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Emerging technology and nuclear security: What does the wisdom of the crowd tell us?

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ABSTRACT

What is the impact of emerging technologies on nuclear security and disarmament? Current rapid technological advances are taking place against the backdrop of increased investments in modernizing nuclear arsenals, rising tensions among great powers, and increased pressure on nuclear arms control agreements. Yet, the anticipated net effect of these emerging technologies on the nuclear landscape remains ambiguous. Through a survey with 85 experts and a series of elite interviews with 14 decision-makers, this article contends that while emerging technologies destabilize nuclear deterrence by increasing nuclear risk, they can also create fresh opportunities for nuclear disarmament. Given that new technologies are changing the nature of nuclear threats, this article also argues that we need to change the way we think about arms control if we want to respond effectively to the threats posed by emerging technologies.

KEYWORDS Nuclear disarmament; nuclear weapons; emerging technology; expert survey

The impact of emerging technologies on the future of international security has become a topic of high policy and societal relevance. The United Nations (UN) Secretary-General, Antonio Guterres, noted in 2020 that the rapid advancement of technology is one of the most formidable security challenges we will face this century (Guterres, 2020). Increasingly, issues related to emerging technologies are being discussed in the nuclear realm. Advances in cyberspace and new technologies like artificial intelligence (AI) and hypersonic weapons are directly impacting the ways in which we think about nuclear deterrence, crisis stability, nuclear monitoring and verification as well as nuclear disarmament. These emerging technologies have at once produced a set of challenges and opportunities for the nuclear field.

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Scholars and practitioners have begun to study the intersection of emerging technologies and nuclear deterrence (Acton, 2018, 2020; Chyba, 2020; Sechser et al., 2019; Williams, 2020). Much of this work focuses on the impact that emerging technologies have on risk perception, crisis instability, and crisis escalation. Less attention has been devoted to the impact of these new technologies on disarmament. The purpose of this article is to fill this gap by focusing more precisely on the potential new technologies have in supporting or impeding nuclear disarmament efforts. The research question we focus on is what are the impacts of emerging technologies on nuclear security and in particular on nuclear disarmament? By answering this question, we contribute to a better understanding of the broader impacts that new technologies have on international security.

A technology, on its own, does not have agency; it needs to be applied by people. What people believe to be the effects of the technology influences how these technologies act. Therefore, we set out to study how policymakers and experts *perceive* the impact of emerging technologies on the nuclear enterprise. Here, we present the results of a survey of 85 security experts and 14 decision-makers and experts, through which we studied their views on the impact of emerging technologies on nuclear deterrence and disarmament. Through our survey, we demonstrate that experts expect emerging technologies to have mixed results. On the negative side, they are perceived to destabilize nuclear deterrence by increasing the risk of nuclear use and by compounding close calls, mishaps, and misunderstandings in the nuclear realm. On the positive side, they have encouraged creative and more robust measures for safeguarding nuclear materials and verifying steps toward disarmament.

The article is structured as follows. It first provides an overview of the literature on emerging technologies, nuclear deterrence, and disarmament. It then presents the scope of the research and the methodology used. It continues to discuss the findings from the expert survey and the interviews, namely that emerging technologies undermine nuclear deterrence in significant ways but also create fresh opportunities for nuclear disarmament. Finally, it concludes with a discussion on future avenues for research.

Emerging technologies and nuclear security

When referring to an "emerging technology," we draw on Chyba's (2020) definition that classifies a technology as "emerging" in the sense that either its "greatest potential impact in warfare remains undemonstrated and recessed" (as is the case with enabling dual-use technologies like AI and cyber) or the technology "has not yet been overtly significantly deployed by any nation's military" (as is the case with new weapons systems like hypersonic gliding vehicles [HGVs]) (p. 152). We are not concerned with the

emergence of these technologies themselves but rather with the emergence of the strategic applications of these technologies (Bauer, 2020). Scholars have previously captured the strategic consequences of different emerging technologies, noting that these new technologies have produced a variegated, often contradictory, set of effects on strategic stability and nuclear deterrence (Futter, 2020; Sechser et al., 2019; Talmadge, 2017). Thus, any impact that emerging technologies have on credibility, capability, signaling, or the perception of these three, will have an impact on nuclear deterrence. Moreover, if nuclear deterrence relations are destabilized, nuclear weapons possessors may be less willing to engage in nuclear disarmament.

Emerging technologies and nuclear deterrence

There has been a long history of competing schools of thought when it comes to the impact that technology has on nuclear deterrence and crisis stability. In one camp are those who believe that emerging technologies are ultimately disruptive because they destroy the foundations of nuclear deterrence. Nuclear deterrence is predicated on a nuclear arsenal that is both able to survive a first strike from an adversary and retaliate in such a way that immense damage is inflicted on that adversary. For Lieber and Press (2017), the survivability of nuclear forces depends, to a large extent, on the hardening and concealment of these forces. According to these authors, advances in new technologies (e.g., remote sensing and pinpoint accuracy capabilities) have made nuclear forces more vulnerable thus significantly undermining nuclear deterrence.

Similarly, other scholars believe that new technologies are fundamentally disruptive because they undermine crisis stability by providing a first-mover advantage and increasing the risk of a first-strike. For example, efforts to jam AI-enabled systems may be interpreted as a prelude to a nuclear strike (Chyba, 2020), exploiting the security dilemma described by international relations scholars since the 1950s (Herz, 1950). Moreover, the implementation of AI may increase first-mover advantage. Particularly for countries without a secure second-strike capability, incentives to attack preemptively increase as the speed of combat increases (Horowitz, 2019). The advances in HGVs bring about a similar situation: They create risks that the target's strategic forces will be obliterated before they can be engaged (Speier et al., 2017).

Some have posited that dual-use technologies like AI, cyber, and HGVs are particularly disruptive because they create what Lupovici (2021) calls a "dual-use security dilemma." In theorizing this term, Lupovici extends the theory of the traditional security dilemma to include the ways in which dual-use technologies affect security dilemma dynamics. In short, a state faces a dual-use security dilemma when its adversary possesses destructive

military and civil technologies (Lupovici, 2021). The key here is that the dual-use nature of certain new technologies—like cyber but also AI and HGVs—create an added layer of uncertainty to the security dilemma: Given the dual-purpose of the technology, a state may not be able to discern whether the technology will be used for civil (peaceful) or military (harmful) means and so, fearing the worst, it may adopt a dangerous (nuclear) posture. Indeed, Speier et al. (2017) note that the integration of dual-use HGVs into the arsenal of major nuclear powers only serves to increase the risk for misperception and miscalculation.

Others still view the disruptive nature of new technologies through the ways in which they affect the entanglement of nuclear and non-nuclear capabilities as well as how they shape the likelihood of crisis escalation (Acton et al., 2017; Talmadge, 2019). Entanglement has several manifestations including dual-use delivery systems, the co-location of nuclear and non-nuclear forces, and non-nuclear emerging technology threats on nuclear weapons and associated command and control networks (Acton et al., 2017, p. 1). This entanglement, according to Acton (2020), results in a significant security threat. For example, cyber interference with nuclear systems can be misinterpreted as an attack but can also increase the risk of miscalculation in case of malfunctioning (U.S. Department of Defense 2018; Acton, 2020). For other, slightly more skeptical, scholars like Talmadge (2019), new technologies *could* create opportunities for crisis escalation, though, importantly, these technologies are what Talmadge considers an intervening variable, arguing instead that strategy and politics are more important drivers of escalation.

In contrast, there are some like Cox and Williams (2021) who believe that new technologies like AI can have a stabilizing effect on nuclear deterrence but that these stabilizing effects are often ignored in favor of a more alarmist view. The authors see this view as particularly unhelpful since nuclear policymakers will have to face the rapid, "unavoidable" advances in AI (Cox & Williams, 2021). Instead, the authors favor a granular approach and one that pays particular attention to how countries can apply AI in the nuclear domain in ways that allow the stabilizing potential of AI to be fully harnessed and the risks of AI to be sufficiently mitigated. They argue that AI can strengthen nuclear deterrence by improving early warning and detection (through e.g., more precise target identification) and strengthening the infrastructure around nuclear weapons (through e.g., improvements to command-and-control systems) (Cox & Williams, 2021).

In a similar vein, Saalman (2018) argues that AI can strengthen nuclear deterrence by enhancing nuclear decision-making. She remarks that the integration of autonomy and AI in China's systems of reconnaissance could provide Chinese nuclear decision-makers with greater situational awareness and could also strengthen its nuclear retaliatory abilities, both of which could

be stabilizing (Saalman, 2018). Building on Saalman's work, Kania (2019) notes, more specifically, that emerging technologies like quantum computing and quantum sensing could make China's nuclear arsenal more secure and could enhance detection, respectively.

To be sure, scholars have cautioned against the overreliance on AI support in nuclear decision-making noting that AI cannot replace the human cognitive abilities of intuition, empathy, and critical thinking (Johnson, 2020). Moreover, introducing emerging technologies, especially AI, into nuclear decision-making makes nuclear signaling more difficult, for two reasons. Firstly, any action might be misperceived by a machine on the other end. This may be because of a simple "misunderstanding" or by deliberately setting up a machine in a way that interprets any attempts at de-escalation as a tactical opportunity advantage (Wong et al., 2020). The resulting uncertainty is potentially severely destabilizing, since in a crisis situation, this might lead to an exacerbation of conflict, rather than its mitigation.[1]

Lastly, and more worryingly, no technology is immune to failure. In the nuclear field, the instances of technological failures have been multiple (Lewis et al., 2014; Sagan, 1995; Schlosser, 2014). Even deterrence optimists argue that the reason why these failures have not led to catastrophe is because of the institutionalized practices implemented by "the man in the loop" (Tertrais, 2017). Human beings can make ethical judgments and question orders from superiors in ways that machines cannot. Moreover, machines are themselves vulnerable to hostile takeover. Especially in the nuclear realm, the more technologically driven the decision-making loop is, the higher the chance that a blip on the screen can lead to calamitous consequences. By decreasing strategic stability, the potential for disarmament will be decreased, as states may be unwilling to make concessions (e.g., give up their nuclear weapons) in the face of potential uncertainty. Indeed, one could argue that the introduction of new technologies could actually make countries even more reliant on their nuclear deterrents.

Emerging technologies and nuclear disarmament

For decades, there have been competing arguments among scholars over three related, yet separate, issues: nuclear substitution, nuclear monitoring, and nuclear proliferation. Policymakers and scholars have discussed the prospect of conventional substitution for nuclear weapons. Beginning in the 1970s, defense strategists at the Pentagon invested heavily in long-range, precision conventional weapons in an effort to encourage the US to rely less on nuclear weapons for certain strategic tasks (Ford, 2010; Gormley, 2006). According to US defense policy grandee Paul Nitze, the United States would do well to convert its deterrent from nuclear weapons to conventional weapons because they may "one day perform their primary mission of

deterrence immeasurably better than nuclear weapons if only because we can —and will—use them" (Nitze, 1997). In a 1999 column in *The New York Times*, Nitze doubled down on this argument, stating that there is "no compelling reason why we [the United States] should not unilaterally get rid of our nuclear weapons." In the same vein, Gormley (2006) argues that the increased potency of American conventional war-fighting capabilities will "further diminish the salience of nuclear alternatives" (p. 140). More recently, the Trump administration's 2018 U.S. Nuclear Posture Review spoke of the use of cyber weapons with strategic effects, hinting that emerging technologies may (in practice) replace nuclear weapons to achieve similar effects (U.S. Department of Defense, 2018).

On the other hand, there are a number of scholars who believe that substitution is not possible and even undesirable for a number of reasons. For instance, Colby (2010) makes a number of strategic arguments against substitution. He argues that while certain technological advances have improved Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance (C4ISR) capabilities markedly, such that conventional weapons could disable certain targets with reasonable assurance, other targets that have been immune to such advances in C4ISR remain susceptible only to nuclear weapons (Colby, 2010). Similarly, Kofman and Fink (2020) look at nuclear substitution in the Russian context. They note that while it may be desirable for conventional weapons to substitute nuclear weapons in the early stages of a conflict (particularly in a regional or local conflict) because conventional weapons include less escalatory risk, Russia finds the total substitution of nuclear weapons by conventional capabilities undesirable, namely because nuclear weapons have a psychological impact (that is, the threat of immeasurable destruction) in a way that conventional weapons do not. Others still have argued that nuclear weapons make sense from a fiscal perspective. Kroenig (2018) advances a number of key budgetary arguments in his work, namely that, while the United States does spend a significant amount of money on its nuclear forces, these costs only amount to around five percent of the defense budget (p. 187). Moreover, Kroenig argues that if the United States wants to maintain a robust strategic deterrent, it is actually cheaper to invest in nuclear weapons because the development of conventional capabilities to carry out the tasks previously carried out by nuclear weapons would be much more costly.

New technologies also have the potential to create novel approaches to nuclear non-proliferation and disarmament by enhancing safeguards and verification regimes, which remain crucial for monitoring whether or not parties are complying with arms control measures. While the use of emerging technologies in strengthening safeguards is still incipient, some note that new technologies like distributed ledgers, additive manufacturing, remote sensing and advances in image-recognition software show promise

for intelligence collection of nuclear programs, nuclear non-proliferation, nuclear verification and the safeguarding of nuclear materials (Kaspersen & King, 2019; Vestergaard, 2018).

Others note that emerging technologies show promise when it comes to collecting intelligence on budding nuclear programs. In a recent article, Volpe (2019) examines how additive manufacturing shape proliferation dynamics. He argues that on the one hand, additive manufacturing can make it easier for nuclear-aspirants to acquire nuclear weapons but, on the other hand, this emerging technology can be used to allow burgeoning nuclear programs to showcase their peaceful motives, thus quelling fears of arms races.

Koichi (2019), using East Asia as an example, notes that intelligence, surveillance and reconnaissance (ISR) systems can be enhanced through the integration of AI and that this could strengthen transparency, through compliance monitoring of nuclear arsenals and treaty verification, among nuclear states. Of course, optimizing AI's potential in verification and monitoring will depend on the level of trust among countries as well as their willingness to engage in confidence-building measures (Koichi, 2019).

There has been an increase in debates on nuclear disarmament, spurred by developments such as the Humanitarian Initiative giving rise to the Treaty on the Prohibition of Nuclear Weapons. Among deterrence experts, these debates have ushered in discussions on the conditions necessary for nuclear disarmament. Roberts (2019) notes that some of these conditions include the resolution of regional geopolitical conflicts that encourage adversarial states to acquire nuclear weapons, more sophisticated verification measures and increased transparency of nuclear capabilities. The recent U.S.-led initiative on Creating an Environment for Nuclear Disarmament echoes many of these views (Gibbons, 2019). Müller (2020) argues that nuclear disarmament "will lead to the desired result only when it is embedded in a supporting institutional framework" (p. 151). Importantly, Müller recognizes that in order for non-nuclear peace to be achieved "the real, alleged or perceived war-prevention functions of nuclear deterrence" would have to "be taken over by other means" (pp. 151–152). To be sure, there is much less research on emerging technologies and nuclear disarmament through the substitution path, even though the replacement of nuclear weapons has been, as we indicated above, on the agenda for decades.

Finally, Williams (2020) argues that incorporating emerging technology into disarmament discussions, for instance, in the NPT setting, could act as a successful bridge builder among different actors who otherwise have "fundamental ideological differences about pathways to disarmament" (p. 13). In other words, the mutual recognition that including emerging technologies in NPT discussions is necessary could also help encourage cooperation among NPT parties on other issues.

Expert survey and interviews

Since the impact of emerging technologies on nuclear deterrence and nuclear disarmament is difficult to observe, we have approached experts in the field. We wanted to ascertain how experts and practitioners view and discuss the impact of emerging technologies on nuclear deterrence and disarmament. We used multi-method research, relying on two main methods of collecting data: a survey distributed to experts and a series of interviews with decision-makers and those directly advising them.

The expert survey was conducted between 25 June and 21 July 2020 on a sample of 85 experts (out of 427 invited experts, yielding a response rate of 20%). All of these experts responded to the majority of our substantive questions; there were a few questions that were not answered by all, yielding slightly fewer than 85 responses to some of the questions. Out of all of the groups of experts, the largest segment self-identified as nuclear weapons experts, accounting for 39.7% of those who participated in the survey; followed by 36% of respondents who identified as experts on security and strategy; and 19% who identified as experts on international politics broadly conceived. The experts came from all over the world to ensure that there was adequate geographical representation. However, the respondents, who answered the survey, came predominantly from Europe (55 respondents; 65% of the sample), followed by the United States (19 experts; 23% of the sample); remaining 9 experts were from other parts of the world.

We focused on three sampling frames: authors of recent publications in major international peer-reviewed journals; non-governmental experts who participated in the 2015 NPT Review Conference and the Preparatory Committees for the upcoming NPT Review Conference; and then academic and think-tank experts affiliated with the EU Nonproliferation and Disarmament Consortium. We then excluded experts whose individual contact details could not be established from their professional websites or from their publications. We thus established a broad sample of experts with broad expertise in nuclear politics, nuclear weapons, and/or emerging technologies. We opted for this broad sample, because existing research persuasively demonstrates that "[a]ggregating a large, diverse 'crowd' of opinions, even if members of the crowd possess incomplete knowledge, can produce superior forecasts to a single individual, regardless of how expert he or she might be" (Surowiecki 2014, as cited in Maestas, 2016). As Maestas (2016)'s comprehensive review of the use of expert surveys demonstrates, "larger pools of raters, even if less expert" produce more reliable and valid results compared to smaller pools of more qualified experts.[2]

The survey was relatively long and took between 15 and 20 min to complete. The survey was not scenario-based but instead contained nine

questions, most of which asked the participants to evaluate whether emerging technologies had a stabilizing or destabilizing effect on nuclear dynamics.

The expert survey we fielded allowed us to gain insight into how the epistemic community views these effects. The experts were able to authoritatively discuss the technical aspects of how new technologies affect the nuclear enterprise and how these technologies will shape the future of both nuclear risk and nuclear disarmament.

In addition to the expert survey, we conducted 14 interviews with officials —and those directly advising them—from a mix of nuclear weapons states and non-nuclear weapons states as well as officials belonging to international organizations active in the nuclear field.

We chose the respondents with two criteria in mind: geographical representation (to be able to cover a number of countries, within the North Atlantic area, as well as from outside of it) and portfolio (whether the nuclear policy or emerging technology fell within their purview). Our sample included currently serving officials, as well experts who have a long track-record of directly advising decision-makers. The views of the 14 elite interviewees whom we interviewed are particularly consequential since these individuals are responsible for designing, implementing and monitoring strategic policies. All of the interviewees were informed that their responses would be used for research but were assured of full anonymity. Our research therefore yielded a number of qualitative insights into how the impacts of emerging technologies on nuclear deterrence and nuclear disarmament are viewed and discussed by both experts and decision-makers, which when combined provide us with the "wisdom of the crowd."

Findings and discussion

Our first finding is that a sizeable majority of the experts we surveyed stated that emerging technologies destabilize nuclear deterrence because they increase the risk of inadvertent escalation and complicate nuclear signaling. While the decision-makers whom we interviewed agreed that emerging technologies destabilize nuclear deterrence, their views on technologies' destabilizing impacts were more measured.

Emerging technologies destabilize nuclear deterrence

In our survey, we focused on AI, cyber threats, and hypersonic weapons because these are the technologies that are most widely discussed in scholarly and policy circles. When we refer to cyber threats we are referring to cyber interference in nuclear command and control systems that have become

more vulnerable to this type of interference since these systems "have come to rely increasingly on digital technology" (Acton, 2020, p. 133).

Our survey included some questions that asked about the effects of emerging technologies on nuclear deterrence as well as questions about the impacts of specific technologies on deterrence to try to gauge whether certain technologies generate more risk than others. More specifically, when assessing the impact these new technologies have on nuclear deterrence, we focus on how these technologies affect inadvertent or accidental escalation risks seeing as this is the area of risk where new technologies have the most destabilizing impact (Acton, 2020; Chyba, 2020). When asked about the strategic impacts of certain emerging technologies in the nuclear field, around 85% reported that HGVs are destabilizing; 84% reported that cyber is destabilizing; and 72% said that artificial intelligence is destabilizing.

In recent years, a lot of attention has been devoted to increased automation in nuclear decision-making. Some scholars have posited that countries that are concerned about their second-strike capabilities may be more willing to "use risky forms of autonomy," which can increase the chances of accidental crisis escalation (Horowitz et al., 2019). Around 70–80% of the experts we surveyed stated that the inclusion of AI in nuclear command and control increases the risk of inadvertent escalation. This finding was consistent among experts across the United States, Europe, Russia, Latin America, Australia, Africa and Asia (see Table 1).[3]

Other scholars have noted that the inclusion of artificial intelligence in nuclear command and control can cause automation bias to creep into decision-making (Johnson, 2020). This can be worrisome because machines remove human judgment when, in fact, human judgment is needed. What's more, Johnson (2019) notes that "AI systems operating at machine-speed will push the pace of combat to the point where the actions of machines surpass the (cognitive and physical) ability of human decision makers to control (or even comprehend) events" (p. 11). Yet contrarily, one policymaker claimed that massive integration of AI into nuclear command and control systems is unlikely, while another official said human beings will never be completely out of the loop and that launch decisions will never be delegated to machines (Interviewees I & L).

Around 85% of the surveyed experts remarked that cyber interference increases the risk of escalation to the nuclear level. This finding was also consistent across regions (see Table 1). The decision-makers whom we interviewed claimed that the opacity and complexity of cyber warfare make it a significant threat to strategic stability. For example, one cyber policymaker noted that cyber is unable "to guarantee wholly predictable effects" which can increase the probability of conflict escalation (Interviewee A). Another cyber decision-maker agreed, noting

Table 1. The impact of emerging technologies on inadvertent escalation by region.

	Decreasing risk		Somewhat decreasing risk		Neutral		Somewhat increasing risk		Increasing risk	
How would you describe artificial intelligence's impact on the risk of inadvertent escalation?										
Europe (excluding Russia)	0	0.0%	5	9.1%	6	10.9%	18	32.7%	26	47.3%
United States	0	0.0%	1	5.3%	3	15.8%	9	47.4%	6	31.6%
Other	0	0.0%	0	0.0%	3	33.3%	5	55.6%	1	11.1%
In your opinion, what impact do cyber capabilities have on inadvertent escalation?										
Europe (excluding Russia)	0	0.0%	3	5.5%	5	9.1%	26	47.3%	21	38.2%
United States	0	0.0%	2	10.5%	1	5.3%	12	63.2%	4	21.1%
Other	0	0.0%	0	0.0%	1	11.1%	4	44.4%	4	44.4%
In your opinion, what impact do hypersonic missiles have on escalation?										
Europe (excluding Russia)	1	1.8%	1	1.8%	3	5.5%	26	47.3%	24	43.6%
United States	0	0.0%	0	0.0%	4	21.1%	11	57.9%	4	21.1%
Other	0	0.0%	1	11.1%	0	0.0%	1	11.1%	7	77.8%

Note: Number of respondents and percentages ($n = 83$).

that it is exceedingly difficult to control the effects of a cyber operation and that it is for this reason that cyber not only raises escalation risks it also makes it a dangerous tool to use from a military perspective (Interviewee N). Others however found that because cyber is still relatively unfamiliar, it is not a huge concern, illustrating that there are still competing visions and a broader ambivalence when it comes to the strategic effects of cyber (Interviewee B).

Finally, as Table 1 illustrates, experts across regions believed that hypersonic weapons have the most disruptive potential in the nuclear field because they severely shorten the time within which a targeted party will receive, interpret, and respond to a warning. Some decision-makers agreed that hypersonic weapons will have the greatest impact because they are the most imminent threat to strategic stability because they can disrupt the posture of military alliances (Interviewee M). There were however a couple of decision-makers whom we interviewed who expressed that the strategic and operational effects of HGVs are exaggerated. One policymaker noted that an HGV is just a "fancy missile," while another one noted that her country is skeptical about the hype surrounding HGVs since the vulnerability and speed associated with this type of weapon are not new risks (Interviewees C & F).

Notably, during the elite interviews, we conducted there were some interviewees who mentioned that emerging technologies and nuclear weapons are discussed separately in their respective organizations. In particular, some European experts we interviewed mentioned that there is a fairly substantial division within the bureaucracy between those who work on or are concerned with nuclear weapons and those who work on emerging technologies (Interviewees C & D), suggesting that these discussions largely still occur in organizational silos. Similarly, another expert we interviewed noted that in his country the only new technology that is included in strategic documents are hypersonic weapons and that discussions of AI and cyber are talked about outside of discussions on arms control and nuclear issues (Interviewee B). However, a majority of policymakers—especially those in the West—mentioned that relevant governmental institutions have recently started to view emerging technologies across a number of domains including pertinently arms control and non-proliferation (Interviewee L). In other words, they view emerging technologies as a cross-cutting issue.

Decision-makers did not view emerging technologies to be as destabilizing as the experts did. While there were many who agreed that new technologies are putting nuclear deterrence under strain, others seemed to suggest that the destabilizing effects on nuclear deterrence are overblown. In particular, there were a number of decision-makers who argued that emerging technologies do not challenge or undermine the mechanism of nuclear deterrence (Interviewee F).

Emerging technologies are not likely to carry out strategic tasks

We were principally concerned with whether technologies that improve the discriminate and precise application of smart conventional weapons could decrease reliance on nuclear weapons for strategic tasks and even, perhaps, make the substitution of nuclear weapons (by conventional capabilities) more feasible. Experts and policymakers generally agreed that it is not likely that emerging technologies will substitute nuclear weapons in carrying out strategic tasks. However, among the experts whom we surveyed there was a slight variation depending on their region. Experts who were the most skeptical of cyber supplanting nuclear weapons in carrying out strategic tasks came from the United States, followed by those in Europe. By contrast, around 60% of those experts belonging to the category "Other" seemed to believe that cyber capabilities are likely to replace nuclear weapons in carrying out strategic tasks (see Table 2).[4]

Decision-makers whom we interviewed tended to agree with experts from the United States and Europe. One interviewee reasoned that when it comes to trying to guarantee a strategic outcome, cyber is not the best capability because it is still far too complex and there is still much we do not know (Interviewee A). Another interviewee agreed saying that cyber is "not designed to be a strategic weapon" (Interviewee F). Other respondents agreed that new technologies are not likely to supplant nuclear weapons in carrying out strategic tasks simply because nuclear weapons have such a significant place in international politics and play such a pivotal, central role in deterrence. On this point, one interviewee remarked that the very debate that we have over nuclear weapons "is a vindication of the importance of nuclear weapons in politics and society" (Interviewee K). Another interviewee stated that the "horrifying stigma" around nuclear weapons evokes a certain respectability for the weapons as an effective deterrent (Interviewee L). This is particularly true when it comes to the role of nuclear weapons in deterrence by punishment, which elevates the costs of attack (Mazarr, 2018). Moreover, another policymaker stated that there is a conservative, doctrinal and institutional vision in their country that sees nuclear

Table 2. How likely are cyber technologies to supplant nuclear weapons in carrying out strategic tasks?

	Unlikely		Somewhat unlikely		Neutral		Somewhat likely		Likely	
Europe (excluding Russia)	17	30.9%	7	12.7%	8	14.5%	16	29.1%	7	12.7%
United States	8	42.1%	3	15.8%	0	0.0%	6	31.6%	2	10.5%
Others	1	12.5%	0	0.0%	1	12.5%	1	12.5%	5	62.5%

Note: Number of respondents and percentages ($n = 82$).

weapons as essential in the country's strategic thinking, making it very difficult to "relativize their importance" (Interviewee D).

Policymakers generally agreed that the sheer destructiveness of nuclear weapons, which is—in the minds of experts and policy elites—assured and certain, makes them different from any other technology. These views come close to arguments outlined by Ford (2010), who argued that nuclear weapons are uniquely well-suited for both counterforce and countervalue targeting. Other experts, particularly those versed in cyber technology, pointed to a curious contradiction: The effectiveness of offensive cyber weapons is unclear unless they are tested, but as soon as they are used, the gaps they exploit might be patched up.

Emerging technologies could create new opportunities for disarmament

Our third finding focuses on whether emerging technologies could enhance or impede nuclear disarmament efforts. Some work has already exposed how new technologies have the potential to strengthen nuclear disarmament and verification measures. A prototype "SLAFKA" was recently jointly developed by a nuclear regulator in Finland (STUK), the University of New South Wales in Australia, and the Stimson Center in the United States which tests whether a distributed ledger technology (DLT) can effectively safeguard nuclear material (Stimson Center, 2020). A DLT platform is "a system of electronic records that enables independent entities to establish consensus around a "ledger"—without relying on a central coordinator to provide the authoritative version of the records" (Rauchs et al., 2018, p. 23). Blockchain is the most well-known type of distributed ledger. Importantly, blockchain is structured in such a way that all who participate in the shared ledger must agree upon a set of records or data, and this data cannot be changed or tampered with by one actor alone (Rockwood et al., 2018). When it comes to accounting for nuclear materials, blockchain could be used by member states to confidentially and securely provide data to the IAEA (Vestergaard, 2018). By using a shared ledger system, the transmission of data by a member state would be visible to other member states, while maintaining the anonymity of participants (Rockwood et al., 2018).

In a recent report, Burford (2020) notes that the characteristic features of blockchain, namely its immutability and security as a data management tool, are uniquely suited to "help to build technical capacity among [non-nuclear weapons states] and habits of cooperation among NPT parties, while protecting proliferation-sensitive data" (p. 21). Finally, others have noted that advances in image-recognition software combined with the increased sophistication in and availability of satellite imagery could open up space for more actors to get involved in verification activities (Kaspersen & King, 2019). This

would make verification more robust by allowing a greater number of states to participate in what has traditionally been the domain of states that are more technologically superior.

The security, transparency, and confidence-building features of these emerging technologies could thus enhance verification by strengthening the safeguards system as well as increasing trust and cooperation among states normally suspicious of one another. These features could prove useful in helping to close both institutional and compliance gaps within the non-proliferation regime. That said, as with any other global governance regime, a compliance gap is very difficult to fully bridge. On this point, Sagan notes that even with advances in verification technology "there will remain the problem of what to do if an erstwhile nuclear nation is caught secretly preparing to rearm" (see Sagan in Sagan & Waltz, 2010, p. 90). While the inclusion of new technologies in verification and safeguards will not wipe away the challenges associated with verification, emerging technologies can play a role in strengthening verification and safeguarding measures.

Since we were interested in whether the experts and policymakers considered the positive applications of new technologies on disarmament efforts, our final question in the survey asked experts to express their views on nuclear disarmament.

Table 3 illustrates that the majority of our experts across regions agreed that complete nuclear disarmament would happen when leaders are confident that technology will allow for its verification, underlining the pivotal role verification plays in disarmament. This was echoed by some of the policymakers whom we spoke to who said that AI and remote sensing could help make verification measures more robust (Interviewee I & F). On the other hand, Table 3 also highlights that European and American experts are more skeptical (than experts in other regions) of the fact that nuclear disarmament will occur when leaders believe new technologies make nuclear weapons unnecessary.

Given that experts and policymakers agreed that emerging technologies are unlikely to carry out strategic tasks, it is perhaps not surprising that they also believed that emerging technologies are unlikely to supplant nuclear weapons. This is reflected in the fact that most experts disagreed that complete nuclear disarmament would occur when leaders believe emerging technologies will make nuclear weapons unnecessary. This finding strongly suggests that the value of nuclear weapons goes beyond their roles as deterrents. Some decision-makers agreed, noting that not only are nuclear weapons the "ultimate security guarantor" (Interviewee F) but they are also seen as a guarantor of independence and sovereignty (Interviewee B). These views support the existing literature: Scholars have long recognized the symbolic value of nuclear weapons, going well beyond their military utility (Abraham, 1998; Harrington de Santana, 2009; Hecht,

Table 3. Nuclear disarmament and emerging technologies.

	Strongly disagree		Disagree		Slightly disagree		Slightly agree		Agree		Strongly agree	
Complete nuclear disarmament will happen when world leaders are confident that the technology allows for its verification												
Europe (excluding Russia)	2	3.6%	10	18.2%	5	9.1%	14	25.5%	16	29.1%	8	14.5%
United States	3	15.8%	4	21.1%	0	0.0%	7	36.8%	4	21.1%	1	5.3%
Others	4	44.4%	0	0.0%	0	0.0%	3	33.3%	2	22.2%	0	0.0%
Complete nuclear disarmament will happen when leaders believe emerging technologies make nuclear weapons unnecessary												
Europe (excluding Russia)	3	5.6%	12	22.2%	17	31.5%	11	20.4%	6	11.1%	5	9.3%
United States	4	21.1%	5	26.3%	4	21.1%	1	5.3%	3	15.8%	2	10.5%
Others	2	25.0%	1	12.5%	0	0.0%	2	25.0%	3	37.5%	0	0.0%

Note: Number of respondents and percentages ($n = 83$ and $n = 81$).

2012; Sagan, 1996). The view that emerging technologies are unlikely to supplant nuclear weapons also reflects the difficulty of verifying and monitoring the nuclear weapon ban. These difficulties have been broadly recognized. Some scholars are positive about the potential future normative developments (Considine, 2019; Egeland, 2018; Ritchie, 2019), others see risks associated with looking at the nuclear weapon ban and disarmament from an arms control perspective (Onderco, 2017; Müller, 2020).

Emerging technologies will force us to think more creatively about arms control

Our final and most thought-provoking finding is that emerging technologies will force the nuclear community to think more creatively about traditional arms control measures. The vast majority of policymakers whom we interviewed believe that emerging technologies like AI and cyber will not be amenable to traditional arms control measures. Many remarked that traditional arms control measures are about laying out what one has and tracking tangible, quantifiable hardware like missiles (Interviewees N & K). In lay terms, traditional arms control is about "counting things" and limiting what one has and does not have. Export control regimes also ascribe to this logic and have been used to control hypersonic technology and hardware. However, many of these measures have been unilateral in nature; being able to scale these measures up to a multilateral policy of export control (that is, through a test ban, a global ban or a non-proliferation treaty) remains exceedingly difficult (Speier et al., 2017, p. 37).

Given the relative invisibility and decentralization of cyber and AI and given how ubiquitous the civilian applications of these technologies are, they are unlikely to be effectively governed by traditional arms control measures. As a result, many officials actively spoke about the need for "arms control" of emerging technologies to focus on behavior, not capabilities. This is in line with what Futter (2020) considers to be a fundamental question when dealing with cyber: "what exactly are we trying to "control" and how?" (p. 2). One policymaker mentioned that "a patchwork of rules that try to govern behavior" was likely to emerge rather than arms control measures per se (Interviewee A). A similar point was made by the German Deputy Federal Commissioner for Disarmament and Arms Control, Rüdiger Bohn, during his remarks at the 2020 EU Nonproliferation and Disarmament Conference.

Yet, some policymakers opined that while governing the application of certain technologies is the way forward, this remains difficult because it requires a considerable level of trust in other parties (Interviewee K). This problem is not unique to emerging technologies. International relations specialists have long recognized that trust is key for overcoming the security

dilemma (Booth & Wheeler, 2008) and that even in tense settings of rivalry, trust can be built (Wheeler, 2018). Therefore, any thinking about future arms control measures must start with confidence-building mechanisms and norm-building (Nye, 2018). That future arms control measures will have to focus on governing the behaviors of states and non-state actors does not privilege a particular form of cooperation over another. That said, future arms control discussions could include a mixture of stricter regulatory frameworks and forms of soft law. Soft law is particularly useful for AI and cyber given the rapid pace of development and complexity of both domains, which can outstrip traditional regulatory frameworks (Villasenor, 2020).

The role of private actors poses a further challenge. The fact that cyber space is populated by technology companies and thus unwilling to respond to regulations restricting capabilities advanced by states compounds these issues. In the nuclear domain, states and state leaders have been the architects of arms control measures but when it comes to the cyber domain the situation is different. In other words, the traditional state-centric arms control measures are not likely to successfully govern the cyber realm given its decentralized nature and the multiplicity and diversity of actors that occupy this space. This highlights yet another important point: there is a difference between what we want to control and "what realistically we can control" (Futter, 2020, p. 2).

While traditional, formal arms control measures in the nuclear realm cannot be neatly exported to enabling dual-use technologies like cyber and AI, the regulation of a technology like a hypersonic missile is comparatively easier because it can be accomplished using conventional arms control tools. Similar to current missiles, these new weapons are conspicuous and so can be traced, counted and monitored. Indeed, when it comes to hypersonic weapons in the nuclear domain, engaging in arms control depends "only" on finding the political will do so. By contrast, informal arms control arrangements are most likely the best approach to regulate cyber and AI in their relation to nuclear deterrence and disarmament. These informal measures should include multi-stakeholder discussions on the parameters of cyber use or the use of AI within the nuclear domain. As one of our interviewees noted, the Organization for Security and Co-operation in Europe's (OSCE) confidence-building measures that try to limit conflict caused by cyber technologies could be a useful model for these informal arrangements (Interviewee L). These regional efforts should be scaled up to the international level though, admittedly, this will be difficult to do in the short to medium terms.

Given the increasing role that new technologies are playing in the nuclear domain, there is a need to include emerging technologies in nuclear weapons treaties. This is precisely the point that Williams (2020) highlights when she states that "emerging technologies are an unavoidable reality in nuclear weapons policy" and thus must be taken into account (p. 7). She notes that

when it comes to the discussions within the NPT, there are a couple of key reasons as to why emerging technologies have not been included: namely that there is skepticism on the part of both nuclear weapons states and non-nuclear weapons states to include "*non*-nuclear weapons in their discussions" and that the NPT as an institution lacks the flexibility "to adapt to rapidly changing geopolitical and technological developments" (Williams, 2020, p. 7).

Similarly, many of our interviewees expressed that the NPT was not the most appropriate setting for discussions on emerging technologies. Some reasoned that including new technologies into NPT discussions was mixing too many issues together, further complicating a set of discussions amongst an already divided set of state parties to the treaty (Interviewees C, K & M). Others mentioned that emerging technologies should be included in discussions on nuclear risk reduction within the NPT, since these new technologies have the potential to increase the risk of nuclear use in significant ways (Interviewees E & H).

Conclusion

We have studied the views that experts and decision-makers have when it comes to the impact of emerging technologies on nuclear deterrence and disarmament. Beyond the substantial findings, discussed below, our article also demonstrates that expert surveys might be a suitable measure to map the views of epistemic community when faced with future, unpredictable developments. Regardless of a particular approach one uses, using multiple expert insights is a promising way to deal with uncertainty about the future. This is not related only to the field of security policy or international relations. As DeWees and Minson (2018) note, "the combination of multiple, independent judgments is often more accurate than even an expert's individual judgment." While there are possible risks (as DeWees and Minson make clear, once experts make up their mind, it is difficult to persuade them otherwise), faced with uncertainty the wisdom of the crowd offers an attractive option.

Our respondents noted that the destabilizing impacts of emerging technologies in the nuclear realm come from the fact that these technologies compound the risks of close calls, mishaps and misunderstandings. They were concerned about the potentials for future close calls and misinterpretation and therefore thought that as emerging technologies become more ubiquitous, they also make nuclear deterrence more unstable.

Some of the decision-makers felt that some of the threats commonly associated with emerging technologies in the scholarly discourse are overblown. There was, for example, skepticism about whether nuclear launch decisions will ever be delegated to an entity other than humans, or whether HGVs are anything other than fancy missiles. Our interviewees were concerned about cyber risks, but they also felt that the use of cyber technologies for strategic

purposes is most likely not going to happen. These findings underline that in spite of the growing attention given to emerging technologies among think-tankers and academics alike, decision-makers are less concerned about these technologies. This means that either the experts are alarmist, or that they need to build better epistemic communities to convey to decision-makers the risks that these technologies pose. Furthermore, the centrality attached to nuclear weapons in strategic thinking and planning appears to undermine any idea of weakening. Our survey and interviews showed that while the respondents could imagine that emerging technologies will have a more prominent role in deterrence by denial; nuclear weapons will remain dominant in deterrence by punishment. This is rather curious since recent work in thinking about long-range conventional strikes highlights that these technologies might change the calculus and appear to affect deterrence by punishment (Montgomery, 2020). However, when it comes to technologies like HGVs or cyberwarfare, the scholars are much more skeptical.

When referring to the positive applications of emerging technologies, many of those surveyed reported that technologies can be used to enhance nuclear safeguarding and verification measures. In this respect, decision-makers felt that if there is one contribution that emerging technologies can make to nuclear disarmament, it would be here. Curiously, our experts were quite skeptical about the prospects for global nuclear disarmament. The majority of the experts did not think that nuclear disarmament was going to happen in the next 50 years, and a large portion of the experts did not think that nuclear disarmament would make us safer. This seems to support the realist view that nuclear proliferation is a result of the security dilemma, and the removal of nuclear weapons would not resolve the underlying calculus but might make conflict more likely (Waltz, 1981). This is doubly curious, since the majority of our experts came from European countries, where civil society pressure for nuclear disarmament is growing. Therefore, we observe that both the general public and civil society are out of step with the experts. The perception that nuclear disarmament is unachievable (in a reasonable timeframe) and that it would not make the world safer might explain why nuclear disarmament is not a policy priority for numerous experts. As Pelopidas (2020) recently remarked, if elites believe that nuclear weapons are eternal, then the motivation for doing something about disarmament is not as much of a priority for them.

Lastly, our article highlights that thinking about the inclusion of emerging technologies in nuclear arms control will require a shift in the mindset that the negotiators and their advisors (and policy principals) have. Given that many of these technologies cannot be controlled by traditional arms control measures, resorting to a combination of soft law and political commitments will be required. This shift will not be easy in all fields. But as the European Union Special Envoy for Nonproliferation and Disarmament

Marjolijn van Deelen recently argued, a "political agreement which could be more of a pledge which will take place in a broader context in which verification could be defined a bit more loosely" could be a road ahead for arms control measures when agreement on verification is difficult (for political or technical reasons; European Leadership Network, 2020).

Such steps are possible only when there is an atmosphere of trust among the states, and therefore confidence-building is a necessary precondition for any future arms control discussions involving emerging technologies, such as cyber and AI. One therefore needs to take the political effects and political situation into account when considering the effect of technologies; the two cannot be separated. This is also a possible limitation of our surveys: experts have, likely, a particular conflict setting in mind when making their judgments about the effect of particular technologies. As was long recognized by international relations scholars, whether particular technologies are seen as dangerous depends on how we perceive their possessors. In a famous quip, Wendt (1995) wrote that "500 hundred British nuclear weapons are less threatening to the US than 5 North Korean ones" (p. 73). Relations between the states therefore influence not only solutions that are feasible, but also how are the intentions of the other parties interpreted. We need to keep that in mind when considering when thinking about how to move arms control discussions forward.

Notes

1. This view assumes that humans are inherently better than machines at interpreting risk and making decisions under uncertainty. It is far from certain that this is the case.
2. For an example of an expert survey which went in the other direction – looking at a smaller pool of more qualified experts, see Favaro (2020) who uses STREAM approach developed by RAND Corporation.
3. We collapsed Russia, Latin America, Australia, Africa, and Asia into the category "Other".
4. We found similar results when we asked experts about the likelihood of AI supplanting nuclear weapons.

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