | Arms Control Association."

arms racing. Finally, deterrence postures are inherently linked to discussions on arms control, whereby states could examine their nuclear arsenals' survivability in relation to adversaries' strategic missile defense postures.

- ❖ Ensure and communicate that defensive systems are not intended to undermine second strike capabilities
- ❖ Clearly separate strategic from theater missile defense efforts
- ❖ Consider regional rather than global solutions tailored to specific regional strategic constraints
- ❖ Determine and limit the minimally required nuclear arsenal size to ensure a second strike capability vis-à-vis adversaries' strategic missile defense postures

Offensive cyber operations

Key takeaways

Given the technology's intangibility and secrecy, countering the production, proliferation, deployment and employment of offensive cyber capabilities is challenging. Yet, efforts could focus on reducing opportunities to exploit zero-days, limiting cyber capability transactions, building confidence through norm-setting and deconfliction, and strengthening attribution capabilities as part of deterrence postures.

Production

The fast-paced development of cyber technologies complicates efforts to control their production. While other weapons may have long development cycles, cyber capabilities innovate constantly and quickly. An arms control agreement hence risks being outdated by the time it is ratified.[476] Therefore, curbing the production of offensive cyber capabilities will prove nearly impossible. Still, some options are certainly worth exploring, especially those that further increase the complexity to produce cyber capabilities. Reducing chances to exploit zero-days by preventing the introduction of vulnerabilities in the coding stage is one such venue that can be promising.[477] Artificial intelligence would be critical here. In addition, bug bounty programs such as Hack the Pentagon that seek to identify and patch zero-days can further bolster defenses.[478]

- ❖ Invest in AI-enabled coding to limit opportunities for zero-day exploits
- ❖ Impose stricter regulations for software developers to prioritise security over efficiency
- ❖ Identify and fix potential zero-day exploits by bolstering cooperation with hackers

476 Erica D Borghard and Shawn W Lonergan, "Why Are There No Cyber Arms Control Agreements?," Council on Foreign Relations, January 16, 2018, https://www.cfr.org/blog/why-are-there-no-cyber-arms-control-agreements; Owens, Dam, and Lin, *Technology, Policy, Law, and Ethics Regarding U.S. Acquisition and Use of Cyberattack Capabilities*.

477 Segal, "Using Incentives to Shape the Zero-Day Market."

478 "Department of Defense's 'Hack the Pentagon' Bug Bounty Program Helps Fix Thousands of Bugs," WIRED, October 11, 2017, https://www.wired.com/story/hack-the-pentagon-bug-bounty-results/.

Proliferation

Controlling the proliferation of offensive cyber capabilities is challenging. A previous attempt to include intrusion software (as well as the facilities and technologies necessary to produce malware) to the Wassenaar Arrangement in 2013 has been met with strong opposition, due to a variety of reasons, not least because it would undermine the production and spread of legitimate cyber defense tools. In addition, the technology's intangibility, movability and secrecy would vastly undermine verification.[479]

The access-as-a-service (AaaS) industry should be subject to "know your vendor law" when selling their services to governments

Despite its limited success, other attempts at controlling the proliferation of cyber capabilities have crystalized. The EU added a list of malwares to its dual-use export control list, subjecting companies to an approval process when exporting these technologies that would include information reporting requirements on location tracking devices, biometrics and surveillance equipment.[480] In 2018, the concept of intrusion software was included in the EU regulations.[481] And in September this year new EU rules, were introduced to increase transparency in controlling dual-use technologies, especially cyber surveillance technology. Due diligence guidelines are to follow.[482] It is key to continue such efforts to review and update regulations, especially given cyber technology's rapid advancements. One caveat to add is that Member States tend to apply export guidelines somewhat leniently to attract companies to seek licenses.[483]

Alternatively, in an effort to circumvent the challenges that come with restricting the proliferation of cyber products, the Atlantic Council recently suggested a framework to focus on cyber transactions rather than products. The access-as-a-service (AaaS) industry, which sells zero-days and exploitation services – and thus plays a key role in the proliferation of offensive cyber capabilities – should be subject to "know your vendor law" when selling their services to governments. A convincing case has been made that: "Coalition states should block companies that are caught misusing cyber capabilities or selling capabilities to states or entities on lists of concern from consideration in future government contracts, and further penalize their customers and partners."[484] Standardized risk assessment templates should further help AaaS companies self-regulate.

- ❖ Continuously review and update the EU dual-use export regulation
- ❖ Introduce "know your vendor laws" to the access-as-a-service industry
- ❖ Impose stricter regulations on cyber specialists offering their services to work for foreign governments

479 Joel P Trachtman and Herb Lin, "Using International Export Controls to Bolster Cyber Defenses," October 9, 2018, 17; Sergey Bratus et al., "Why Wassenaar Arrangement's Definitions of Intrusion Software and Controlled Items Put Security Research and Defense At Risk—And How To Fix It," October 9, 2014, 13.

480 Even before these changes, offensive cyber operations would be covered by Article 4 of the EU's dual-use regulation. This article is a catch-all clause that subjects the export of any good, software or technology which is not listed, but still requires authorization because the exporter is aware that they will be used in a way that would make them subject to export restrictions such as in the production of weapons of mass destruction. In these cases, the exporter is subject to reporting requirements. Blomstein, "Cybersecurity and Export Control," Company website, *Blomstein* (blog), November 5, 2020, https://www.blomstein.com/en/news.php?n=cybersecurity-and-export-control.

481 Jukka Ruohonen and Kai Kimppa, "Updating the Wassenaar Debate Once Again: Surveillance, Intrusion Software, and Ambiguity," *Journal of Information Technology & Politics* 16, no. 2 (April 3, 2019): 169–86, https://doi.org/10.1080/19331681.2019.1616646.

482 "#EUTrade News," Trade - European Commission, accessed September 14, 2021, https://trade.ec.europa.eu/doclib/press/index.cfm?id=2297.

483 Catherine Stupp, "Commission Plans Export Controls for Surveillance Technology," *Euractiv*, July 22, 2016, sec. Trade & Society, https://www.euractiv.com/section/trade-society/news/technology-companies-face-export-hurdles-under-draft-eu-rules/.

484 Winnona DeSombre et al., "A Primer on the Proliferation of Offensive Cyber Capabilities," Issue Brief (Washington D.C.: Atlantic Council, March 1, 2021), 21, https://www.atlanticcouncil.org/in-depth-research-reports/issue-brief/a-primer-on-the-proliferation-of-offensive-cyber-capabilities/.

Deployment

Controlling the deployment of offensive cyber operations is extremely complex given that cyber capabilities are intangible and secret, obstructing the verification mechanisms needed to ensure compliance to an agreement.[485] Verification would imply intrusive access to government networks that hardly any state would accept.[486] Moreover, it would not solve the use of offensive cyber capabilities by non-state actors.

Employment

Confidence-building measures could be a viable way to regulate offensive cyber capabilities.[487] These could include "notification of activities that might be observed but misinterpreted, means for communication during times of tension, agreed conventions for behavior, and non-interference with gathering data for verification of compliance."[488] An example is the US-Russia cyber hotline established in 2013. Previous efforts to build norms including those undertaken by the UN Group of Governmental Efforts (2015) and the Paris Call for Trust and Security in Cyberspace (2018) could be continued. Drawing red lines and making doctrines and capabilities more explicit can similarly be a form of arms control. Publicly attributing cyber-attacks is also a way to enforce arms control. While attribution is risky, it contributes to the development of cyber deterrence, which plays an important role in controlling the employment of offensive cyber capabilities.[489] The Netherlands recently included public attribution of cyber-attacks into its Cyber Defense Strategy as a mean to deter cyber aggression.[490] Remaining options include adding weapons of mass *disruption* to existing treaties.[491]

- Build notification procedures and crisis deconfliction mechanisms
- Build on efforts to set norms in cyberspace, including by the UN Group of Governmental Efforts and the Paris Call for Trust and Security in Cyberspace
- Add weapons of mass disruption to existing regulatory frameworks
- Enhance cyber situational awareness to increase transparency in the cyber domain
- Develop attribution frameworks (digital forensic, legal, political) to facilitate timely attribution and support deterrence
- Develop cyber deterrence (capability, communication, political will) posture

485 Andrew Futter, "What Does Cyber Arms Control Look like? Four Principles for Managing Cyber Risk" (European Leadership Network, June 2020).

486 Borghard and Lonergan, "Why Are There No Cyber Arms Control Agreements?".

487 Futter, "What Does Cyber Arms Control Look like? Four Principles for Managing Cyber Risk"; Borghard and Lonergan, "Why Are There No Cyber Arms Control Agreements?".

488 "Cybersecurity Dilemmas: Technology, Policy, and Incentives: Summary of Discussions at the 2014 Raymond and Beverly Sackler U.S.-U.K. Scientific Forum" (Washington, D.C.: National Academies Press, 2015), https://doi.org/10.17226/21833. 26.

489 Florian J. Egloff and Max Smeets, "Publicly Attributing Cyber Attacks: A Framework," *Journal of Strategic Studies*, March 10, 2021, 1–32, https://doi.org/10.1080/01402390.2021.1895117.

490 "Defensie Cyber Strategie 2018 - Investeren in digitale slagkracht Nederland," publicatie (Ministerie van Defensie, November 12, 2018), https://www.defensie.nl/downloads/publicaties/2018/11/12/defensie-cyber-strategie-2018.

491 Futter, "What Does Cyber Arms Control Look like? Four Principles for Managing Cyber Risk."

Lethal autonomous weapon systems

Key takeaways

As with AI, controlling the production and proliferation of LAWS is made difficult by the dual-use nature and intangibility of several of its components. While export regimes regulate some of these dual-use hardware and software, there are currently no international treaties and provisions specifically aimed at limiting the deployment of LAWS. Efforts could focus on norm-setting and deterrence postures.

Production

Standards and guidelines should be decided upon based on discussions generated in multistakeholder working groups

The current geopolitical situation makes it difficult to envision an international ban on the production and testing of LAWS. However, states could continue efforts to set national standards for the design, testing and evaluation of production of AI-enabled military systems, whereby ethical standards are translated into practical requirements for those involved in the development of LAWS, including programmers.[492] Such standards and guidelines should be decided upon based on discussions generated in multistakeholder working groups.[493] International efforts to share best practices and set international rules to produce LAWS could follow suit.

Legal compliance could be promoted. Article 36 of the Protocol Additional to the Geneva Conventions establishes that new weapons must undergo a legal review at the developmental stage to determine the legality of a weapon.[494]

- Ensure high-level ethical standards in the production phase and promote morally responsible engineering through the introduction of industry codes of conduct
- Work with multistakeholder working groups to ensure implementability and support
- Continue international dialogue, such as initiated by the CCW Group of Governmental Experts, to agree and commonly adopt system-tailored rules ensuring meaningful human control
- Promote legal compliance, e.g., through formalizing Article 36 in domestic procedures

Proliferation

The production of LAWS requires not only chips produced by semiconductor machinery, but also sophisticated hardware such as short-durability batteries and heavy power sources.[495] Such hardware components including delivery systems are often of dual-use nature and hence included in the dual-use control lists of export control regimes such as the Wassenaar Arrangement, the MTCR, the NSG, and the Australia Group. The Wassenaar Arrangement, the newly updated EU Regulation 2021/821, and the US Commerce Control List additionally

492 Jane Vaynman, "Better Monitoring and Better Spying: The Implications of Emerging Technology for Arms Control," *Texas National Security Review*, September 23, 2021, https://tnsr.org/2021/09/better-monitoring-and-better-spying-the-implications-of-emerging-technology-for-arms-control/. Esther Chavannes, Klaudia Klonowska, and Tim Sweijs, "Governing Autonomous Weapon Systems" (The Hague: The Hague Centre For Strategic Studies, 2020).

493 Frank Sauer, "Stopping 'Killer Robots': Why Now Is the Time to Ban Autonomous Weapons Systems," Arms Control Association, October 2016, https://www.armscontrol.org/act/2016-09/features/stopping-%E2%80%98killer-robots%E2%80%99-why-now-time-ban-autonomous-weapons-systems.

494 Daan Kayser and Stepan Denk, *Keeping Control: European Positions on Lethal Autonomous Weapon Systems* (PAX, 2017); "Additional Protocol (I) to the Geneva Conventions, 1977 - 36 - New Weapons," International Committee of the Red Cross, accessed September 16, 2021, https://ihl-databases.icrc.org/applic/ihl/ihl.nsf/WebART/470-750045.

495 Boulanin and Verbruggen, "Mapping the Development of Autonomy in Weapon Systems."

cover software embedding C3I and C4I systems as well as narrow, application-specific AI software, trained algorithms and dual-use datasets.[496] It is key to continuously revise and adjust existing export control lists including implementation and transparency mechanisms.[497] As will also be highlighted in the section on AI, regulating semiconductor machinery and expertise may be more promising, and less controversial, compared to using export controls for software and chips.[498]

Despite the existence of such tools, challenges for future export control remain. The fact that software underpinning autonomous weapons perform functions such as target identification, classification, or selection are developed through collaborative methods, such as open-source software, undermine efforts to stop the proliferation of different components of these weapons.[499] Furthermore, in June 2020, the Trump administration announced the loosening of export restrictions on unmanned aerial vehicles through the country's reinterpretation of the Missile Technology Control Regime (MTCR). The loosening of export restrictions exempts unmanned aerial vehicles that fly at speeds below 800 kph from the "presumption of denial" under the MTCR regime.[500] Finally, experts have argued that export controls will unlikely be successful in restraining the development of AI capabilities given that the private sector and government regulation usually lag emerging technologies.[501] Finally, imposing restrictions in this field may hinder the civilian development and use of such technology.

- ❖ Continuously revise and adjust existing export control lists, including the Wassenaar Arrangement, the MTCR and EU dual-use regulations
- ❖ Strictly control the export of semiconductor equipment while implementing tailored end-use and end-user controls on chips only
- ❖ Explore options to limit the proliferation of expertise, e.g., imposing contract obligations

Deployment

Because the *use* of a weapon system, rather than its technological features, renders it a lethal autonomous weapon system, traditional quantitative arms control efforts are unlikely to succeed.[502] Instead, international efforts could focus on ensuring that meaningful human control is maintained when autonomous weapon systems are deployed.[503] Through international dialogue, consensus needs to be built on the minimum standards for human control over systems to be deployed. Such standards will likely vary broadly as each system, its intended use, and operating environment will be different (see the next section on employment).[504] If successful, future efforts may then focus on establishing verification mechanisms.

496 "LAWS and Export Control Regimes: Fit for Purpose?"

497 Chavannes, Klonowska, and Sweijs, "Governing Autonomous Weapon Systems."

498 "Export Controls in the Age of AI," War on the Rocks, August 28, 2019, https://warontherocks.com/2019/08/export-controls-in-the-age-of-ai/.

499 "LAWS and Export Control Regimes: Fit for Purpose?"

500 Aaron Mehta and Valerie Insinna, "Trump Admin Officially Makes It Easier to Export Military Drones," *Defense News* (blog), July 24, 2020, https://www.defensenews.com/industry/2020/07/24/us-state-department-officially-makes-it-easier-to-export-military-drones/.

501 Horowitz, "When Speed Kills."

502 Maya Brehm, "Defending the Boundary: Constraints and Requirements on the Use of Autonomous Weapon Systems Under International Humanitarian and Human Rights Law," Academic Briefing, May 2017, 16, http://www.ssrn.com/abstract=2972071.

503 "Autonomous Weapons: The ICRC Recommends Adopting New Rules," ICRC, August 3, 2021, https://www.icrc.org/en/document/autonomous-weapons-icrc-recommends-new-rules.

504 Vincent Boulanin, "Limits on Autonomy in Weapon Systems: Identifying Practical Elements of Human Control," n.d., 53.

There is no one-size-fits-all solution

Furthermore, the importance of educating and engaging military personnel on the ethical issues brought along by the deployment of LAWS cannot be overstated.[505]

- ❖ Foster international dialogue on LAWS deployment, especially among US, Russia, and China
- ❖ Provide training to military personnel on the ethical issues related to the deployment of LAWS

Employment

International Humanitarian Law (IHL) has so far been the main legal reference when it comes to controlling the deployment and use of LAWS. The eleven guiding principles suggested by the Group of Governmental Expert of the CCW and adopted by the States Parties highlight how LAWS must comply with existing principles of IHL, especially distinction, proportionality and precaution.[506] This may be challenging. For instance, while the Israeli Harpy can identify a radar, it cannot determine whether it would be surrounded by civilians. Moreover, an autonomous system may find it hard to establish whether the collateral damage or civilian loss of life is excessive in relation the military advantage anticipated. When it comes to precaution, again "the type of assessments required to comply (...) are highly complex and very difficult to translate into an algorithmic form."[507] To regulate the employment of LAWS, it is necessary to retain human control over these systems. A future treaty to regulate the employment of LAWS could include the obligation to have meaningful human control over LAWS.[508]

The key challenge currently lies with designing functions, such as targeting, in ways that meaningful human control is maintained. Such efforts are challenging because there is no one-size-fits-all solution.[509] For instance compare the AI-enabled Goalkeeper used at sea against anti-ship missiles with (semi-) autonomous weapons deployed in urban environments. Sharing best practices and case studies into specific systems are key steps to promote human control in the development, deployment and employment of LAWS. Initiatives in this regard are currently undertaken by the International Panel on the Regulation of Autonomous Weapons (iPRAW). Further progress can be achieved by developing and implementing a general scheme that operationalizes how human control can be ensured in a variety of contexts, prescribing minimum standards of controllability. This would entail setting controls over the parameters of its use (target type and profile, weapon mobility and operation duration, weapon effects, and fail-safe rules and mechanisms); the environments in which LAWS may be used; and how human-machine interaction takes place.[510] Legal accountability could additionally be promoted, also in cases where no harmful intent can be determined, for instance through a tort law approach and the assignation of a legal "personhood" to LAWS.[511]

505 Chavannes, Klonowska, and Sweijs, "Governing Autonomous Weapon Systems," 19.

506 "Meeting of the High Contracting Parties to the Convention on Prohibitions or Restrictions on the Use of Certain Conventional Weapons Which May Be Deemed to Be Excessively Injurious or to Have Indiscriminate Effects - Final Report" (CCW, November 5, 2019).

507 Boulanin and Verbruggen, "Mapping the Development of Autonomy in Weapon Systems," 74.

508 Frank Sauer, "Stepping Back from the Brink: Why Multilateral Regulation of Autonomy in Weapons Systems Is Difficult, yet Imperative and Feasible," *International Review of the Red Cross* 102, no. 913 (April 2020): 235–59, https://doi.org/10.1017/S1816383120000466; Bonny Docherty, "The Need for and Elements of a New Treaty on Fully Autonomous Weapons," Human Rights Watch, June 1, 2020, https://www.hrw.org/news/2020/06/01/need-and-elements-new-treaty-fully-autonomous-weapons.

509 Sauer, "Stepping Back from the Brink."

510 Boulanin, "Limits on Autonomy in Weapon Systems: Identifying Practical Elements of Human Control," 30–33.

511 Elizabeth Fuzaylova, "War Torts, Autonomous Weapons, and Liability," *Cardozo Law Review* 40, no. 3 (March 5, 2019), https://cardozolawreview.com/war-torts-autonomous-weapon-systems-and-liability/; Joanna J. Bryson, Mihailis E. Diamantis, and Thomas D. Grant, "Of, for, and by the People: The Legal Lacuna of Synthetic Persons | SpringerLink," *Artificial Intelligence Law* 25 (September 8, 2018): 273–91.

Finally, unilateral declaratory statements outlining under which circumstances and to what ends LAWS will be employed can further enhance trust. Declaratory policy can also be used to communicate red lines and deterrence by punishment tools a state is willing to implement.

- ❖ Share best practices and develop context-specific human control standards
- ❖ Apply tort law by subjecting LAWS to strict liability regimes that allow to hold a defendant accountable even without evidence of clear fault
- ❖ Assign a legal personhood to LAWS to grant compensation to parties injured by an autonomous system
- ❖ Promote trust by declaring the ways in which LAWS could be used
- ❖ Examine the possibilities and constraints associated with deterring adversaries from deploying LAWS

Remote sensing

In contrast with the other technologies discussed, controlling the production, proliferation, deployment and employment of remote sensing technology is unlikely, and undesirable, too. Both academic and public discussions have pointed to the advantages brought about by the proliferation of open-source intelligence, not least through its use for increased verification tools in arms control.[512] Still, the proliferation of remote sensing devices is not unrestricted. In the United States, commercial launch and reentry vehicles and spaceports are regulated by the Federal Aviation Administration; remote sensing satellites are licensed by the National Oceanic and Atmospheric Administration; and the exports of space technology and Earth remote sensing from space are regulated by the Department of Commerce and State.[513] Further, the US Commerce Control List regulates exports of dual-use satellite technologies, including remote sensing satellite components and specially designed complementary accessories.[514] In the EU, Regulation (EC) No 2021/821 subjects special dual-use components used in the production of remote sensors to export controls. These include "monospectral imaging sensors and multispectral imaging sensors designed for remote sensing application."[515] Additionally, regulations in the aviation sector have long hampered the use of UAVs for remote sensing capabilities,[516] but recently some of these restrictions were eased.[517] Such efforts remain key to restrain the spread of such systems to certain actors. Further study is needed to examine ways to increase the resilience of systems whose survivability may be undermined by remote sensing and minimize the risks associated with the technology.

- ❖ Continue to implement, verify and update export control regimes applicable to remote sensing
- ❖ Increase the resilience of systems whose survivability may be undermined by remote sensing

512 Christopher Lawrence, "Heralds of Global Transparency: Remote Sensing, Nuclear Fuel-Cycle Facilities, and the Modularity of Imagination," *Social Studies of Science* 50, no. 4 (August 1, 2020): 508–41, https://doi.org/10.1177/0306312719879769; "Open-Source Intelligence Challenges State Monopolies on Information," *The Economist*, August 7, 2021, https://www.economist.com/briefing/2021/08/07/open-source-intelligence-challenges-state-monopolies-on-information?itm_source=parsely-api.

513 Daniel Morgan, "Commercial Space: Federal Regulation, Oversight, and Utilization" (Congressional Research Service, November 29, 2018), https://sgp.fas.org/crs/space/R45416.pdf.

514 U.S. Department of Commerce and Federal Aviation Administration, "Introduction to U.S. Export Controls for the Commercial Space Industry" (Washington D.C.: U.S. Department of Commerce, 2017), https://www.faa.gov/about/office_org/headquarters_offices/ast/media/export_controls_guidebook_for_commercial_space_industry_doc_faa_nov_508.pdf.

515 Annex I – Category 6 – Sensors and Lasers – 6A001; Regulation (EU) 2021/821 of the European Parliament and of the Council of 20 May 2021.

516 Mohd Noor, Abdullah, and Hashim, "Remote Sensing UAV/Drones and Its Applications for Urban Areas: A Review."

517 The Economist, "Business Is Booming as Regulators Relax Drone Laws," *The Economist*, June 17, 2021, https://www.economist.com/science-and-technology/2021/06/17/business-is-booming-as-regulators-relax-drone-laws.

Table 19. Arms control policy agenda

	Production	Proliferation	Deployment	Employment
Hypersonic missiles	• Expand the HCoC to including pre-launch notification obligations for hypersonic missile tests	• Expand coverage of existing export regimes, notably MTCR and UNSCR 1540	• Limit sites where nuclear-tipped (hypersonic) missiles may be deployed.	• Promote data exchanges including advance test notifications • Restrain sea-based tests • Separate launch locations as well as nuclear and conventional assets • Publicly specify that hypersonic missiles will be conventionally-tipped only and used against conventional targets only • Explore both punishment- and denial-based deterrence options
Anti-satellite weapons (ASATs)	• Clear inconsistencies in the OST and further control ASAT tests • Promote pre-launch notifications for ASATs tests under existing regimes such as the HCoC	• Expand coverage and increase verification of existing export regimes, such as MTCR and UNSCR 1540	• Clear inconsistencies in the OST and (further) limit the deployment of ASATs • Place limits on the proximity of space objects • Enhance verification through broadcasting obligations and potentially shared SSA capabilities	• Work towards an international code of conduct for space, building on existing efforts such as the UK-sponsored UN resolution A/RES/75/36 • Implement national and international space situational awareness systems to monitor and enforce space activities • Explicitly include the risks associated with ASATs in bilateral and multilateral strategic dialogues concerning nuclear weapons • Examine the possibilities and constraints associated with space deterrence
Directed-energy weapons	• Clear inconsistencies in the OST and further regulate the testing of space-based DEWs • Step up verification, potentially through shared situational awareness capabilities	• Refine and reinforce existing arms control regimes including the Arms Trade Treaty and the Wassenaar Arrangement	• Start the discussion of international rules limiting the number of DEWs that can be deployed through formal gov-to-gov talks (track 1) and expert-to-expert (track 2) meetings	• Establish a working group of legal experts to reflect on the legal implications of collateral damage of DEW • Include the use of DEWs in the efforts to set norms for behavior in space
Dual-capable Missiles		• Reinforce the implementation and verification of MTCR	• Limit the deployment of nuclear-tipped missiles, e.g. by banning nuclear weapons from sites	• Publicly commit to no-first-use • Work internationally to create pre-launch notification protocols
Missile defense			• Reflect on the utility of missile defense as a bargaining chip to facilitate further arms control discussions, also including offensive weapons	• Ensure and communicate that defensive systems are not intended to undermine second strike capabilities • Clearly separate strategic from regional missile defense efforts • Consider regional rather than global solutions tailored to specific regional strategic constraints • Determine and limit the minimally required nuclear arsenal size to ensure a second strike capability vis-à-vis adversaries' strategic missile defense postures
Offensive cyber capabilities	• Invest in AI-enabled coding to limit opportunities for zero-day exploits • Impose stricter regulations for software developers to prioritise security over efficiency • Identify and fix potential zero-day exploits by bolstering cooperation with hackers	• Continuously review and update EU export control rules • Introduce "know your vendor laws" to the access-as-a-service industry • Impose stricter regulations on cyber specialists offering their services to work for foreign governments		• Build notification procedures and crisis deconfliction mechanisms • Build on efforts to set norms in cyberspace, including by the UN Group of Governmental Efforts and the Paris Call for Trust and Security in Cyberspace • Add weapons of mass disruption to existing regulatory frameworks • Enhance cyber situational awareness to increase transparency in the cyber domain • Develop attribution frameworks (digital forensic, legal, political) to facilitate timely attribution and support deterrence • Develop cyber deterrence (capability, communication, political will) posture

Table 19. Arms control policy agenda (continued)

	Production	Proliferation	Deployment	Employment
LAWS	• Ensure high-level ethical standards in the production phase and promote morally responsible engineering through the introduction of industry codes of conduct • Work with multistakeholder working groups to ensure implementability and support • Continue international dialogue, such as initiated by the CCW Group of Governmental Experts, to agree and commonly adopt system-tailored rules ensuring meaningful human control • Promote legal compliance, e.g., through formalizing Article 36 in domestic procedures	• Continuously revise and adjust existing export control lists, including the Wassenaar Arrangement, the MTCR and EU dual-use regulations • Strictly control the export of semiconductor equipment while implementing tailored end-use and end-user controls on chips only • Explore options to limit the proliferation of expertise, e.g., imposing contract obligations	• Foster international dialogue on LAWS deployment, especially among US, Russia, and China • Provide training to military personnel on the ethical issues related to the deployment of LAWS	• Share best practices and develop context-specific human control standards • Apply tort law by subjecting LAWS to strict liability regimes that allow to hold a defendant accountable even without evidence of clear fault • Assign a legal personhood to LAWS to grant compensation to parties injured by an autonomous system • Promote trust by declaring the ways in which LAWS could be used • Examine the possibilities and constraints associated with deterring adversaries from deploying LAWS
Remote sensing		• Continue to implement, verify and update export control regimes applicable to remote sensing		• Increase the resilience of systems whose survivability may be undermined by remote sensing
AI	• Ensure high-level ethical standards in the production phase and promote morally responsible engineering through the introduction of industry codes of conduct • Continue international dialogue, such as initiated by the CCW Group of Governmental Experts, to agree and commonly adopt system-tailored rules ensuring meaningful human control • Promote legal compliance, e.g., through formalizing Article 36 in domestic procedures	• Continuously review and update tailored dual-use export control lists that include AI software, algorithms and datasets • Strictly control the export of semiconductor equipment while implementing tailored end-use and end-user controls on chips only • Explore options to limit the proliferation of expertise, e.g., imposing contract obligations	• Share best practices and develop context-specific human control standards • Establish regulations limiting the deployment of AI-enabled systems involved in warfighting only to highly tested and proven technologies under strict ethical regulations • Keep humans *in the loop* and require strict operator trainings; • Specify the conditions under which a human *on the loop* and *out of the loop* is legitimate and illegitimate • Implement cross-checking requirements • Boost system resilience through bolstering cyber security • Separate early warning from command and control	• Share best practices and develop context-specific human control standards • Promote the use of goal functions that cannot be changed by the AI-enabled system to ensure compliance with ethical, legal and military guidelines • Introduce the use of ethical governors to verify the legality of AI-driven actions (and potentially block them) • Openly communicate national regulatory frameworks, strategies and policies • Lower alert levels of AI enabled weapon systems in order to reduce inadvertent escalation (e.g., a battlefield equivalent of the "flash crash")
Dual-capable 3CI				• Establish confidence-building measures such as hotlines between key nuclear adversaries • Publicly highlight the escalatory risks associated with C3I entanglement • Publicly commit to not targeting one another's C3I capabilities • Strengthen deterrence by punishment posture by clearly communicating the consequences of attack on C3I capabilities

Artificial intelligence

Key Takeaways

The production, deployment and employment of AI-enabled military systems could to be controlled through setting baseline standards for meaningful human control, for which multistakeholder partnerships and national regulatory frameworks are key tools. Existing export control regimes are applicable to narrow and specific items only, but results are limited. Focusing on controlling semiconductor manufacturing equipment and expertise is most promising.

Production

While there may be no formal international agreements to limit the production and testing of AI-enabled weapons, the production of such systems is limited by the complexity of the machinery, enablers and technical expertise needed. For instance, the chips used in AI are produced through advanced semiconductor manufacturing equipment owned by very few countries, one of which being the Netherlands.[518] For now, access to advanced algorithms and extensive datasets is similarly limited to a selected group of states.

Limitations to the production of AI could be implemented at the national level through national directives aimed at "creating a common baseline understanding of concepts, actors, roles and responsibilities for the use of AI in military applications, including those supporting decision-making."[519] National guidelines for designing, testing and evaluating the broad variety of AI-enabled military systems could inform international discussions, such as held by the CCW Group of Governmental Experts. Finally, to promote legal compliance, states could formalize Article 36 of the Protocol Additional to the Geneva Conventions which establishes that new weapons must undergo a legal review at the developmental stage to determine the legality of a weapon.[520]

- ❖ Ensure high-level ethical standards in the production phase and promote morally responsible engineering through the introduction of industry codes of conduct
- ❖ Continue international dialogue, such as initiated by the CCW Group of Governmental Experts, to agree and commonly adopt system-tailored rules ensuring meaningful human control
- ❖ Promote legal compliance, e.g., through formalizing Article 36 in domestic procedures

Proliferation

Many components of artificial intelligence are intangible or small, complicating export control. Existing regimes, such as the Wassenaar Arrangement, the newly updated EU Regulation 2021/821, and the US Commerce Control List currently cover narrow, application-specific

518 Carrick Flynn, "Recommendations on Export Controls for Artificial Intelligence," CSET Issue Brief (Washington D.C., US: Center for Security and Emerging Technology, February 2020), https://cset.georgetown.edu/publication/recommendations-on-export-controls-for-artificial-intelligence/.

519 Giacomo Persi Paoli et al., "Modernizing Arms Control" (UNIDR, 2020), 24.

520 Kayser and Denk, *Keeping Control*; "Additional Protocol (I) to the Geneva Conventions, 1977 - 36 - New Weapons."

AI software, trained algorithms and dual-use datasets, as well as hardware.[521] Continuously reviewing such dual-use export control lists targeting specific and narrow items is key, even if controllability can prove challenging.

Caveats apply, however. One key concern is that export controls on software and other technologies connected to the development of AI would curb crucial research and development efforts, not only in the military but also in the civilian field. Export controls would undermine competitiveness and innovation.[522] What is more, if technology is being produced elsewhere, too, such restrictions are unlikely to yield desired effects. Instead, they would erode supply chain advantages for producing states including the United States, the Netherlands, South Korea, Germany, Japan and Taiwan.[523] Key exceptions here would be controlling semiconductor manufacturing equipment and expertise. With regard to the former, implementing and verifying controls is indeed relatively straightforward given the tangibility and size of such hardware.[524] When it comes to the latter, options to limit the proliferation of expertise, for instance through imposing contract obligations, could be explored.

Export controls would undermine competitiveness and innovation

- Continuously review and update tailored dual-use export control lists that include AI software, algorithms and datasets
- Strictly control the export of semiconductor equipment while implementing tailored end-use and end-user controls on chips only
- Explore options to limit the proliferation of expertise, e.g., imposing contract obligations

Deployment

Imposing quantitative limitations on carrier systems for AI weapons would not be particularly effective, as AI can easily be deployed on another system. In addition to setting standards on the deployment of AI, based on the principles set by the CCW, several measures could be foreseen to reduce the risks associated with the deployment of AI-enabled weapons. States could adopt unilateral technical measures, such as: rules establishing that only systems which have been tested rigorously can be deployed; ensuring that early warning is separate from command and control while keeping humans in or on the loop; requiring strict operator trainings; and boosting system resilience by setting cross-checking requirements and bolstering cyber security.[525]

- Share best practices and develop context-specific human control standards
- Establish regulations limiting the deployment of AI-enabled systems involved in warfighting only to highly tested and proven technologies under strict ethical regulations
    - Keep humans *in the loop* and require strict operator trainings
    - Specify the conditions under which a human *on the loop* and *out of the loop* is legitimate and illegitimate.
    - Implement cross-checking requirements
    - Boost system resilience through bolstering cyber security
- Separate early warning from command and control

521 Regulation (EU) 2021/821 of the European Parliament and of the Council of 20 May 2021.

522 Cade Metz, "Curbs on A.I. Exports? Silicon Valley Fears Losing Its Edge," *The New York Times*, January 1, 2019, sec. Technology, https://www.nytimes.com/2019/01/01/technology/artificial-intelligence-export-restrictions.html.

523 Flynn, "Recommendations on Export Controls for Artificial Intelligence."

524 "Export Controls in the Age of AI."

525 Hautecouverture, Maitre, and Tertrais, "The Future of Strategic Stability," March 2021, 12.

Employment

While there are no specific agreements regulating the employment of AI, ethical and moral considerations related to International Humanitarian Law somewhat restrict its employment for military purposes. Indeed, if applied in specific ways, such as swarming very large numbers of AI-enabled weapons, military AI could be considered a weapon of mass destruction and hence its employment could be limited. More importantly, principles of distinction, proportionality and precaution hinder the use of AI-enabled weapon systems. These principles indeed form the bedrock for the eleven principles set by the Group of Governmental Experts of the CCW. Principle-based standards to ensure meaningful human control in the use of AI can be implemented nationally. For instance, AI-enabled systems could be given goal functions, whereby intelligent systems cannot change mission or tasks mid-operation to ensure compliance with legal, ethical and military guidelines.[526] Furthermore, the use of an "ethical governor" could verify if algorithm-driven decisions comply with IHL and respond to operational orders, and blocking action if this is not the case.[527]

Confidence-building measures could be used to promote good practices in AI. An example of a successful confidence-building measure is the Global Partnership on Artificial Intelligence, a multistakeholder partnership promoting trust and the sharing of AI research and development efforts.[528] In addition, openly communicating national regulatory frameworks, strategies and policies for the use of AI to potential adversaries could help avoid misinterpretation and therewith reduce risks of escalation.[529] Finally, changing alert levels is an option to be considered.[530]

- ❖ Share best practices and develop context-specific human control standards
- ❖ Promote the use of goal functions that cannot be changed by the AI-enabled system to ensure compliance with ethical, legal and military guidelines
- ❖ Introduce the use of ethical governors to verify the legality of AI-driven actions (and potentially block them)
- ❖ Openly communicate national regulatory frameworks, strategies and policies
- ❖ Lower alert levels of AI enabled weapon systems in order to reduce inadvertent escalation (e.g., a battlefield equivalent of the "flash crash")

Dual-capable C3I systems

Key Takeaways

Arms control options for dual-capable C3I systems are limited. Because C3I assets are an enabler and not a weapon, efforts are limited to reducing and highlighting escalation risks, such as deconfliction lines and declaratory postures. Nuclear powers are the principal, if not the sole, players in such efforts.

526 Frans, "Governing ethical and effective behaviour of intelligent systems," Text, June 21, 2019, https://www.militairespectator.nl/thema/operaties-ethiek/artikel/governing-ethical-and-effective-behaviour-intelligent-systems.

527 Bonnie Docherty, *Losing Humanity: The Case against Killer Robots* (Amsterdam Berlin: Human Rights Watch, 2012).

528 Between Australia, Brazil, Canada, France, Germany, India, Italy, Japan, Mexico, Netherlands, New Zealand, Poland, South Korea, Singapore, Slovenia, Spain, the United Kingdom, the United States and the European Union.

529 Persi Paoli et al., "Modernizing Arms Control," 3.

530 Hautecouverture, Maitre, and Tertrais, "The Future of Strategic Stability," 12.

Production, proliferation, deployment

Limiting dual-capable command, control, communications and intelligence (C3I) will prove challenging, especially as countries increasingly rely on the entanglement of these assets for practical or strategic reasons – as discussed in Chapter 2. As is the case for dual-capable missiles, attempts at controlling the production and proliferation of dual-capable C3I will likely prove futile, since production is straightforward and no specific dual-capable technologies can be targeted. The EU Dual-Use Regulation 2021/821 does however subject components of command, control, communications and intelligence (C3I), including software, to export controls.[531] In theory, agreements can be sought to limit the deployment of such assets, but issues of verification will likely stand in the way since countries are deliberately ambiguous about their nuclear C3I.

Employment

Nuclear states could declare to avoid attacks on C3I assets altogether to reduce risks of escalation

When it comes to the use of such assets, efforts could focus on reducing the escalation risks associated with entanglement. These include establishing deconflicting channels between nuclear adversaries in case assets used for both nuclear and conventional forces are hit.[532] Alternatively, declaratory policy highlighting the risk of dual-use C3I may be used for risk management. In its 2018 Nuclear Posture Review, the United States for instance warned of a potential nuclear response to a conventional attack on a nuclear-related C3I asset. Some have warned that this statement is too bellicose, and advise that declaratory policies are formulated more vaguely.[533] Alternatively, nuclear states could declare to avoid attacks on C3I assets altogether to reduce risks of escalation.[534]

- ❖ Establish confidence-building measures such as hotlines between key nuclear adversaries
- ❖ Publicly highlight the escalatory risks associated with C3I entanglement
- ❖ Publicly commit to not targeting one another's C3I capabilities
- ❖ Strengthen deterrence by punishment posture by clearly communicating the consequences of attack on C3I capabilities

Conclusion: from measures individual to a comprehensive policy agenda

This chapter has set out a policy agenda for measures aimed at reducing the risk of arms races, seeking to limit the production, proliferation, deployment and employment (PPDE) of emerging technologies; and at tools aimed reducing the risks of escalation associated with new technologies. These are summarized in Table 19.

531 Regulation (EU) 2021/821 of the European Parliament and of the Council of 20 May 2021.

532 Steven E. Miller, "Nuclear Hotlines: Origins, Evolution, Applications," *Journal for Peace and Nuclear Disarmament* 4, no. sup1 (March 5, 2021): 176–91, https://doi.org/10.1080/25751654.2021.1903763; Dmitri Trenin, "Stability amid Strategic Deregulation: Managing the End of Nuclear Arms Control," *The Washington Quarterly* 43, no. 3 (July 2, 2020): 161–75, https://doi.org/10.1080/0163660X.2020.1813401.

533 Acton, "Escalation through Entanglement."

534 Favaro, "Weapons of Mass Distortion: A New Approach to Emerging Technologies, Risk Reduction, and the Global Nuclear Order," 21.

6. **Conclusion:** key findings and recommendations

Key takeaways

- This chapter synthesises the major findings and outlines recommendations for an arms control, non-proliferation and deterrence agenda.
- Europeans could dampen escalatory pressures on the US by strengthening their capability for conventional deterrence-by-denial.
- In contrast to the Cold War, arms control could shift from production to limiting application.
- But production and proliferation can be dampened through coordination and collaboration.
- Risk reduction can be strengthened through specification, verification, and declaration.
- Norms and rules are more difficult in a low-trust, competitive environment; however, shared interests to prevent inadvertent escalation remain consistent.

Intensifying geopolitical competition and multipolarity have created opportunities for rivals of the United States to use emerging technologies for strategic advantage against an extra-regional guarantor, meaning the United States, that relies on access to the regions where it has extended deterrence commitments. The United States dominated the post-Cold War environment and was able to project its power anywhere on the planet. In response, its adversaries looked at both conventional and nuclear means to raise the costs for a US presence in their vicinity, and thereby the costs of a possible US intervention.[535] The key message here is that increased geopolitical competition and hostility has not only brought nuclear weapons back on the global stage as a major tool of grand strategic statecraft, but that the full return of nuclear politics interacts with the struggle over conventional advantages through emerging technologies. Actors of all kinds – great powers, regional powers, and states that have become nuclear powers only in the last decades – are engaged in both dynamics. While we separate geopolitical trends from technological trends throughout the report for the sake of analytical clarity, clearly both trends interact with and reinforce each other. Yet, many technologies that are part of this conventional agenda – missiles, C3I, and countermeasures in a heavily informationized environment – have clear applications in and consequences for both the conventional and nuclear domains.

535 Biddle and Oelrich, “Future Warfare in the Western Pacific”; Montgomery, “Contested Primacy in the Western Pacific”; Tangredi, *Anti-Access Warfare*; Van Hooft, “All-In or All-Out: Why Insularity Pushes and Pulls American Grand Strategy to Extremes.”

Non-proliferation, arms control and deterrence measures are part of a policy portfolio that states use to strengthen strategic stability. Both geopolitical and technological developments are fundamentally reshaping the foundations of strategic stability. This study has offered an analysis of the impact of these developments in order to highlight risks as well as opportunities for an arms control agenda going forward. In addition, it has introduced a new analytical framework to assess the difficulty with which weapon technologies can be produced, proliferated, deployed and employed. Using this framework to analyze the ten emerging technologies, the report has identified tailored policy measures to limit their risks. In addition, the overview of measures provides policymakers with a blueprint for a broader integrated arms control, non-proliferation and deterrence agenda for the 2020s. The analysis warrants the following key conclusions and recommendations:

Keep a lid on further nuclearization, Europe

Conventional deterrence could offer an avenue to keep a lid on the Pandora's Box of re-nuclearization of European security

Europe has a limited role in the emerging geopolitical environment that centers around a trilateral American-Russian-Chinese nuclear relationship interacting with other smaller regional relationships. However, European states could further address the conventional imbalance between NATO Europe and Russia. The conventional imbalance in NATO's northeast adds escalatory pressure to the United States to fill the deterrence gaps in the escalation ladder through greater flexibility in its nuclear arsenal and investments in advanced conventional weapons. In the realm of strategic stability, a distinction can be made between deterrence by punishment (raising costs of aggression by punishment after the fact) and deterrence by denial (raising costs during aggression). Nuclear weapons are nearly exclusively used for deterrence by punishment. An avenue to prevent the re-nuclearization of European security is therefore to strengthen Europe's capability for conventional deterrence by denial. In combination with a comprehensive effort to contain and curb proliferation of nuclear weapons as well as critical delivery vehicles, conventional deterrence could offer an avenue to keep a lid on the Pandora's Box of re-nuclearization of European security by the United States, Russia, or others in the 2021-2035 period. Similar to the success of Cold War arms control and non-proliferation efforts, acquiring such capabilities would also improve the negotiation position of European states to pursue new arms control agreements with Russia.

The report has delineated several conventional imbalances that states sought to offset through nuclear weapons, and vice versa, in every region. The status of the United States as guarantor of extended deterrence to its allies in Europe, Asia, and the Middle East, further complicates matters. As an extra-regional hegemon, from the beginning of the nuclear age, the United States has had to make greater efforts to maintain credibility in each region.[536] It has done so by building nuclear and conventional capabilities that give it greater flexibility; its first use policy is a consequence of its extended deterrence policy. While seemingly counterintuitive, and an unconventional avenue for arms control, European improvements to their conventional deterrence by denial postures would increase the costs and lower the benefits

536 Alexander Lanoszka, *Atomic Assurance: The Alliance Politics of Nuclear Proliferation* (Cornell University Press, 2018); Gavin, "Strategies of Inhibition"; Van Hooft, "The US and Extended Deterrence."

of aggression for Russia and thereby diminish the pressure on the United States.[537] NATO's deterrence would consequently be less dependent on a United States that is increasingly under pressure by multi-regional commitments. The alternative is a re-nuclearization of the European theater.

Take nuclear weapons out of their conceptual silo

Compared to the past, today the focus lies much less on arsenal size reductions

Emerging technologies could re-open the door of arms racing for first strike advantages and secure second strikes. Nuclear stalemate is reversible and the nuclear revolution is not absolute, a reality that has not entirely dawned on European policymakers. The sophistication of precision-guided weapons through sensing, data fusion, and machine speed responses provides military planners with nuclear as well as conventional counterforce options, as these advanced conventional weapons can fulfill some of the same tasks as nuclear weapons due to increased precision.[538] Moreover, emerging technologies, such as cyberweapons, can cripple both conventional and nuclear infrastructures, whether deliberately or by accident. The risk of conventional and nuclear entanglement and inadvertent nuclear escalation has therefore significantly increased, as states might increasingly face situations where they use-it-or-lose-it,[539] and blurring the lines between conventional and nuclear war.[540]

Expand the arms control agenda, and differentiate

The good news is that emerging technologies lend themselves to a wide variety of non-proliferation, arms control and deterrence measures along the PPDE chain. The toolbox to limit or control the production, proliferation, deployment and use of new technologies is based on time-tested methods complemented by newer ones. Noticeable is the fact that compared to the past, today the focus lies much less on arsenal size reductions: traditional quantitative arms control measures that were salient in previous times (INF, START, ABM) have become less relevant for newer technologies. This is partly political: multipolarity lends itself for various reasons less to a quantity-based approach because different geopolitical dynamics ask for different arms control solutions. But the intangible nature of several of the emerging technologies makes capping deployment also technically complex, if not impossible. Verification is problematic

537 See recommendations along those lines: Alexander Lanoszka and Luis Simon, "The Post-INF European Missile Balance: Thinking About NATO's Deterrence Strategy," *Texas National Security Review* 3, no. 3 (2020), https://tnsr.org/2020/05/the-post-inf-european-missile-balance-thinking-about-natos-deterrence-strategy/; Eugene Gholz, Benjamin Friedman, and Enea Gjoza, "Defensive Defense: A Better Way to Protect US Allies in Asia," *The Washington Quarterly* 42, no. 4 (October 2, 2019): 173, https://doi.org/10.1080/0163660X.2019.1693103; Paul Van Hooft, "The United States May Be Willing, but No Longer Always Able: The Need for Transatlantic Burden Sharing in the Pacific Century," in *The Future of European Strategy in a Changing Geopolitical Environment: Challenges and Prospects*, ed. Michiel Foulon and Jack Thompson (The Hague, Netherlands: The Hague Centre for Strategic Studies, 2021).

538 O'Donnell, "Managing Nuclear Multipolarity." Glaser and Fetter, "Should the United States Reject MAD?"

539 Acton, "Escalation through Entanglement"; Talmadge, "Would China Go Nuclear?"; Cunningham and Fravel, "Assuring Assured Retaliation."

540 Miller and Arbatov, "The Rise and Decline of Global Nuclear Order?" Lieber and Press, "The New Era of Counterforce."

both politically and technically – and this is not just the case for largely intangible technologies such as cyber but also anti-satellite weapons. At the same time, for some of these technologies, most notably AI and LAWS, the deployment phase does lend itself to novel measures aimed at reducing risks and ensuring compliance with legal, ethical and operational guidelines.

With some exceptions, the emphasis of arms control is shifting from controlling primary production inputs to limiting their military applicability and proliferation. Because emerging technologies are often of dual-use nature and intangible or miniaturized, traditional export control tools are increasingly difficult to design, implement, and verify. As a result, dual-use export control lists need to be highly specific and tailored; and because of the extremely fast-paced environment, continuously revised and updated. For some technologies, such as cyber, AI and LAWS, limiting the proliferation of expertise could be promising. Within this complex set of relationships, four robust and general solutions stand out. Each of these encompasses the longer and more detailed list of solutions presented in chapter 5 Table 19.

Curb production and proliferation: update, coordinate, collaborate

When the deployment of technologies cannot be curbed, at least the risks associated with deployment and use should be controlled to prevent inadvertent escalation

The first entails curbing production and proliferation. Traditional export control regimes are challenged but still relevant. In their role as major producers and consumers of high-end technology, the EU, and the Netherlands particularly, have much greater leverage in setting the standards for dual-use technologies. Constantly reviewing and revising specific and tailored export list is key, even if they are hard to implement and verify, and technological developments fast outpace regulation efforts. Involving the private sector in creating and evaluating export regulations is crucial to ensure support and ease of implementation; while their activities rather than products can also be specifically targeted through know-your-vendor laws. The proliferation of knowledge and expertise can be countered by contract obligations. More traditional measures such as pre-launch notifications for tests or stricter regulation for testing could help curb the production of tangible, more traditional technologies such as hypersonic missiles, ASATs, DEWs and missile defense.

Reduce risk through technical and political means: specify, verify, declare

The second type of solutions involves risk reduction: when the deployment of technologies cannot be curbed, at least the risks associated with deployment and use should be controlled to prevent inadvertent escalation. Risk reduction can be achieved both through technical and political means. Cross-checking is crucial when dealing with automation, but necessary more generally in an age of mis- and disinformation. Relevant confidence-building measures include political deconfliction lines (“hotlines”), technical cross-verification measures, and optimal situational awareness capabilities, preferably shared. Unilateral declaratory statements may further enhance trust, specifying the ways in which weapons may be used. For hypersonic missiles, this could entail declaring conventional use only; refraining from deploying dual-capable missiles could similarly be considered. Declaratory statements can also be used to increase risk-awareness.

Develop norms and rules: shape, regulate, demonstrate

The third set of measures aims at regulating the production, deployment and use of technologies by setting norms and rules. Developing and implementing frameworks through which self-restraint is exercised is a good start; efforts to share such rules and norms internationally should follow suit. Europe could play the role of a mediator between the US and Russia, and between the US and China. Particularly with China, Europe could help with the socialization of the norms built up during the Cold War. Currently, tools that are being developed include frameworks that ensure human control over AI-enabled systems. Discussions here are led by states that cherish principles set by International Humanitarian Law, yet they should not be limited to democratic states only. Even if underlying motivations may differ, the incentive to maintain certain degrees of human control is shared more widely if it comes down to preventing nuclear escalation. Furthermore, regulation tools should be co-developed and shared with (and, if needed, imposed on) private sector actors. Industry codes of conduct and security-over-efficiency rules are among the tools at hand.

Strengthen integrated deterrence: communicate, attribute, reciprocate

Finally, deterrence remains an important policy pillar in support of strategic stability. While not commonly discussed in tandem with arms control and non-proliferation, integrated deterrence postures may complement these measures aimed at risk reduction. It is noticeable that deterrence by denial is becoming increasingly difficult and that given the expansion of domains and instruments, deterrence is likely to be more cross domain in nature than in the past, which requires robust, integrated deterrence postures. New technologies are ever faster and more efficient, to the detriment of traditional defensive measures such as hardening. And while defense against cyber tools can certainly be enhanced, completely bulletproof software is unlikely. Transparency and attribution is key, especially when it comes to more secretive technologies such as cyber. As a result, one can either foresee a shift to deterrence by punishment or newer forms such as deterrence through entanglement (even if risky) and cumulative deterrence complemented with efforts to build norms in a more integrated fashion.[541]

Find common ground: we are in this together

In times of increased international competition and eroding trust, working towards arms control and achieving the intended effects of confidence-building measures will prove challenging. States are naturally inclined to seek comparative advantages, a tendency which is

541 See, for example, the discussion on asymmetric deterrence in: de Wijk, "The Role of Deterrence in a New European Strategic Environment."

further exacerbated by notions such as a winner-takes-all market for AI and fears of a hypersonic missile gap. The current climate of increasing geopolitical competition between great powers and regional powers alike only further undermines collective action. Fortunately, it can be concluded that the arms control agenda expands, combining time-tested measures with novel ones. Finding ways to develop an arms control and counterproliferation agenda in times of low trust will thus be one of the major challenges ahead. But efforts are by no means futile. The stakes in strategic stability are high for everyone. It is only through negotiation and communication that states can hope to prevent the breakdown of strategic stability and avoid disaster.

The stakes in strategic stability are high for everyone

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