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The 2021 UK PONI Papers

Edited by Ana Alecsandru

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Editor's Note

THE UK PROJECT on Nuclear Issues (UK PONI) aims to foster the emergence of a next generation of nuclear experts and build a broad knowledge base for the nuclear community, from technical intricacies to international security dynamics.

UK PONI is funded and supported by a consortium of government and industry stakeholders. This support allows UK PONI to maintain an independent forum where emerging scholars can contribute new ideas on ongoing nuclear issues. UK PONI enjoys the support and guidance of its Board of Advisors, which includes representatives from government, industry, the military and academia.

The 2021 UK PONI Annual Conference gathered established and emerging experts from academia, industry, government and the military to share insights and debate a broad range of civil and military topics. Emerging experts who presented at the conference have adapted those presentations for this publication.

All views expressed in this publication are the authors' own and do not necessarily reflect those of the authors' institutions, UK PONI or RUSI.

Section I. New Perspectives on Arms Control and Disarmament

I. The 'Hijacked' Initiative: From the Humanitarian Initiative to the Ban Treaty … and Back Again?

Ekaterina Lapanovich

DISARMAMENT HAS LONG been a highly divisive issue in nuclear policy debates. Without doubt, it will continue to be one of the points of contention in the upcoming Review Conference of the Parties to the Treaty on Non-Proliferation of Nuclear Weapons (NPT)[1] to be held in January 2022. This will be the first conference since the entry into force of the Treaty on the Prohibition of Nuclear Weapons (TPNW) – also known as the Ban Treaty[2] – and the first one to be held shortly before the first meeting of the state parties to the TPNW, to be held in March 2022.

Meanwhile, debates are underway on the TPNW's compatibility with the NPT and its impact on the global nuclear non-proliferation regime.[3] These debates, however, mostly focus on how the

1. The NPT is a nearly universal international treaty that entered into force in 1970 with the aim of preventing further proliferation of nuclear weapons, promoting cooperation in peaceful uses of nuclear energy and achieving nuclear disarmament. A review of the operation of the NPT is undertaken every five years at the NPT Review Conference. See UN, 'Review Conference of the Parties to the Treaty on the Non-Proliferation of Nuclear Weapons (NPT)', <https://www.un.org/en/conferences/npt2020>, accessed 1 September 2021. In the years between the conferences, the preparatory process continues within the NPT Preparatory Committees. For more information on the NPT, see UN Office for Disarmament Affairs, 'Treaty on the Non-Proliferation of Nuclear Weapons (NPT)', <https://www.un.org/disarmament/wmd/nuclear/npt/>, accessed 18 August 2021.
2. The Treaty on the Prohibition of Nuclear Weapons (TPNW) prohibits almost any nuclear weapon activities, including developing, testing, producing, acquiring, possessing and stockpiling nuclear weapons. It also prohibits the use and threat of use of nuclear weapons. It was adopted in 2017 and entered into force at the beginning of 2021. For more information, see UN Office for Disarmament Affairs, 'Treaty on the Prohibition of Nuclear Weapons', <https://www.un.org/disarmament/wmd/nuclear/tpnw/>, accessed 18 August 2021.
3. See, for example, Joelien Pretorius and Tom Sauer, 'Ditch the NPT', *Survival* (Vol. 63, No. 4, July 2021), pp. 103–24, <https://www.tandfonline.com/doi/abs/10.1080/00396338.2021.1956197?journalCode=tsur20>, accessed 18 August 2021; Matthew Harris, 'Response: Keep the NPT', *Survival* (Vol. 63, No. 4, July 2021), pp. 125–30, <https://www.tandfonline.com/doi/abs/10.1080/00396338.2021.1956197?journalCode=tsur20>, accessed 18 August 2021; Michal Onderco and Andrea

Ban Treaty fits into the existing disarmament machinery – not 'the substantive arguments that underpin the logic of the TPNW',[4] which were developed within the Humanitarian Initiative on Nuclear Weapons that arose out of dissatisfaction with existing disarmament forums, and from a shift from national towards human security 'in which all weapons use was viewed through a humanitarian lens'.[5]

Nuclear politics and scholarship have long suffered from inertia, self-censorship and, as a result, a lack of innovative thinking.[6] The Humanitarian Initiative on Nuclear Weapons is a rare example of the 'transformative innovations' that occurred after the end of the Cold War.[7] The importance of the initiative lies in the fact that it problematises nuclear weapons and nuclear deterrence, provides reasons for change and, thus, facilitates changes in beliefs and expectations. It has broken hardened silos in which nuclear weapons were isolated from all other issues on the agenda – the environment, gender, international humanitarian law and others.

However, the initiative has not yet realised its full potential, because no room was left to continue the discussion on the effects of nuclear weapons and the role of humanitarian norms after the initiative's pivoting towards the ban and the adoption of the stigmatisation strategy. Today, the humanitarian agenda is almost entirely monopolised by Ban Treaty discussions. This limits the humanitarian agenda's transformative potential by making the humanitarian domain a restricted area for states that are either members or partners of nuclear alliances or still have reasons to be sceptical about the ban. It contradicts the very nature of the initiative, which is to bring in a variety of perspectives by giving a voice to different stakeholders. The importance of engaging not only those who have traditionally been excluded from nuclear weapons-related discussions but also those who matter to nuclear weapon states' strategic choices should not be

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Farrés Jiménez, 'A Comparison of National Reviews of the Treaty on the Prohibition of Nuclear Weapons', *Non-Proliferation and Disarmament Papers* (Vol. 4, June 2021), p. 16, <https://www.nonproliferation.eu/wp-content/uploads/2021/06/EUNPDC_no-76.pdf>, accessed 18 August 2021.

4. Alexander Kmentt, *The Treaty Prohibiting Nuclear Weapons: How it Was Achieved and Why it Matters* (New York, NY and London: Routledge, 2021), p. 272; Ray Acheson, *Banning the Bomb, Smashing the Patriarchy* (Lanham, MA: Rowman & Littlefield, 2021), p. 438.
5. See Heather Williams, Patricia Lewis and Sasan Aghlani, 'The Humanitarian Impacts of Nuclear Weapons Initiative: The "Big Tent" in Disarmament', Chatham House Research Paper, March 2015, p. 7, <https://www.chathamhouse.org/sites/default/files/field/field_document/20150331HumanitarianImpactNuclearWilliamsLewisAghlani.pdf>, accessed 18 August 2021.
6. Benoît Pelopidas, 'Nuclear Weapons Scholarship as a Case of Self-Censorship in Security Studies', *Journal of Global Security Studies* (Vol. 1, No. 4, November 2016), pp. 326–36, <https://academic.oup.com/jogss/article-abstract/1/4/326/2841104>, accessed 30 June 2021; Benoît Pelopidas, 'The Birth of Nuclear Eternity' in Sandra Kemp and Jenny Andersson (eds), *Futures* (Oxford: Oxford University Press, 2021), <https://www.oxfordhandbooks.com/view/10.1093/oxfordhb/9780198806820.001.0001/oxfordhb-9780198806820-e-28>, accessed 30 June 2021.
7. Benoît Pelopidas, 'Re-Imagining Global Nuclear Ordering Beyond Proliferation and Deterrence', paper presented to POSSE 2015, p. 3, <https://posse.gatech.edu/sites/default/files/pubfiles/Pelopidas_Re-imagining_POSSE2015.pdf>, accessed 30 June 2021.

underestimated. This paper argues that to bring authentic inclusion into humanitarian debates, there is a need to demonopolise the humanitarian agenda and to move from anti-nuclear *activism* back to *factivism* (a recent term referring to fact-based activism inspired by concrete evidence that rejects purely ideological or emotional approaches).

This paper begins with an outline of the key turning points in the history of the Humanitarian Initiative leading to the nuclear ban. Then, focusing on takeaways from that history, it shows how nuclear weapon states' disregard for the developing initiative proved crucial to its pivot towards the ban. Finally, within this context, policy recommendations are discussed.

The Road to the Ban

The Ban Treaty is a relatively recent phenomenon. Some important accounts of its development have become available recently,[8] but there are still many unexplored gaps in the literature on the history of the Humanitarian Initiative and the Ban Treaty and, most significantly, the interplay between them. One of the most pressing questions has been whether the Humanitarian Initiative was originally designed to lead up to the Ban Treaty. At least some authoritative and reputable accounts contradict this view.[9]

According to a recent book on the Ban Treaty by Alexander Kmentt, Director of the Department for Disarmament, Arms Control and Non-Proliferation at the Austrian Foreign Ministry and one of the architects of the initiative, its original objective had been 'to generate momentum for progress on nuclear disarmament within the established UN disarmament architecture, in particular the NPT'.[10] However, a few exogenous factors determined the direction of the initiative, shifting it from something initially mostly depoliticised,[11] fact-based and focused on re-energising existing forums into something that was politicised, ideologised and focused on stigmatisation – devaluing and discrediting nuclear weapons as an instrument of security and statecraft.

First, the failure to implement previously agreed disarmament actions indicated in the 2010 Action Plan[12] inspired a group of states to find new ways 'to overcome the inertia in the existing

8. See, for example, Kmentt, *The Treaty Prohibiting Nuclear Weapons*, p. 438.
9. Kmentt, *The Treaty Prohibiting Nuclear Weapons*; Acheson, *Banning the Bomb, Smashing the Patriarchy*.
10. Kmentt, *The Treaty Prohibiting Nuclear Weapons*, p. 72.
11. Alexander Kmentt, 'The Development of the International Initiative on the Humanitarian Impact of Nuclear Weapons and its Effect on the Nuclear Weapons Debate', *International Review of the Red Cross* (Vol. 97, No. 899, 2015), p. 690, <https://international-review.icrc.org/sites/default/files/irc97_11.pdf>, accessed 30 June 2021.
12. A consensus final document was adopted as an outcome of the NPT Review Conference in 2010. States agreed to the Action Plan, comprised of 64 items on nuclear disarmament, non-proliferation and peaceful uses of nuclear energy. Disarmament commitments included, *inter alia*: reducing the role and significance of nuclear weapons in military and security concepts;

fora'.[13] Additionally, it motivated Norway to 'operationalise' the Humanitarian Initiative[14] by initiating a discussion outside the established disarmament machinery – a series of conferences on the humanitarian impact of nuclear weapons in Oslo, Nayarit and Vienna that would be the main platforms on which the Humanitarian Initiative developed in 2013–2014.

Second, the nuclear weapon states' disengagement from or late engagement with the conferences was counterproductive. Nuclear weapon states did not participate in either the Oslo or Nayarit conferences as they saw them as a distraction from 'a practical, step-by-step approach' to nuclear disarmament.[15] Having realised that the 'boycott policy' turned out to be damaging, the Obama administration decided to participate in the third humanitarian conference in Vienna in 2014.[16] The UK followed suit. That said, the UK and the US used the Vienna conference not as an opportunity to reflect on substantive issues of the Humanitarian Initiative but to criticise it as impractical and dangerous and to promote the step-by-step approach through the NPT. The persistent problem with this approach has been that it was bankrupted by the failure of nuclear weapon states to act in accordance with the very approach they themselves promoted – to ensure progress on, *inter alia*, the entry into force of the Comprehensive Test Ban Treaty and starting negotiations on a Fissile Material Cut-Off Treaty.[17]

Third, the 2015 NPT Review Conference was 'the last straw for many governments', as nuclear weapon states neither implemented previous disarmament commitments made in 1995, 2000

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preventing the use of nuclear weapons; undertaking to ratify the Comprehensive Nuclear-Test-Ban-Treaty; and commencing negotiations on a treaty banning the production of fissile material. An assessment of the implementation of the Action Plan was made for the James Martin Center on Nonproliferation Studies prior to the 2015 Review Conference. The conclusion was that progress in the implementation of the disarmament part of the Plan was 'very limited'. For more information on the implementation of the 2010 Action Plan, see Gaukhar Mukhatzhanova, 'Implementation of the Conclusions and Recommendations for Follow-on Actions Adopted at the 2010 NPT Review Conference. Disarmament Actions 1-22: 2014 Monitoring Report', James Martin Center for Nonproliferation Studies, p. 91, <https://nonproliferation.org/wp-content/uploads/2014/04/CNS-Monitoring-Report_2014_web.pdf>, accessed 18 August 2021.

13. Kmentt, *The Treaty Prohibiting Nuclear Weapons*, p. 20.
14. *Ibid.*, p. 28.
15. UN Office for Disarmament Affairs, 'Statement on Nuclear Disarmament by Ambassador Joanne Adamson, UK Permanent Representative to the Conference on Disarmament', Geneva, 5 March 2013, <https://docs-library.unoda.org/Conference_on_Disarmament_(2013)/1281UK.pdf>, accessed 19 August 2021.
16. Kmentt, 'The Development of the International Initiative on the Humanitarian Impact of Nuclear Weapons and its Effect on the Nuclear Weapons Debate', p. 696.
17. Vienna Center for Disarmament and Non-Proliferation (VCDNP), 'Nuclear Risk Reduction and the Tenth Non-Proliferation Treaty (NPT) Review Conference', VCDNP webinar, 25 January 2021, <https://vcdnp.org/the-treaty-on-the-prohibition-of-nuclear-weapons-whats-next-2/>, accessed 19 August 2021.

and 2010, nor were ready to accept new ones.[18] Moreover, 'the refusal of nuclear weapon States to engage on the Humanitarian Initiative's arguments to compromise on disarmament' was also 'a moment of clarity' about the Humanitarian Initiative's future trajectory – the Ban Treaty.[19]

Key Takeaways

The main takeaway from the history of the Humanitarian Initiative is that dismissal can backfire. According to Martha Finnemore, 'dismissal is very different from disagreement'.[20] It is about subordination – in which nuclear weapon states impose their particular definition of reality and security on non-nuclear weapon states.[21] It is counterproductive as it delegitimises and damages the order that was created by nuclear weapon states mostly for nuclear weapon states. Legitimacy – when something is recognised as reasonable and appropriate – is vital to the stability of the nuclear order and should not be taken for granted. It cannot be sustained by nuclear weapon states themselves, but must be granted by those who accepted these rules, namely non-nuclear weapon states. Moreover, the dismissal of humanitarian arguments by nuclear weapon states and their disengagement from the Humanitarian Initiative have created the conditions for a pivoting of the initiative towards the Ban Treaty. This is something officials at the Norwegian Ministry of Foreign Affairs call the '"hijacking" of the initiative',[22], claiming that the initiative Norway forged was at some point ostensibly 'hijacked' by the more radical ban movement pushing ideas that it neither shared nor intended to serve as a basis for the initiative.

Furthermore, opportunities for productive deliberations between nuclear weapon states and non-nuclear weapon states based on the Humanitarian Initiative were, unfortunately, lost. These concerned the legality and ethics of nuclear deterrence more than two decades after the end of the Cold War, the humanitarian preparedness to face the consequences of any use of nuclear weapons, a humanitarian rationale for nuclear risk reduction, and many more issues. It is for this reason that Scott Sagan and Benjamin Valentino regard the Ban Treaty as 'a symbol of missed opportunities'.[23] They have convincingly argued that some particularly important issues that were high on the agenda for the Humanitarian Initiative – for example, the health consequences of the clean-up of nuclear facilities and the environmental impact of nuclear weapons infrastructure – were sidelined as the ban became the end goal.[24]

18. Acheson, *Banning the Bomb, Smashing the Patriarchy*, p. 198.
19. *Ibid.*, p. 70.
20. Martha Finnemore, 'Legitimacy, Hypocrisy, and the Social Structure of Unipolarity: Why Being a Unipole Isn't All It's Cracked up to Be', *World Politics* (Vol. 61, No. 1, January 2009), p. 68.
21. *Ibid.*
22. Author interview with an official of the Norwegian Ministry of Foreign Affairs, Geneva, 30 April 2018.
23. Benjamin A Valentino and Scott D Sagan, 'The Nuclear Weapons Ban Treaty: Opportunities Lost', *Bulletin of the Atomic Scientists*, 16 July 2017, <https://thebulletin.org/2017/07/the-nuclear-weapons-ban-treaty-opportunities-lost/>, accessed 3 July 2021.
24. *Ibid.*

Policy Recommendations

This paper offers three policy recommendations.

Recommendation 1

It is crucial for nuclear weapon states to engage with the humanitarian agenda. It seems to be more viable to try to inject some humanitarian elements into existing frameworks rather than to create any new mechanisms that are likely to be too ambitious for now. The P5 Process may be an option.[25] It is a consultative process involving the five nuclear weapon states (China, France, Russia, the UK and the US), established in 2009 to demonstrate nuclear weapon states' commitment to their obligations under the NPT and to advance progress on nuclear disarmament. Importantly, the 2010 Action Plan's reference to 'the need for all States at all times to comply with applicable international law, including international humanitarian law [IHL]' may serve as a mandate for this conversation.[26]

On some specifics, it would be useful to start a conversation about the application of IHL to nuclear planning. This is something leading experts, such as George Perkovich, Scott Sagan and Allen S Weiner, are calling for.[27] Technically, it may be a part of the P5 Process's doctrinal discussion, whereby the P5 states exchange relevant information on one another's nuclear doctrine, policy and posture.[28] However, for the discussion to allow the P5 to constructively exchange views on the issue, it is important to bring in not only P5 officials and nuclear policy experts but also lawyers and, at some point, military officials.

One significant challenge is that not all nuclear weapon states will wholeheartedly agree to include a humanitarian agenda item. And there is little hope that this conversation will be launched under

25. For more information, see Centre for Science and Security Studies, King's College London, 'The P5 Process: Opportunities for Success in the NPT Review Conference', June 2020, <https://www.kcl.ac.uk/csss/assets/the-p5-process-opportunities-for-success-in-the-npt-review-conference.pdf>, accessed 20 August 2021.
26. Mukhatzhanova, 'Implementation of the Conclusions and Recommendations for Follow-on Actions Adopted at the 2010 NPT Review Conference', p. 6.
27. George Perkovich, 'Toward Accountable Nuclear Deterrents: How Much Is Too Much?', Carnegie Endowment for International Peace, 11 February 2020, <https://carnegieendowment.org/2020/02/11/toward-accountable-nuclear-deterrents-how-much-is-too-much-pub-80987>, accessed 10 July 2021; Scott D Sagan and Allen S Weiner, 'The Rule of Law and the Role of Strategy in U.S. Nuclear Doctrine', *International Security* (Vol. 45, No. 4, 2021), pp. 126–66, <https://direct.mit.edu/isec/article/45/4/126/100569/The-Rule-of-Law-and-the-Role-of-Strategy-in-U-S>, accessed 10 July 2021.
28. See Centre for Science and Security Studies, King's College London, 'The P5 Process', p. 13.

the French presidency.[29] France was the most vocal opponent of the humanitarian language[30] in the 2010 Action Plan.[31] Russia and China are less transparent regarding the interplay between IHL and nuclear planning than the US and the UK, but some representatives of some states have expressed an interest in having these discussions.[32] If the P5 Process does not lead to dialogue on this topic, those states that claim to be 'responsible nuclear weapon states'[33] and therefore appreciate the importance of beginning this deliberation should take the lead and provide the international community with their assessment of how IHL applies to their nuclear doctrines and war planning. If a P5 state provides this assessment within the NPT Review Conference, other P5 states will be expected to follow suit.

Recommendation 2

The mission of multilateral groupings, such as the Stockholm Initiative,[34] is to identify some landing zones and to put forward concrete proposals on forging progress in nuclear disarmament.

29. At the moment France serves as a coordinator of the P5 Process. The presidency rotates among the P5 states.
30. The language in the Action Plan to ensure adoption of a consensus outcome states that the NPT Review Conference 'expresses its deep concern at the catastrophic humanitarian consequences of any use of nuclear weapons and reaffirms the need for all States at all times to comply with applicable international law, including international humanitarian law'. See '2010 Review Conference of the Parties to the Treaty on the Non-Proliferation of Nuclear Weapons Final Document. Volume I. Part I. Review of the Operation of the Treaty, as Provided for in its Article VIII (3), Taking into Account the Decisions and the Resolution Adopted by the 1995 Review and Extension Conference and the Final Document of the 2000 Review Conference Conclusions and Recommendations for Follow-On Actions', p. 19, <https://www.nonproliferation.org/wp-content/uploads/2015/04/2010_fd_part_i.pdf>, accessed 20 August 2021.
31. Kmentt, *The Treaty Prohibiting Nuclear Weapons*, p. 16.
32. Author online conversation with representatives of states, 25 March 2020.
33. Every P5 state has recently described itself as a 'responsible nuclear weapon state', despite the absence of a shared understanding of what this actually means. For more on nuclear responsibilities, see BASIC's Programme on Nuclear Responsibilities, <https://basicint.org/portfolio/nuclear-responsibilities/>, accessed 20 August 2021; Foreign and Commonwealth Office and Tobias Wood MP, 'Written Ministerial Statement on the 2015 Review Conference of the Nuclear Non-Proliferation Treaty', <https://www.gov.uk/government/speeches/written-ministerial-statement-on-the-2015-review-conference-of-the-nuclear-non-proliferation-treaty>, accessed 15 September 2021; Permanent Mission of France to the UN in New York, '2015 Review Conference of the Parties to the Treaty on the Non-Proliferation of Nuclear Weapons (NPT) – Statement by Mr Jean-Hugues Simon-Michel, Permanent Representative of France to the Conference on Disarmament – Main Committee I – "Nuclear Disarmament and Security Assurances" – 1 May 2015', <https://onu.delegfrance.org/NPT-Nuclear-disarmament-cannot-be>, accessed 15 September 2021.
34. The Stockholm Initiative for Nuclear Disarmament was launched by Sweden in 2019 to forge a successful outcome of the 2020 Review Conference (which was postponed due to the coronavirus pandemic and is to be held in January 2022). Its objective is to build support for 'a pragmatic

The Stockholm Initiative, which is quite diverse in terms of representation and focused on the disarmament pillar, is promising in this respect. One of its priorities is nuclear risk reduction. It is heartening that the Initiative's working paper on nuclear risk reduction for the 2022 NPT Review Conference features catastrophic humanitarian consequences.[35] This gives hope that it may be the platform for deliberations about widening the approach to nuclear risks and going beyond strategic risk reduction.

Furthermore, it would be helpful to bridge the Stockholm Initiative with the P5 Process, in order to discuss different perspectives on risk reduction. Accordingly, Heather Williams from King's College London states that more cooperation between the P5 Process and the Stockholm Initiative would be very welcome.[36] Speaking on this issue, Ambassador Yann Hwan, Permanent Representative of France to the Conference on Disarmament in Geneva, hopes that the P5 states will be able to launch a dialogue with the Stockholm Initiative similar to the one they have with the Non-Proliferation and Disarmament Initiative (NPDI),[37] but his main concern is that not all the nuclear weapon states will agree.[38] One suggestion for the P5 is to engage with the Stockholm Initiative to pursue not only briefings – as is the case with the NPDI – but actual dialogue.

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and result-oriented nuclear disarmament agenda'. The Initiative gathers together 16 non-nuclear states: Argentina, Canada, Ethiopia, Finland, Germany, Indonesia, Japan, Jordan, Kazakhstan, the Netherlands, New Zealand, Norway, the Republic of South Korea, Spain, Sweden and Switzerland. See Government Offices of Sweden, 'Stockholm Initiative for Nuclear Disarmament', 30 July 2021, <https://www.government.se/government-policy/stockholm-initiative-for-nuclear-disarmament/>, accessed 20 August 2021.

35. VCDNP, 'A Nuclear Risk Reduction Package, Working Paper by the Stockholm Initiative, Supported by Argentina, Belgium, Canada, Denmark, Ethiopia, Finland, Germany, Iceland, Indonesia, Japan, Jordan, Kazakhstan, Luxembourg, the Netherlands, New Zealand, Norway, the Republic of Korea, Spain, Sweden and Switzerland', 10th Review Conference of the Parties to the Treaty on the Non-Proliferation of Nuclear Weapons, 11 May 2021, <https://vcdnp.org/wp-content/uploads/2021/05/WorkingPaperNuclearRiskReduction_StockholmInitiative_submitted-May-11.pdf>, accessed 11 July 2021.
36. VCDNP, 'Nuclear Risk Reduction and the Tenth Non-Proliferation Treaty (NPT) Review Conference', webinar, 31 March 2021, 53.07, <https://www.youtube.com/watch?v=khVed1c5MZg>, accessed 13 July 2021.
37. The Non-Proliferation and Disarmament Initiative (NPDI) is a group of states within the NPT Review Conference that was founded in 2010 to promote the Action Plan of the 2010 Review Conference. This group continues to work on advancing the nuclear disarmament agenda. Its members are Australia, Canada, Chile, Germany, Japan, Mexico, the Netherlands, Nigeria, the Philippines, Poland, Turkey and the United Arab Emirates. See NTI, 'Non-Proliferation and Disarmament Initiative (NPDI)', last updated 31 May 2021, <https://www.nti.org/learn/treaties-and-regimes/non-proliferation-and-disarmament-initiative-npdi/>, accessed 20 August 2021.
38. Fondation pour la recherche stratégique, 'The NPT and the P5 Process', webinar, 16 June 2021, 38.08.01, <https://www.youtube.com/watch?v=IgINxlJdhlU>, accessed 13 July 2021.

Recommendation 3

It is essential to de-polarise the humanitarian agenda – to stop treating it as a battlefield for opposing ideological views and to engage in evidence-based discussion. 'Respectful disagreement' will make it easier for nuclear weapon states and their allies and supporters of the humanitarian agenda to engage with one another.[39] One of the prospective landing zones may be, again, nuclear risk reduction. It is not, however, an easy task to draw the line between risk reduction for the stability of deterrence and that for the sake of humanity.

Conclusion

In conclusion, it is important to continue the conversation about the humanitarian consequences of nuclear weapons in a manner that is not centred on prohibition and does not rely on stigmatisation, but is more inclusive and holistic. Serious consideration should be given to the ways in which humanitarian concerns might affect practices of nuclear deterrence. To answer this difficult question, scholars and policymakers should engage in dialogue at the intersection of nuclear deterrence and the Humanitarian Initiative.

39. Finnemore, 'Legitimacy, Hypocrisy, and the Social Structure of Unipolarity', p. 68.

II. Revival of the ‘Dead Hand’? Russian Political and Military Elites’ Debates on AI and Autonomy in Conventional and Nuclear Forces

Lydia Wachs

RUSSIA IS FREQUENTLY cited in Western literature as a state that is heavily investing in the military use of AI, seeking to further automate its conventional and nuclear systems.[1] However, a thorough analysis of the main debates among the Russian political and military elites on the use of AI for military purposes, as well as its risks and opportunities, is missing from this literature. To contribute to a more nuanced understanding of the Russian perspective, this paper analyses how Russian political and military elites[2] debate AI and autonomy in the military domain, in general, and the nuclear forces, in particular. It specifically examines what kinds of opportunities and risks the Russian elites emphasise, and assesses the implications thereof for strategic stability. In doing so, the paper relies on a constructivist understanding of the social world, assuming that ‘military technologies are not deterministic, but socially constructed’[3] and shaped by the ideas and beliefs of political elites.

To investigate the debates, the research for this paper included a qualitative content analysis of articles that centre around military AI and autonomy published between 2017 and 2021 in the journal *Voyennaya Mysl* (*Military Thought*), as well as statements by Russian President Vladimir Putin and Defence Minister Sergey Shoigu that refer to AI and autonomy from the same time

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1. See, for example, Michael C Horowitz, ‘When Speed Kills: Lethal Autonomous Weapon Systems, Deterrence and Stability’, *Journal of Strategic Studies* (Vol. 42, No. 6, 2019), pp. 764–88; James Johnson, ‘Artificial Intelligence & Future Warfare: Implications for International Security’, *Defense & Security Analysis* (Vol. 35, No. 2, 2019), pp. 147–69.
2. This paper uses and slightly amends Anne Clunan’s definition of political elites to define political and military elites as ‘politically active and influential individuals in government … the intelligentsia’, and the military. See Anne L Clunan, *The Social Construction of Russia’s Resurgence: Aspirations, Identity, and Security Interests* (Baltimore, MD: Johns Hopkins University Press, 2009), p. 228.
3. Dima Adamsky, *Culture of Military Innovation: The Impact of Cultural Factors on the Revolution in Military Affairs in Russia, the US, and Israel* (Stanford, CA: Stanford University Press, 2010), p. 7.

period.[4] *Voyennaya Mysl* is the oldest and leading military-theoretical journal of the Russian Ministry of Defence, featuring articles by members of the Russian ministry, the general staff, and other military officials and scientists, and is selected here to capture the main debates on AI among Russian military elites.[5] Similarly, statements by Putin and Shoigu are thought to give insight into the perspectives of political elites.

Based on the analysis, the paper highlights the following findings. While Russian political and military elites see a growing role for AI in various military applications, there is a prevalent view that – especially in the nuclear domain – humans should not be replaced by AI-infused systems and processes entirely. What Russian elites do not discuss, however, is the level of human involvement they deem necessary, nor the risks stemming from the interaction between humans and machines. The paper therefore concludes that the risks for strategic stability, raised by these findings, call for arms control and confidence-building measures.

Opportunities of Using AI for Military Purposes

A dominant theme in the Russian military debates on AI is the idea that AI has a huge transformative potential for warfare and that Russia must be among the leading states in AI development and application.[6] Russian political and military elites have, in particular, discussed the use of AI in the area of early warning, ISR and command and control (C2), as well as in the context of control systems of weapon systems and platforms. The Russian elites have also mentioned the use of AI for logistics and weapon maintenance, and for cyberspace and information operations. Yet, as

4. The keywords that were used to identify the relevant literature include: *iskusstvennyy intellekt* ['artificial intelligence'], *intellektualizatsiya* ['intellectualisation'], *mashinnoye obucheniye* ['machine learning'], *avtonomnyy* ['autonomous'], *bespilotnyye sistemy'* ['unmanned systems'], and *avtomatizirovannyye sistemy upravleniya* ['automated control systems'] when used in conjunction with 'new technologies'. In total, 50 sources were analysed. Throughout the paper, all translations are the author's.
5. This paper's findings are limited to unclassified debates and do not cover the whole spectrum of Russian military journals. For further information on *Voyennaya Mysl'* [*Military Thought*], see <https://vm.ric.mil.ru/>, accessed 19 July 2021.
6. Russia uses the following definition of AI in its National Strategy on AI, released in 2019: 'AI is a set of technological solutions that allows to imitate human cognitive functions (including self-learning and search for solutions without a predetermined algorithm) and to obtain, when performing specific tasks, results comparable, at least, to the results of human intellectual activity'. See Official Website for Legal Information, 'Ukaz Prezidenta Rossiyskoy Federatsii ot 10.10.2019 No. 490 'O razvitii iskusstvennogo intellekta v Rossiyskoy Federatsii' i Natsional'naya strategiya razvitiya iskusstvennogo intellekta na period do 2030 goda' ['Order of the President of the Russian Federation of 10.10.2019 No. 490 on the Development of Artificial Intelligence in the Russian Federation and the National Strategy for the Development of Artificial Intelligence for the Period up to 2030'], p. 2, <http://publication.pravo.gov.ru/Document/View/0001201910110003>, accessed 19 July 2021.

these latter areas have received less attention in the reviewed literature, this paper focuses on the first two categories.[7]

In the area of early warning and ISR, as well as C2, the elites have especially underlined the use of AI to improve situational awareness and decision-making processes. In this context, they have, for example, examined the utility of using advanced machine learning techniques to enhance the information-processing capacity of early-warning radars, improving the detection and tracking of targets.[8] Moreover, Russian military officials have also discussed how AI technologies could be used to improve and accelerate information management and C2 more broadly, helping the military in identifying emerging threats and actions by adversaries more quickly and reliably and thereby enabling faster decision-making processes.[9] Multiple articles that were examined, for example, assess how different systems and assets could be integrated into a unified automated control system.[10] In this setting, AI methods would allow the processing of all available

7. See Jeffrey Edmonds et al., 'Artificial Intelligence and Autonomy in Russia', CNA, May 2021, p. 84.
8. See, for example, A V Zhuravlev, 'Vozmozhnost' primeneniya iskusstvennogo intellekta pri vedenii radiolokatsionnoy razvedki' ['The Chances of Using Artificial Intelligence in Radar Reconnaissance'], *Voyennaya Mysl'* [*Military Thought*] (No. 5, May 2021), pp. 82–87; D V Galkin, P A Kolyandra and A V Stepanov, 'Sostoyaniye i perspektivy ispol'zovaniya iskusstvennogo intellekta v voyennom dele' ['The Condition and Use Prospects of Artificial Intelligence in Military Affairs'], *Voyennaya Mysl'* [*Military Thought*] (No. 1, January 2021), pp. 113–24.
9. See, for example, Galkin, Kolyandra and Stepanov, 'Sostoyaniye i perspektivy ispol'zovaniya iskusstvennogo intellekta v voyennom dele' ['The Condition and Use Prospects of Artificial Intelligence in Military Affairs'], pp. 113–24; V M Burenok, 'Iskusstvennyy intellekt v voyennom protivostoyanii budushchego' ['Artificial Intelligence in the Military Confrontation of the Future'] *Voyennaya Mysl'* [*Military Thought*] (No. 4, April 2021), pp. 106–12; Yu A Matviyenko and A V Uvarov, 'Nauchno-tekhnicheskiye problemy primeneniya tekhnologiy iskusstvennogo intellekta i neyrosetevykh tekhnologiy obrabotki dannykh v avtomatizirovannykh sistemakh Raketnykh voysk strategicheskogo naznacheniya' ['Science-and-Technology Issues of Using Artificial Intelligence Technologies and Neural Network Technologies of Data Processing in the Automated Systems of Strategic Missile Forces'], *Voyennaya Mysl'* [*Military Thought*] (No. 4, April 2021), pp. 113–18; V G Ivanov and V N Luk'yanchik, 'Ob evolyutsii teorii i praktiki postroyeniya sushchestvuyushchikh sistem svyazi voyennogo naznacheniya na osnove sozdaniya mul'tikonvergentnoy sistemy svyazi gruppirovki voysk (sil) na teatre voyennykh deystviy' ['On the Evolution of the Theory and Practice of Building Currently Operational Military Communication Systems Based on Making a Multi-Convergent Communication System for the Troop/Force Grouping at the Theatre of Operations'], *Voyennaya Mysl'* [*Military Thought*] (No. 1, January 2021), pp. 66–78; O V Maslennikov et al., 'Ob informatizatsii Vooruzhennykh Sil Rossiyskoy Federatsii' ['On Computerising the Armed Forces of the Russian Federation'], *Voyennaya Mysl'* [*Military Thought*] (No. 12, December 2019), pp. 57–67.
10. This debate resembles discussions in US military circles about the concept of Joint All-Domain Command and Control (JADC2). For more information, see Edmonds et al., 'Artificial Intelligence and Autonomy in Russia', pp. 96–99. JADC2 essentially 'envisions providing a cloud-like environment for the Joint force to share intelligence, surveillance, and reconnaissance data, transmitting across many communications networks, to enable faster decisionmaking'. See John R

information from a variety of sources, automatically addressing variances from input data and thereby generating a 'global operating picture' in real time.[11] A key theme underlined in this context is the need for information dominance in modern conflicts.[12]

Beyond information management and C2, a second major application area of AI highlighted in the Russian military literature examined for this paper is the use of AI to improve weapon systems and platforms.[13] First, AI technologies are thought to enable unmanned systems to navigate autonomously which can improve their endurance, reach and agility, as well as their immunity to potential interferences with communication lines.[14] Relatedly, military elites also debate the use of AI to enable swarm operations of several autonomous unmanned systems that execute tasks collectively and teaming operations of both manned and unmanned aircraft.[15] In the latter case, a manned aircraft could be equipped with AI-enabled decision-support and communication

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Hoehn, 'Joint All-Domain Command and Control (JADC2)', Congressional Research Service, updated 1 July 2021, <https://crsreports.congress.gov/product/pdf/IF/IF11493>, accessed 19 July 2021.

11. Galkin, Kolyandra and Stepanov, 'Sostoyaniye i perspektivy ispol'zovaniya iskusstvennogo intellekta v voyennom dele' ['The Condition and Use Prospects of Artificial Intelligence in Military Affairs'], p. 116. An article from April 2021 illustrates this discussion by stating: 'The importance of AI in the military sphere is determined by the high speed of processing large volumes of heterogeneous data, which makes it possible to significantly reduce the duration of the command and control cycle of troops and weapons in military operations of various scales, from the tactical to the strategic levels, in air, space, sea, land, cyber and electromagnetic environments'. See D V Galkin and A V Stepanov, 'Voprosy bezopasnosti primeneniya iskusstvennogo intellekta v sistemakh voyennogo naznacheniya' ['Issues of Safe Employment of Artificial Intelligence in Military Systems'], *Voennaya Mysl'* [*Military Thought*] (No. 4, April 2021), p. 73.
12. Information dominance means a superiority in the generation and availability of information over an adversary, causing military advantages. See, for example, Maslennikov et al., 'Ob informatizatsii Vooruzhennykh Sil Rossiyskoy Federatsii' ['On Computerising the Armed Forces of the Russian Federation'], pp. 57–67.
13. See, for example, V B Zarudnitskiy, 'Kharakter i soderzhaniye voyennykh konfliktov v sovremennykh usloviyakh i obozrimoy perspektive' ['The Nature and Content of Military Conflicts in Present-Day Conditions and in the Foreseeable Future'], *Voennaya Mysl'* [*Military Thought*] (No. 1, January 2021), pp. 34–44; Galkin, Kolyandra and Stepanov, 'Sostoyaniye i perspektivy ispol'zovaniya iskusstvennogo intellekta v voyennom dele' ['The Condition and Use Prospects of Artificial Intelligence in Military Affairs'], pp. 113–124.
14. See, for example, N A Rudianov and V S Khrushchov, 'Kontseptual'nyye voprosy postroyeniya i primeneniya avtonomnykh robototekhnicheskikh kompleksov voyennogo naznacheniya' ['Conceptual Issues of Making and Using Military-Purpose Autonomous Robotic Units'], *Voennaya Mysl'* [*Military Thought*] (No. 6, June 2019), pp. 55–61.
15. See, for example, Burenok, 'Iskusstvennyy intellekt v voyennom protivostoyanii budushchego' ['Artificial Intelligence in the Military Confrontation of the Future'], pp. 106-112; I Yu Makushev et al., 'Intellektualizatsiya bortovykh sistem upravleniya aviatsionnykh kompleksov' ['Intellectualisation of Onboard Control Systems of Aircraft Systems'], *Voennaya Mysl'* [*Military Thought*] (No. 7, July 2019), pp. 68–76; V A Khariton, A A Pavlova and A M Lukashov, 'Problemnyye voprosy formirovaniya ratsional'nogo oblika perspektivnykh aviatsionnykh kompleksov novogo

tools and control one or several UAVs that would support the pilot by providing reconnaissance and protection for the aircraft and carry out additional combat tasks. Considering recent tests, this could potentially be conducted for both non-nuclear and nuclear operations.[16]

Risks and Limits of Using AI for Military Purposes

While much of the analysis and discussion on military AI and autonomy has revolved around its benefits and opportunities, the risks and limits of the application of AI for military purposes have also been part of the recent debates in Russia. In multiple statements made by both Putin and Shoigu, as well as in the analysed military writings, it is emphasised that the increasing use of AI applications should not replace the role of humans entirely. A recurring theme is that advanced AI-enabled systems should instead aide human decision-makers and that humans should still retain control over decisions to use force. In December 2020, Putin, for example, stated that: 'Artificial intelligence will never replace humans. This is why I said that, yes, machines will control people to a large extent, just like many other modern technological devices do, but in the final analysis, people must control these machines'.[17] Similarly, an article from 2020 describes that a 'man plus machine' concept is the preferred design, meaning that 'machines with AI would support people and expand their capabilities in military affairs, allowing them to achieve the results that were considered impossible before'.[18]

At the same time, however, several articles and statements point to US advancements in the area of military AI, noting that the US is deviating from the concept of human control in the use of AI and machine autonomy by pursuing increasingly autonomous systems and processes in both conventional and nuclear forces. For example, an article from January 2021 mentions that US experts had proposed creating an AI-based automated nuclear retaliation system: 'It should be noted that in American expert circles there is also an opposite point of view. Thus, an American analogue of the Soviet system of automated nuclear retaliation, called "Dead Hand"

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pokoleniya' ['Issues of Creating an Efficient Composition of Next-Generation Aviation Systems'], *Voennaya Mysl'* [*Military Thought*] (No. 4, April 2018), pp. 71–75.

16. See *TASS*, 'Strategicheskiy raketonosets Tu-95MS otrabotal upravleniye bespilotnikom v polete' ['Strategic Bomber Tu-95MS Succeeded in Controlling Drone in Flight'], 23 December 2020, <https://tass.ru/armiya-i-opk/10329081>, accessed 19 July 2021; *RIA Novosti*, 'Voyennyy ekspert otsenil vozmozhnosti noveyshego bespilotnika "Okhotnik"' ['Military Expert Assessed the Possibilities of the Newest Drone "Hunter"'], 12 January 2021, <https://ria.ru/20210112/bespilotnik-1592682275.html>, accessed 19 July 2021.
17. President of Russia, 'Artificial Intelligence Conference', 4 December 2020, <http://en.kremlin.ru/events/president/news/64545>, accessed 19 July 2021.
18. O V Maslennikov et al., 'Intellektualizatsiya – vazhnaya sostavlyayushchaya tsifrovizatsii Vooruzhennykh Sil Rossiyskoy Federatsii' ['Intellectualisation as a Major Part of Digitalisation in the Armed Forces of the Russian Federation'], *Voennaya Mysl'* [*Military Thought*] (No. 7, July 2020), pp. 74. See also Maslennikov et al., 'Ob informatizatsii Vooruzhennykh Sil Rossiyskoy Federatsii' ['On Computerising the Armed Forces of the Russian Federation'], pp. 57–67.

according to Western terminology, is proposed to be created based on the principles of AI'.[19] Based on this assessment, several Russian officials therefore conclude that, in the long run, in order to successfully compete with potential adversaries, there will probably be a replacement of humans by machines – at least in the conventional realm.[20]

Furthermore, despite these statements in favour of continued human control, it remains unclear as to what extent humans should retain control and how this should be ensured in practice against the backdrop of the use of increasingly sophisticated AI systems. Several military writings discuss potential technical challenges and risks, such as the dependence of AI, especially machine learning, on adequate training data that may be limited or biased, and that such systems may operate poorly in unexpected situations or may be hacked or otherwise manipulated.[21] However, they do not discuss challenges in the context of human–machine interaction. Indeed, what is missing from the Russian elites' debates are discussions on the risks associated with the potential inability of humans to retrace the decision-making process of advanced algorithms due to their highly complex and opaque functioning, rendering effective human oversight over such systems impossible. Similarly, neither risks of automation bias – cases where humans blindly trust systems with autonomous functions without questioning them – nor risks stemming from the increasing speed of warfare that can overwhelm human commanders have received attention in Russian military writings.

Implications for Strategic Stability

The precise impact of military AI on strategic stability depends, to a large extent, on its application.[22] Several of the applications of AI and machine autonomy that Russian officials are debating might not be inherently destabilising. Yet, the crucial question here is how they are being used and to what extent the military will rely on them. Therefore, even if the Russian

19. Galkin, Kolyandra and Stepanov, 'Sostoyaniye i perspektivy ispol'zovaniya iskusstvennogo intellekta v voyennom dele' ['The Condition and Use Prospects of Artificial Intelligence in Military Affairs'], p. 115.
20. See, for example, A M Goncharov and S V Ryabov, 'Iskusstvennyy intellekt kak osnovnoye napravleniye razvitiya robototekhnicheskikh kompleksov' ['Artificial Intelligence as the Main Development Trend in Advancing Robotechnical Systems'], *Voennaya Mysl'* [*Military Thought*] (No. 6, June 2021), pp. 65–70.
21. See, for example, Galkin and Stepanov, 'Voprosy bezopasnosti primeneniya iskusstvennogo intellekta v sistemakh voyennogo naznacheniya' ['The Condition and Use Prospects of Artificial Intelligence in Military Affairs'], pp. 72–79; Matviyenko and Uvarov, 'Nauchno-tekhnicheskiye problemy primeneniya tekhnologiy iskusstvennogo intellekta i neyrosetevykh tekhnologiy obrabotki dannykh v avtomatizirovannykh sistemakh Raketnykh voysk strategicheskogo naznacheniya' ['Science-and-Technology Issues of Using Artificial Intelligence Technologies and Neural Network Technologies of Data Processing in the Automated Systems of Strategic Missile Forces'], pp. 113–18.
22. See Jessica Cox and Heather Williams, 'The Unavoidable Technology: How Artificial Intelligence Can Strengthen Nuclear Stability', *Washington Quarterly* (Vol. 44, No. 1, 2021), pp. 69–85.

military-political leadership underlines the need to keep humans in the decision-making loop, especially in the nuclear domain, an extensive use of advanced AI-based decision-support systems that may be opaque and encourage automation bias could undermine effective human judgement and control. Consequently, this could hamper the ability of humans to manage escalation in crisis situations. An important question that seems to be missing from the debate among Russian political and military elites is, therefore, the point at which a human verifies the information of an AI-based analysis or alert process. Tasking a human operator only with rubber-stamping the actions of machines could have detrimental effects.

The impact of AI on strategic stability does not depend solely on the actual application of AI. It will perhaps, more significantly, depend on how adversaries perceive each other's AI capabilities.[23] As the research for this paper has demonstrated, Russia is already closely following US technological developments and policies in the area of AI which, to a certain extent, dictate its own AI policies and developments. Russia might, therefore, feel increasingly insecure in relation to US technological advances that might undermine its nuclear deterrent, especially its land-based nuclear forces.[24] Similarly, advances in AI will also likely aggravate Russia's concerns over US missile defence capabilities. As a consequence, technological developments could further exacerbate threat perceptions and provoke the adoption of riskier applications and postures.

Recommendations

In order to ensure that neither dangerous AI applications nor perceptions about adversaries' AI capabilities undermine strategic stability, arms control should be used to increase transparency and confidence.

First, the US and Russia – or the P5[25] as a whole – should declare that only human beings can authorise the employment of nuclear weapons.[26]

Second, while this could strengthen confidence, only declaring human control over nuclear launch decisions will not solve all related problems. Thus, the US and Russia should also address

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23. See James Johnson, 'The Impact of Artificial Intelligence on Strategic Stability, Escalation and Nuclear Security', in Sam Dudin and Chelsey Wiley (eds), 'The 2019 UK PONI Papers', RUSI, 2019, pp. 43–47.
24. A fear that has also been voiced in military writings is that the US efforts in the area of autonomous underwater vehicles could significantly improve submarine reconnaissance and make specific sea areas transparent. See V P Spiridonov, 'Napravleniya razvitiya atomnykh podvodnykh lodok i avtonomnykh podvodnykh apparatov VMS SSHA' ['Development Trends Regarding Nuclear Submarines and Autonomous Submersible Vessels of the US Navy'], *Voyennaya Mysl'* [*Military Thought*] (No. 3, March 2020), pp. 122–32.
25. The permanent members of the UN Security Council and nuclear weapon states (China, France, Russia, the UK and the US).
26. This should also rule out the use of potentially autonomous nuclear delivery vehicles that undermine positive human control over the decision to use nuclear weapons.

the military applications of AI in their strategic stability dialogues and discuss how they seek to apply AI, how this might impact their policies and postures, and exchange their views on AI safety. This could lay the groundwork for further steps, such as codes of conduct or joint principles on AI safety.

Finally, states should individually invest in rigorous testing, evaluation, verification and validation processes of applications of AI and machine autonomy. In the absence of multilateral policy and regulatory regimes on military AI, this measure can signal the importance of ensuring reliable and safe AI to other states.

III. The UK's Integrated Review: Implications for Transparency Measures Within the P5 Process

Claudia Westwood

THE UK'S INTEGRATED Review, entitled *Global Britain in a Competitive Age: The Integrated Review of Security, Defence, Development and Foreign Policy*, was released in March 2021 and outlined the greatest shift in UK nuclear policy since the end of the Cold War.[1] It was released in the midst of a deteriorating international security environment, with tensions rising between the five nuclear weapon states recognised under the Treaty on the Non-Proliferation of Nuclear Weapons (NPT) (China, France, Russia, the UK and the US). Whilst the nuclear stockpile cap increase has been widely discussed among disarmament groups,[2] the policy shift to strategic ambiguity has not resulted in as much debate within the nuclear field. Given that the UK has positioned itself as a leader on doctrinal transparency since the mid-2000s,[3] this paper examines the implications of this under-discussed point for transparency within the P5 Process and the stability of the international security environment.[4]

1. HM Government, *Global Britain in a Competitive Age: The Integrated Review of Security, Defence, Development and Foreign Policy,* CP403 (London: The Stationery Office, 2021).
2. Kingston Reif and Shannon Bugos, 'UK to Increase Cap on Nuclear Warhead Stockpile', *Arms Control Today,* April 2021, <https://www.armscontrol.org/act/2021-04/news/uk-increase-cap-nuclear-warhead-stockpile>, accessed 8 August 2021; James McKeon, 'Reversing Course: The UK's Decision to Increase the Cap on Nuclear Warheads', Nuclear Threat Initiative (NTI), 18 March 2021, <https://www.nti.org/analysis/atomic-pulse/reversing-course-the-uks-decision-to-increase-the-cap-on-nuclear-warheads/>, accessed 8 August 2021; Tom Plant and Matthew Harries, 'Going Ballistic: The UK's Proposed Nuclear Build Up', RUSI Commentary, 16 March 2021.
3. Marina Favaro, 'Weapons of Mass Distortion: A New Approach to Emerging Technologies, Risk Reduction, and the Global Nuclear Order', Centre for Science and Security Studies, King's College London, 2021, <https://www.kcl.ac.uk/csss/assets/weapons-of-mass-distortion.pdf>, accessed 16 June 2021; Sebastian Brixey-Williams, 'The P5 Process: The United Kingdom's Coordination in 2019-2020', European Leadership Network, 30 April 2020, <https://www.europeanleadershipnetwork.org/commentary/the-p5-process-the-united-kingdoms-coordination-in-2019-2020/>, accessed 9 August 2021.
4. The P5 refers to the Permanent Five of the UN Security Council: Russia, China, France, the UK and the US. These states are also the five nuclear weapon states recognised under the Treaty on the Non-Proliferation of Nuclear Weapons (NPT), sometimes referred to as the 'N5'. The P5 Process consists of the five nuclear weapon states recognised under the NPT and is the main forum for

The key points of the nuclear section of the Integrated Review include a 10% increase in the UK's nuclear stockpile cap (reverting its previous disarmament goal of 180 warheads[5]), a 'once-in-two-generations' modernisation programme, a policy of maintaining ambiguity over when, how and at what scale the UK would make use of its nuclear arsenal, as well as an announcement that the government will no longer release figures for its operational stockpile, deployed warhead count or deployed missile numbers.[6] The implications of these changes for disarmament efforts have been analysed,[7] along with those for the UK's nuclear reputability,[8] for the UK going into the delayed 2020 NPT Review Conference,[9] and for the credibility of the UK's nuclear force.[10]

This paper seeks to add to the conversation around the Integrated Review by examining the shift away from transparency to strategic ambiguity and assessing the implications for transparency between the P5 states. The P5 Process is the key forum for discussions between the five nuclear weapon states recognised under the NPT, and transparency has been a fundamental element of the process since its formation in 2009. Limiting this examination to a P5 context, both in what it means for transparency discussions and what the implications could be for strategic stability, allows for insight into how the risk of nuclear weapons use will be affected by the Integrated Review.

A Shift Away from Doctrinal Transparency

Nuclear transparency is a well-researched topic,[11] but the term encompasses a variety of actions for differing purposes. A clear definition of the type and purpose of transparency is crucial for

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these states to discuss nuclear issues. Transparency measures have been a key topic of discussion within this forum.

5. HM Government, *Securing Britain in an Age of Uncertainty: The Strategic Defence and Security Review* (SDSR), Cm 7948 (London: The Stationery Office, 2010).
6. HM Government, *Global Britain in a Competitive Age*, pp. 77–79.
7. Sebastian Brixey-Williams, 'The Nuclear Weapons Dimensions of the 2021 Integrated Review: A First Look', BASIC, 16 March 2021, <https://basicint.org/the-nuclear-weapons-dimensions-of-the-2021-integrated-review-a-first-look/>, accessed 11 July 2021.
8. James McKeon, 'Q&A: Des Browne on the UK's Decision to Increase the Cap on Nuclear Warheads', NTI, 14 April 2021, <https://www.nti.org/analysis/atomic-pulse/qa-des-browne-on-the-uks-decision-to-increase-the-cap-on-nuclear-warheads/>, accessed 11 July 2021.
9. Julia Berghofer, 'The UK Government's Change in Nuclear Policy Could Raise Difficult Questions With the Non-Proliferation Treaty (NPT) Community', European Leadership Network, 22 March 2021, <https://www.europeanleadershipnetwork.org/commentary/the-uk-governments-change-in-nuclear-policy-could-raise-difficult-questions-with-the-non-proliferation-treaty-npt-community/>, accessed 12 July 2021.
10. Nick Childs and Douglas Barrie, 'The UK and Nuclear Warheads – Stretching Credibility?', IISS, 26 March 2021, <https://www.iiss.org/blogs/military-balance/2021/03/uk-nuclear-warheads-integrated-review>, accessed 11 July 2021.
11. See Nicholas Zarimpas (ed.), *Transparency in Nuclear Warheads and Materials: The Political and Technical Dimensions* (Oxford: Oxford University Press, 2003); Pavel Podvig, 'Transparency in

assessing its implications, so this paper will limit the scope of research to examine doctrinal transparency between nuclear weapons states within the P5 Process. Nuclear doctrine can be defined as the factors which guide the instances where nuclear weapons are deployed, when their use is considered, and the force structure and declaratory policy of the nuclear weapon states.[12] The purpose of this doctrinal transparency is to minimise the risk of misunderstanding and miscommunication that might lead to nuclear escalation or use. To assess the implications of the Integrated Review's shift to strategic ambiguity, this paper used a qualitative content analysis[13] of the Integrated Review and P5 Process documents, primarily joint statements following P5 conferences from 2009 to 2020, supplemented with wider P5 statements, national security documents released by the P5 states, and secondary sources.

Since 2009, P5 Process Joint Statements have shifted gradually from emphasising transparency for confidence-building to risk reduction. The 2009 Joint Statement on the first P5 Conference outlined the group's goal to '[build] mutual confidence through voluntary transparency and other measures'.[14] From 2010 to 2016, documents indicate that P5 states 'continued their previous discussions on the issues of transparency and mutual confidence, including nuclear doctrine and capabilities'.[15] Following the deterioration of P5 relations in 2017 and 2018, which prevented P5 Process meetings from taking place, China's 2019 Briefing on the Beijing Conference specified that the P5 sought to 'enhance dialogue on nuclear policies and doctrines … to prevent nuclear risks, in particular resulting from miscalculation and misperception'.[16]

While the UK has positioned itself as a leader on doctrinal transparency within the P5, there has been a definitive shift in focus to risk reduction since 2019. This language is not dissimilar to the language on transparency within the Integrated Review, which states that: 'The UK will … champion strategic risk reduction and seek to create dialogue among states possessing nuclear weapons … to increase understanding and reduce the risk of misinterpretation and miscalculation.'[17]

Nuclear Disarmament', UN Institute for Disarmament Research, March 2012, <https://unidir.org/files/publications/pdfs/transparency-in-nuclear-disarmament-390.pdf>, accessed 9 August 2021.

12. Paul Ingram, 'Discussion Paper: Nuclear Doctrine', NTI, January 2019, <https://media.nti.org/documents/Discussion_Paper-Nuclear_Doctrine.pdf>, accessed 1 July 2021.
13. Content analysis is a qualitative research method in which the researcher uses the content of documents, including primary and secondary sources, to draw conclusions about the author, the audience or the message itself. For further reading, see Robert Philip Weber, 'Basic Content Analysis', 2nd edition (London: Sage, 1990).
14. P5 Process, 'Joint Statement on the First P5 Conference, London, 2009'. See Maximilian Hoell and Andreas Persbo, 'Overcoming Disunity: Reinvigorating the P5 Process a Decade On', July 2020, European Leadership Network, p. 36, <https://www.europeanleadershipnetwork.org/wp-content/uploads/2020/07/P5-Process-report-1.pdf>, accessed 14 September 2021.
15. P5 Process, 'Joint Statement on the Second P5 Conference, Paris, 2011'.
16. P5 Process, 'Briefing on P5 Beijing Conference by Ambassador Li Song', 2019.
17. HM Government, *Global Britain in a Competitive Age,* p. 78.

In both cases, the language has shifted to focus on doctrinal transparency for risk reduction and crisis aversion. This indicates that the Integrated Review reflects the UK's alignment with language it has been supporting within P5 joint statements, rather than a shift from its position within the P5 Process. Therefore, there is a degree of continuity with the P5 Process on doctrinal transparency and the Integrated Review is unlikely to undermine the UK's position on this. This does not mean, however, that the Integrated Review will have no implications for transparency measures in multilateral arms control forums such as the P5 Process; rather, it suggests that a broader examination of the effect of strategic ambiguity on strategic stability is required to shed light on the wider implications this policy shift will have for the international environment.

Strategic Ambiguity and Strategic Stability

Although there is no universally agreed definition, 'strategic stability' can be defined in narrow terms as consisting of arms race stability – 'the absence of incentives to build up a nuclear force' – and crisis stability – 'the absence of incentives to use nuclear weapons first'.[18] The latter is especially relevant for doctrinal transparency because the aim of such transparency is to make clear the circumstances in which nuclear use would be considered by a state, thus reducing the risk of misinterpretation of action by an adversary leading to an accidental retaliatory or pre-emptive nuclear strike.

The Integrated Review highlights that the UK now operates in a 'deteriorating security environment', noting the following areas of concern:

> Proliferation of CBRN weapons, advanced conventional weapons and novel military technologies will increase the risk and intensity of conflict and pose significant challenges to strategic stability … Opportunistic states will increasingly seek strategic advantage through exploiting and undermining democratic systems and open economies. Russia will be more active around the wider European neighbourhood, and Iran and North Korea will continue to destabilise their regions. The significant impact of China's military modernisation and growing international assertiveness within the Indo-Pacific region and beyond will pose an increasing risk to UK interests.[19]

Beyond these threats to the UK, the nuclear section explicitly links this context to the shift to strategic ambiguity, noting the need for a new nuclear policy as a result of 'the changing security and technological environment'.[20] P5 Joint Statements in 2019 and 2020 also stated that 'the P5 [recognise] that the current international security environment is facing severe challenges'.[21] Thus, the shift to ambiguity must be understood as a response to the international environment.

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18. James M Acton, 'Reclaiming Strategic Stability', Carnegie Endowment for International Peace, 5 February 2013, <https:// carnegieendowment.org/2013/02/05/reclaiming-strategic-stabilitypub-51032>, accessed 15 June 2021.
19. HM Government, *Global Britain in a Competitive Age,* p. 29.
20. *Ibid.,* p. 77.
21. P5 Process, 'Briefing on the Eighth P5 Conference, Beijing 2019 by Ambassador Li Song to the Conference on Disarmament, Geneva', 2019; P5 Process, 'Statement by China on Behalf of the P5

The UK's Integrated Review asserts that ambiguity 'complicates the calculations of potential aggressors, reduces the risk of deliberate nuclear use by those seeking a first-strike advantage, and contributes to strategic stability'.[22] However, as a leader on transparency, the UK has previously pushed Russia and China to be more transparent on doctrine, arguing that it would be a stabilising manoeuvre. It is important to critically evaluate whether the shift away from transparency in the Integrated Review is indeed stabilising in order to assess repercussions for the wider security environment.

Strategic ambiguity as outlined in the Integrated Review could increase the potential for miscalculation and miscommunication resulting in nuclear use. Notwithstanding the UK's assurance that nuclear use would only be considered 'in extreme circumstances of self-defence',[23] the UK's description of the deteriorating security environment shows how complicated threat perception calculations are. The Integrated Review reserves the UK's right to potentially broaden the consideration of nuclear use in response to a wider range of threats, including emerging technology.[24] A similar trend towards increased ambiguity in definitions of self-defence can also be seen in Russia's 2014 Military Doctrine, which stated that the country could consider nuclear use in response to an attack with 'conventional weapons'.[25] The trajectory in clarity about when nuclear weapons could be used appears to be towards a wider range of circumstances, inherently decreasing crisis stability. As a result of this increasingly ambiguous declaratory policy, there is a need to enhance risk-reduction transparency and crisis communication channels within the P5 Process to avoid miscommunication leading to accidental pre-emptive or retaliatory nuclear use.

Policy Recommendations

While the Integrated Review saw the UK, the most prominent P5 advocate for transparency, shift its focus to risk reduction, the UK remains the most transparent state of the P5 in a broader sense. It is committed to domestic transparency measures with mechanisms for government oversight, civil society debate of nuclear policy, and transparency about the total number of warheads. It is this strength that makes the UK best equipped to pursue multilateral nuclear transparency measures within the P5 Process.

As the international environment deteriorates, the UK should reassert a leadership role on transparency within the P5 Process. If the hostile state of the international environment has limited the viability of doctrinal transparency within the process for the time being, the UK should instead aim to add concrete risk-reduction measures to the agenda. Given that heightened

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to the Third Preparatory Committee for the 2020 NPT Review Conference', 1 May 2019, p. 79. See Hoell and Persbo, 'Overcoming Disunity', p. 79.

22. HM Government, *Global Britain in a Competitive Age,* p. 77.
23. *Ibid.,* p. 76.
24. *Ibid.,* p. 77.
25. Embassy of the Russian Federation to the United Kingdom of Great Britain and Northern Ireland, 'The Military Doctrine of the Russian Federation', press release, 29 June 2015, <https://rusemb.org.uk/press/2029>, accessed 6 September 2021.

tension increases nuclear risk, the UK should push to establish P5 crisis communication forums, including a procedural framework for their use during emergencies.

While nuclear discussions between the P5 states necessitate secrecy, both the UK and the P5 can do more to make transparency measures more visible to civil society and non-nuclear weapons states. Such transparency – while maintaining a degree of secrecy to protect national security – is possible, and it is encouraging that China's Statement to the Third Preparatory Committee 2020 highlighted that the P5 planned 'to explore the possibility of explaining respective nuclear policy and doctrine through jointly holding a side event during the 2020 Review Conference'.[26] In a concerning international environment, such measures can reassure civil society and non-nuclear weapons states that the P5 are actively aiming to secure a safer nuclear environment.

Conclusion

The language on doctrinal transparency in the UK's Integrated Review is not dissimilar to that of P5 joint statements, shifting the focus to risk-reduction dialogue as the international security environment has deteriorated. There is a worrisome trajectory in national defence postures towards ambiguity about situations where nuclear use could be considered within this environment, enhancing the risk of miscalculation and miscommunication. The UK should reassert its commitment to P5 transparency by leading on concrete risk-reduction measures, including forums for crisis communications. The P5 Process remains a vital forum for nuclear weapons states, and while it cannot be expected to supersede the constraints of the international security environment within which it operates, there is room for the UK to lead on risk reduction within the P5 Process to make the nuclear environment safer and more stable.

26. 'Review Conference' (or RevCon) refers to the Review Conference of the Parties to the Treaty on the Non-Proliferation of Nuclear Weapons. Within the NPT, states agreed to meet every five years to review the status of the Treaty's implementation. A Review Conference was scheduled for 2020, but it has been postponed twice due to the coronavirus pandemic and is currently scheduled for 4–28 January 2022. See P5 Process, 'Statement by China on Behalf of the P5 to the Third Preparatory Committee for the 2020 NPT Review Conference', 1 May 2019; Hoell and Persbo, 'Overcoming Disunity', p. 79.

Section II. New Technologies and Deterrence

IV. The Rupture-Talk of ‘Emerging Tech’ Versus Nuclear Deterrence

Cameron Hunter

GOVERNMENTS AND EXPERTS have proclaimed a ‘rupture’ is taking place in the practices and stability of nuclear deterrence, citing technologies such as AI, hypersonic delivery vehicles, counterspace techniques and ballistic missile defence. For example, both the US 2018 Nuclear Posture Review and UK 2021 Defence White Paper invoke ‘new’ domains of ‘cyberspace’, outer space, ballistic missile defence and the emergence of hypersonic missiles as evidence that stability is decreasing and existing deterrence postures need to be modified. Fiona S Cunningham and M Taylor Fravel also report that Chinese experts expect US missile defences to continue improving to the point that a Chinese retaliatory strike against the US could be unviable.[1] These official and semi-official pronouncements position ‘emerging tech’[2] as a suite of inevitable technical advances that will unavoidably transform nuclear deterrence. This perspective, however, is logically and empirically flawed. Rather than a set of strictly technical developments, the impact of ‘new’ technologies is deeply political and contingent. Consequently, proclamations of transformative technical capability should be met with scepticism.

The Concept of Rupture-Talk

Gabrielle Hecht writes that rupture-talk is ‘the rhetorical invocation of technological inventions to declare the arrival of a new era or a new division in the world’, her prime example being the ‘repeated political proclamations that nuclear weapons had produced a new world order’.[3]

1. See US Department of Defense, Office of the Secretary of Defense, ‘Nuclear Posture Review 2018’, February 2018, pp. v, 9, <https://media.defense.gov/2018/Feb/02/2001872886/-1/-1/1/2018-NUCLEAR-POSTURE-REVIEW-FINAL-REPORT.PDF>, accessed 16 August 2021; Ministry of Defence, *Defence in a Competitive Age*, CP 411 (London: The Stationery Office 2021), pp. 1–7; Fiona S Cunningham and M Taylor Fravel, ‘Assuring Assured Retaliation: China’s Nuclear Posture and U.S.-China Strategic Stability’, *International Security* (Vol. 40, No. 2, 2015), pp. 17–18.
2. This paper conceives of ‘emerging tech’ as a discourse, using the shortened form of ‘technology’ that is customarily adopted within discussions among experts. In this way, the paper aims to differentiate this narrower discourse from more general discussions of the same technologies.
3. Gabrielle Hecht, ‘Globalization Meets Frankenstein? Reflections on Terrorism, Nuclearity, and Global Technopolitical Discourse’, *History and Technology* (Vol. 19, No. 1, 2003), p. 2.

Rupture-talk tends to be obscuring something – Hecht reveals the hidden colonial and post-colonial dynamics that made the nuclear age possible, for example. The colonial underpinnings of the global nuclear arsenal demonstrate immediately that rupture-talk is not tantamount to total 'newness'. Instead, it is often about how longstanding phenomena are redrawn and repurposed alongside technological developments.

Hecht's idea of rupture-talk is a valuable route to understanding the significance of the reluctance of the policy world to confidently engage with the technical detail of emerging tech. It leads to two initial insights: first, retreating from technical debate is only conceivable because of how settled and ordered nuclear deterrence discourse has become; and second, that predominantly policy-minded people have a valuable contribution to make in shaping, perhaps even setting, what these developments mean for the nuclear predicaments of the coming decades.

Viewed this way, the emerging-tech discourse is, at its core, a proxy disagreement within the nuclear community about theories of deterrence. Questions of how (and if) nuclear deterrence can be practised, and whether a defence will ever be possible against nuclear attack, go back to the 1940s.[4] 'New' technologies – many of which have their roots in the mid-20th century – have provided a new impetus to revisit these core questions of deterrence theory, but the rupture-talk character of the discourse makes the discussion elliptical and unclear.[5]

Reframing debates over 'emerging' and 'disruptive' technologies relating to nuclear deterrence as a form of 'rupture-talk' deterrence guides analysis towards what is hidden, missing or recycled from the past. Since technological change cannot independently transform politics and strategy, claims to the effect that 'emerging tech' constitutes a rupture in deterrence can be termed as hype. This is because these claims misleadingly inflate the transformative potential of 'new' technologies. Applying the analytical lens of rupture-talk, developed by Hecht,[6] provides a way to cut through hype by drawing attention to how the rupture-talk of emerging-tech discourse conceals the troubling continuities of the nuclear age. It directs attention away from the capability of nuclear arsenals to wreak mass destruction on human lives, and it is this mass

4. Bernard Brodie, 'Implications for Military Policy', in Bernard Brodie et al., *The Absolute Weapon: Atomic Power and World Order*, President Eisenhower's Copy of Preliminary Draft (New Haven, CT: Yale Institute of International Studies: 1946), Chapter 2, <https://www.osti.gov/opennet/servlets/purl/16380564>, accessed 15 July 2021.
5. There is also a flavour of what might be called 'wishful worries' (following David Brock and Lee Vinsel): more esoteric, 'interesting' concerns that distract from more mundane but tangible problems. Many thanks to Marina Favaro who made this observation. See David C Brock, 'Our Censors, Ourselves: Commercial Content Moderation', *Los Angeles Review of Books*, 25 July 2019, <https://lareviewofbooks.org/article/our-censors-ourselves-commercial-content-moderation/>, accessed 15 July 2021; Lee Vinsel, 'You're Doing it Wrong: Notes on Criticism and Technology Hype', *STS News*, February 2021, <https://sts-news.medium.com/youre-doing-it-wrong-notes-on-criticism-and-technology-hype-18b08b4307e5>, accessed 15 July 2021.
6. Gabrielle Hecht, 'Rupture-Talk in the Nuclear Age: Conjugating Colonial Power in Africa', *Social Studies of Science* (Vol. 32, No. 5–6, 2002), pp. 691–727.

killing capability that remains the key predicament characterising the 'nuclear age'.[7] For the advocates of nuclear deterrence, it is this inescapable possibility of nuclear mass destruction that is central to the validity of the theory. The emerging-tech discourse attempts to cast doubt on the possibility of stable deterrence, if not deterrence itself, by positioning new technologies as capable of invalidating its basic tenets.[8]

The practical upshot of considering the emerging-tech discourse as rupture-talk is in how people interested in nuclear issues should cooperate. Expertise across social sciences, engineering and physical sciences can be combined to cut through emerging-tech hype and help counter misleading narratives of helplessness in the face of technological determinism.[9] This is because strategic and policy pronouncements can suffer from any combination of mistaken understandings of technical specifications or political dynamics, meaning analysis based on expertise in only one discipline will risk leaving a whole category of claims unscrutinised. Evaluations of strategic risk are not the sole domain of engineers and scientists, despite efforts to this effect in past. The extreme techno-optimism and advocacy of the famous nuclear physicist, Edward Teller, is an emblematic example. While clearly technically brilliant, Teller's lack of grounding in political and strategic theory made his policy advocacy fatally flawed.[10] The worst-case scenario of Teller is by no means the fate of every engineer or scientist. Rather, without sustained partnerships with the policy world, technical specialists will be left without the political and historical expertise they need to understand the impact of their work and the challenges associated with technological development. Technology alone will not dissolve the political predicaments of nuclear weapons.

What Is Emerging Tech Emerging From?

To understand what is disruptive about emerging tech, a rupture-talk approach requires an unpacking of its proponents' historical narrative. The view of the past implied within the emerging-tech discourse makes two mistakes, one on politics and the other on technology. First, this view wrongly re-imagines the political history of nuclear weapons as one of stability, predictability and rationality that recent technical developments are supposedly disrupting.[11]

7. The 'nuclear age' itself is a form of rupture-talk, concealing the survival of colonial forms of exploitation even as formal European empires collapsed. See Hecht, 'Globalization Meets Frankenstein?'.
8. For an example of how deterrence proponents see deterrence stability being threatened by 'emerging-tech', see Edward Geist and Andrew J Lohn, 'How Might Artificial Intelligence Affect the Risk of Nuclear War?', RAND Corporation, 2018.
9. For an indicative academic determinist argument, see Keir Lieber and Daryl Press, 'The New Era of Counterforce: Technological Change and the Future of Nuclear Deterrence', *International Security* (Vol. 41, No. 4, 2017), p. 49.
10. See Carl Sagan, *The Demon-Haunted World: Science as a Candle in the Dark* (New York, NY: Ballantine Books, 1997), pp. 284–89, 419; William Broad, *Teller's War: The Top-Secret Story Behind the Star Wars Deception* (New York, NY: Simon and Schuster, 1992).
11. See, for example, David Rosenburg, 'The Origins of Overkill: Nuclear Weapons and American Strategy, 1945-1960', *International Security* (Vol. 7, No. 4, 1983), pp. 3–71; Benoît Pelopidas and

Second, the discourse mistakenly imagines nuclear deterrence as predominantly untroubled by technical developments during the Cold War. Taken together, imagining 20th-century nuclear politics and technology as settled and uncontroversial makes the emerging-tech discourse diverge significantly from reality.

Starting with Hiroshima and Nagasaki, the effects of the atom bomb were made obvious and indisputable to anyone that could read a newspaper or watch the news reels.[12] However, certainty of the bomb's destructive capacity was not enough to determine a specific political response. It was solely within the realm of policy and strategy that the purpose of nuclear weapons was properly settled (as well as can be, at any rate). Risking caricature, one can look at how the purpose of the A-bomb could have gone another way after 1945 – placed alongside the conventional military arsenals as a bigger bomb, the next development in artillery and long-range strike technology.[13] In 1949, the most senior American military leaders even viewed the fusion bomb as a future tactical weapon.[14] Echoes of this view can still be heard from proponents of low-yield warheads[15] and 'escalate-to-deescalate' debates.[16] The rival idea, best represented by the strategic theorising of Bernard Brodie, was the A-bomb as the ultimate weapon and harbinger of a new primary role for militaries – deterrence.[17] It is almost peculiar to think that the latter won out, when the US was the sole nuclear power (with no nuclear peer to deter), and the only wartime uses of the A-bomb were in effect as a substitute for conventional area bombing missions – a more 'efficient' and 'effective' stand-in for outmoded conventional weapons.[18] Hindsight makes the deterrence school look like the inevitable victor, when it

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Sébastien Philippe, 'Unfit for Purpose: Reassessing the Development and Deployment of French Nuclear Weapons (1956–1974)', *Cold War History* (Vol. 21, No. 3, 2020), pp. 243–60.

12. Bernard Brodie, *Strategy in the Missile Age* (Santa Monica, CA: RAND Corporation, 1959, 1965), p. 150.
13. Ken Young and Warner Schilling, *Superbomb: Organizational Conflict and the Development of the Hydrogen Bomb* (Ithaca, NY: Cornell University Press, 2019), p. 15.
14. *Ibid.*, p. 98.
15. The most notable recent example is the Trump administration's 'low-yield' version of the W-76 warhead for the Trident II (D-5). See Congressional Research Service, 'A Low-Yield, Submarine-Launched Nuclear Warhead: Overview of the Expert Debate', 5 January 2021.
16. See Olga Oliker and Andrey Baklitskiy, 'The Nuclear Posture Review and Russian "De-Escalation": A Dangerous Solution to a Nonexistent Problem', *War on the Rocks*, 20 February 2018.
17. Brodie, *The Absolute Weapon*, p. 62.
18. It should also be noted that the version of deterrence theory produced by thinkers such as Bernard Brodie and Thomas Schelling were not directly implemented in practice by the US – see, for example, Bruce Kuklick, *Blind Oracles: Intellectuals and War from Kennan to Kissinger* (Princeton, NJ: Princeton University Press, 2006). The point here is that civilian US decision-makers never authorised nuclear attacks in a so-called 'tactical' role, despite having weapons designed for that role in the arsenal and advice to the contrary from advisors. See US Department of State, Office of the Historian, 'Foreign Relations of the United States, 1964–1968, Volume VI, Vietnam, January–August 1968. 51. Memorandum from the Chairman of the Joint Chiefs of Staff (Wheeler) to President Johnson', February 1968, <https://history.state.gov/historicaldocuments/frus1964-

was never predetermined to become the dominant idea for how nuclear weapons should be 'used'. The political debate decided what the technical development would mean and be used for, but the result was fraught with contingency. The lesson for today is that the policies of deterrence were not embedded in the first bombs, waiting to be discovered. Likewise, there is no reason to expect emerging tech to determine a new political situation simply due to technical specifications.

The emerging-tech narrative recasts the technological history of nuclear weapons as linear and straightforward until the arrival of new, troublesome technologies. Yet, notably, all of the technologies bedevilling the nuclear policymakers of today have their roots in Cold War research and practice. Command-and-control problems in the face of hypothetical attacks at hypersonic speeds first emerged with the deployment of long-range ballistic missiles.[19] Non-kinetic network interference, in the form of jamming against radio guidance, was a problem for early missile guidance.[20] Unconventional attacks on weapon systems and nuclear command, control and communications were confronted in US Air Force anti-sabotage doctrine from early in the Cold War.[21] But simply observing that emerging tech is not new is, of course, not useful in and of itself. At its simplest, it shows that with the notable exception of the A-bomb itself, 'hype' is usually misplaced, and supposedly inevitable technological transformations fail to materialise.

Understanding that 20th-century nuclear elites also feared that new technologies would invalidate deterrence in the future suggests that uncertainty about the long-term effectiveness of nuclear deterrence is not a result of the emerging tech of today, but rather an enduring characteristic.[22] The debate, then and now, is primarily about rival notions of what nuclear deterrence is, what conditions it requires, and whether it is possible at all. It is this debate that the emerging-tech discourse conceals. The core question at the intersection of nuclear politics and technology remains: is atomic mass-killing possible? Despite the uncertainty of the future

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68v06/d51>, accessed 17 August 2021; Fredrik Logevall, '"We Might Give Them a Few." Did the US Offer to Drop Atom Bombs at Dien Bien Phu?', *Bulletin of the Atomic Scientists*, 21 February 2016, <https://thebulletin.org/2016/02/we-might-give-them-a-few-did-the-us-offer-to-drop-atom-bombs-at-dien-bien-phu/>, accessed 17 August 2021; US Department of State, Office of the Historian, 'Foreign Relations of the United States, 1950, Korea, Volume VII, Editorial Note', <https://history.state.gov/historicaldocuments/frus1950v07/d909>, accessed 17 August 2021; Roger Dingman, 'Atomic Diplomacy During the Korean War', *International Security* (Vol. 13, No. 3, Winter 1988–89), p. 57.

19. Brodie, *Strategy in the Missile Age*, p. 223.
20. Donald Mackenzie, *Inventing Accuracy: A Historical Sociology of Nuclear Missile Guidance* (Cambridge, MA: MIT Press, 1990), pp. 121–22.
21. Melvin Dealie, 'The SAC Mentality', *Air & Space Power Journal* (March–April 2015), p. 65.
22. Recent revisionist literature arguing that the logic of mutually assured destruction never fully persuaded US policymakers provides American case studies of this phenomenon. See, for example, Brendan Green, *The Revolution that Failed: Nuclear Competition, Arms Control, and the Cold War* (Cambridge: Cambridge University Press, 2020).

of technology, both strategic and political theory lend a grim confidence that no technological development will end this possibility.

Conclusion: How to Cut Through the Hype?

A robust, policy-minded intervention in the debate on 'new' technologies and their intersections with nuclear deterrence is necessary and desirable. Nuclear policy analysts should not be ceding the debate to engineers, technologists and scientists, but rather interacting as peers with complementary skillsets.

Hecht's rupture-talk analytical approach provides a way forward. Making the historical comparison with the unsettled controversies of 20th-century nuclear deterrence is a great starting point. Specifically, if it is recognised that even the A-bomb's primary purpose was not predetermined by its technical specifications, then there is little reason to expect 'new', undoubtedly less impactful, technologies to suddenly determine policy responses. From there, asking 'is it worse now?', 'why?' and 'how?' allows today's researchers to build the foundations for a healthy scepticism of how unprecedented this 'emerging tech' actually is, uncovering what has been hidden, or what is missing, from the current debates. For example, comparing 20th-century versions of missile defence, counterspace technology and electronic warfare with their 21st-century descendants provides case studies suggesting where advocates today may be overpromising on technical capability or are misunderstanding the political context of nuclear weapons. In response, policy analysts need to pick up some new technical expertise of their own to enable their own critical engagement with unfamiliar technologies. Revisiting previously fringe interests such as space-based early warning or network connectivity is now indispensable.

Hope can be gained from the fact that there are already well-regarded people working across the technical/policy divide. However, judging by the content of recent government policy pronouncements on emerging tech, this has not been sufficient to banish technically and politically mistaken official assessments.[23] One way or another, emerging tech ensures nuclear policy analysts can no longer be comfortable only parsing the policy and the narrowly defined headline capabilities. Certainty on the implications of the tangle of technologies and policies thought of as the nuclear realm has always been a mirage. Attempting to reduce the core political

23. For example, senior US decision-makers have claimed that existing space-based sensors cannot detect 'hypersonic threats', while independent analysis has shown that legacy space-based infrared sensors are already capable enough. This makes claims to the effect that hypersonic missiles are 'undetectable' misleading at best. See General John E Hyten's comments in Brad Lendon, 'Russia's "Invulnerable" Nuclear Missile Ready to Deploy, Putin Says', *CNN*, 27 December 2018; Douglas M Fraser, Frank Gorenc and John S Shapland, 'Hypersonic Defense Requires Getting Space Sensor System Right', *Real Clear Defense,* 13 May 2020. For the independent analysis disproving these claims, see Cameron L Tracy and David Wright, 'Modeling the Performance of Hypersonic Boost-Glide Missiles', *Science and Global Security*, 16 January 2021, <https://doi.org/10.1080/08929882.2020.1864945>, accessed 13 September 2021.

predicament of the nuclear age – mass destruction – to a matter of technical specification is deeply unproductive.

Cutting through hype requires interdisciplinarity, because as the historical record shows, inflated claims exist at the intersection of the technical and political. Today, professing minimal knowledge of ‘new’ technical ground truths is increasingly impractical while emerging tech barges its way into (what should be) eerily familiar debates on nuclear weapons. Technical developments in and of themselves cannot change the strategic outlook. Their significance always lies within political context. Actively and critically evaluating the qualities of emerging tech is, therefore, definitively the job of the policy community, in partnership with colleagues from technical backgrounds.

V. Autonomous Nuclear Weapons Systems: Ethics, International Law and Future Stability

Josh West, Hazel Carter and James Curtiss

AI ALGORITHMS ARE BEING used in the daily lives of most people in developed countries. These algorithms serve to enhance user experience by, for example, enabling online customer service, providing targeted online advertising and controlling self-driving cars. These decision-making capabilities might also be applied in military sectors, and potentially within nuclear weapon systems. As a result, policies and regulations need to be put in place to govern and restrict the global design and development of autonomous nuclear weapons.

This paper aims to examine the current capability of AI, the principles of the regulation of lethal autonomous weapon systems (LAWS), and the potential for existing regulations in place for AI use in LAWS to be applied to the development and governance of autonomous nuclear weapons.

AI

AI is a system that solves tasks that are understood to require human-like perception, cognition, learning and communication.[1] There are two types of AI: 'Strong' and 'Weak', also known as 'general' and 'narrow', respectively.[2]

Strong AI is frequently portrayed in popular culture, but it is currently purely theoretical in nature. Examples include Hal 9000 from *2001: A Space Odyssey* and Skynet from the *Terminator* franchise. The theoretical models of Strong AI suggest that these systems could make sense of the world and their surroundings in a similar way to humans, including cognitive functions such as puzzle-solving, reasoning and making judgements.[3] There is still considerable debate regarding whether it is possible to develop Strong AI;[4] some experts predict it may be achievable within the next couple of decades, whilst others do not believe that the development of Strong AI is

1. Vincent Boulanin (ed.), 'The Impact of Artificial Intelligence on Strategic Stability and Nuclear Risk: Volume 1: Euro-Atlantic Perspectives', Stockholm International Peace Research Initiative, May 2019.
2. IBM Cloud Education, 'Strong AI', 31 August 2020, <https://www.ibm.com/cloud/learn/strong-ai>, accessed 6 September 2021.
3. *Ibid.*
4. *Ibid.*

possible or, indeed, desirable.[5] Therefore, the risk of this type of AI being used in autonomous nuclear weapons is currently within the realms of science fiction rather than reality. However, given that the theoretical models are in place, now is the time to start to discuss the ethics and regulation of autonomous nuclear weapons.

Weak AI is a type of system that has been designed and developed to execute a limited specific task that it has been trained to do. The main principle of Weak AI is that it lacks human consciousness.[6] For example, an AI system that has been designed and trained to analyse a large collection of data would not be able to challenge a human to a game of chess, or vice versa. Simply, Weak AI is incapable of making decisions and has no problem-solving functions outside of what it is designed to do.

Weak AI systems are widely used in numerous public sectors and private industries, such as the use of bots for online customer service, making online shopping recommendations and controlling self-driving cars.[7] Here, AI is used primarily to analyse large volumes of data using complex algorithms to automate time-consuming tasks.[8] Although AI is also used every day in commercial industries, its use is now starting to be exploited in the defence sector. For example, the Pentagon Project Maven is using machine learning to sort through vast amounts of ISR data.[9]

In military applications, AI could be used to provide future capabilities for more effective cyber security, more accurate targeting and vision, and improved speed of decision-making.[10] These functions could also potentially be applied to the development of an autonomous nuclear weapon system. Such a system would present complex technological and regulatory challenges. Currently, AI technology is not sufficiently well developed to be used for decision-making in potentially complex and adaptive defence situations, and even if this were to be developed, it would take a significant amount of time to train and test the system before it could become operational.

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5. Joanna J Bryson, 'Patiency Is Not a Virtue: The Design of Intelligent Systems and Systems of Ethics', *Ethics and Information Technology* (Vol. 20, 2018), pp. 15–26; Ragnar Fjelland, 'Why General Artificial Intelligence Will Not Be Realized', *Humanities and Social Sciences Communications* (Vol. 7, 2020).
6. Jake Frankenfield, 'Weak AI', Investopedia, updated 25 February 2021, <https://www.investopedia.com/terms/w/weak-ai.asp>, accessed 6 September 2021.
7. European Parliament News, 'What Is Artificial Intelligence and How Is it Used?', updated 29 March 2021.
8. Frankenfield, 'Weak AI'.
9. John Keller, 'Artificial Intelligence (AI) Becomes the Latest Arms Race as Adversaries Seek to Perfect Machine Learning', *Military & Aerospace Electronics*, 22 December 2020, <https://www.militaryaerospace.com/computers/article/14189468/artificial-intelligence-ai-project-maven-arms-race>, accessed 6 September 2021.
10. Forrest E Morgan et al., *Military Applications of Artificial Intelligence: Ethical Concerns in an Uncertain World* (Santa Monica, CA: RAND Corporation, 2020).

Ethics of Warfare

The 'just war' theory can be used to assess the ethicality of war. It states that for a war to be just and ethical, it must meet a list of principles including legitimacy, necessity, intention, discrimination and proportionality.[11] The last two principles mean that, although a war might be considered just, the warfare methods might be unethical, such as chemical and biological or indiscriminate weapons. These include, for example, nuclear weapons, especially autonomous ones.

International humanitarian law (IHL) is a set of rules that govern warfare to protect persons not actively participating in war, and places restrictions on the means of warfare (weapons and military tactics).[12] The 1949 Geneva Conventions and their Additional Protocols are key parts of IHL and apply to four groups during times of war: wounded and sick military personnel on land; wounded, sick or shipwrecked military personnel at sea; prisoners of war; and civilians, including those in occupied territory.[13]

To comply with the ethics of war, IHL and other international laws, AI used in military applications would need the ability to make decisions and adapt to a changing environment, such that it could determine between persons actively engaged in the war and those who are protected under IHL, and to do so indiscriminately.

Ethics of AI Development and Use

When a human makes a decision, especially in warfare, they are held responsible for the accuracy, reliability and soundness of their judgement; and they are accountable for the fairness and reasoning behind their decision. Due to the way that AI systems are designed and developed, currently they cannot be held either directly responsible or morally accountable for their decision-making in the same way as a human.[14] This means that when a decision is made by an AI system, there is an accountability gap; no-one is held responsible or accountable for any consequences of the actions of AI.[15]

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11. Heather Widdows, 'The Ethics of Warfare: Is it Ever Morally Right to Kill on a Massive Scale', University of Birmingham, <https://www.birmingham.ac.uk/research/perspective/ethics-of-warfare-heather-widdows.aspx>, accessed 6 September 2021.
12. International Committee of the Red Cross (ICRC), 'Treaties and Customary Law', 29 October 2010, <https://www.icrc.org/en/document/treaties-and-customary-law>, accessed 6 September 2021; British Red Cross, 'Geneva Conventions', <https://www.redcross.org.uk/about-us/what-we-do/protecting-people-in-armed-conflict/geneva-conventions>, accessed 6 September 2021.
13. ICRC, 'The Geneva Conventions of 1949 and Their Additional Protocols', 29 October 2010, <https://www.icrc.org/en/doc/war-and-law/treaties-customary-law/geneva-conventions/overview-geneva-conventions.htm>, accessed 6 September 2021.
14. David Leslie, 'Understanding Artificial Intelligence Ethics and Safety: A Guide for the Responsible Design and Implementation of AI Systems in the Public Sector', Alan Turing Institute, 2019.
15. Inioluwa Deborah Raji et al., 'Closing the AI Accountability Gap: Defining an End-to-End Framework for Internal Algorithmic Auditing', Proceedings of the 2020 Conference on Fairness,

To address this accountability gap within the public sector, the FAST (Fairness, Accountability, Sustainability and Transparency) Track principles have been implemented.[16] These principles transfer the responsibility and accountability onto humans throughout the lifecycle of AI-enabled systems. When designing an AI system, it is important to understand the real-world effects and outside influences to ensure the safety, accuracy, reliability, security and robustness of the system. All AI systems are developed by humans; therefore, they can only be as fair and unbiased as the human training and input data they receive; hence the prejudices, biases and misjudgements of human developers can also be 'learned' by the system. Automated decision-making cannot be self-justifiable and does not know rationale of use. Therefore, the ability to understand the reasons behind AI system decision-making will depend on the specific context of its development; the accountability of that decision-making must fall to human developers and users. However, the level at which this accountability should be taken must be considered; for example, should this accountability fall solely on the developers or should it fall higher up the command chain, to those who have sanctioned its use and developed the specification of the system?

This accountability gap and outside influences become even more significant in a potential military application, due to the significant consequences of decision-making. It is important that if an AI system is to be implemented into a military application it is thoroughly understood, and potentially constrained, throughout the lifecycle from design to execution. Hence, there must be a transparent audit trail of the processes of development, training, data input and justification of use. There should also be a clear and transparent statement of who holds the accountability for the decisions that are made by an autonomous weapon system, including autonomous nuclear weapons.

Existing and Recommended Regulations

There have been significant efforts to restrict the development, use and testing of nuclear weapons since the US demonstrated the overwhelming destructive capability of nuclear weapons. Agreements include the Nuclear Test-Ban Treaty (1963),[17] which restricted the testing of nuclear weapons; the Treaty on the Non-Proliferation of Nuclear Weapons (1968),[18] which prevents the spread of nuclear weapons; and the Treaty on the Prohibition of Nuclear Weapons (2021),[19] which is the first treaty actively trying to ban nuclear weapons. Through some of these treaties, many of the world's nuclear weapon states have pledged to work towards the goal of disarmament.

The UN Convention on Certain Conventional Weapons (CCW) and the Group of Governmental Experts on LAWS have developed 11 guiding principles for the regulation of LAWS.[20] Forty UN

Accountability and Transparency, January 2020.

16. Leslie, 'Understanding Artificial Intelligence Ethics and Safety'.
17. Lawrence D Freedman, 'Nuclear Test-Ban Treaty', *Britannica*, 29 July 2021, <https://www.britannica.com/event/Nuclear-Test-Ban-Treaty>, accessed 6 September 2021.
18. 'Treaty on the Non-Proliferation of Nuclear Weapons (NPT)'.
19. 'Treaty on the Prohibition of Nuclear Weapons'.
20. UN Office for Disarmament Affairs (UNODA), 'Background on LAWS in the CCW', <https://www.un.org/disarmament/the-convention-on-certain-conventional-weapons/background-on-laws-in-the-

member states signed up to the guiding principles in 2019.[21] Importantly, these principles set out that IHL still applies to LAWS, that the accountability gap must be filled by responsible humans and that the security of the system must be central to the design of the AI algorithm.[22] However, since the guiding principles were published, the progress towards legal instruments that regulate and prohibit LAWS has stalled.[23]

Although there are no policies, conventions or agreements governing the design, development and use of autonomous nuclear weapons, some consideration should be made on the extension of the guiding principles for LAWS to include autonomous nuclear weapons. However, specific treaties should be drawn up to regulate the design and development of AI for use in nuclear weapon systems, especially if AI has any role in the decision-making or deployment processes. Given that the development of Strong AI is unlikely to be ethically desirable in any context, permitting its development would need to be clearly justifiable should the capability be developed in the future.[24] Negotiations surrounding international support regarding regulation or prohibition of autonomous nuclear weapons are likely to be equally, if not more, complex than LAWS, and any such regulations would need to be carefully balanced to exclude AI research for non-military applications.

Conclusion

In conclusion, whilst AI technology is still fairly limited in its scope and capabilities, research into Strong AI is ongoing. Although most military applications would require strong AI capabilities, LAWS are in development and guidance has been put in place. The same is currently not true for autonomous nuclear weapons. However, IHL, ethics of war and the accountability gap of AI mean that similar regulations of AI development for nuclear weapons must be drawn up, and the use of AI in such applications governed carefully.

Thanks go to Yasmin Afina, Research Analyst, International Security Programme (UK PONI Conference Mentor).

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ccw/>, accessed 6 September 2021.

21. Alliance for Multilateralism, ‘11 Principles on Lethal Autonomous Weapon Systems’, 2019, <https://multilateralism.org/actionareas/11-principles-on-lethal-autonomous-weapons/>, accessed 6 September 2021.
22. UNODA, ‘Background on LAWS in the CCW’.
23. Volker Lehmann, ‘Moving Beyond the 11 Guiding Principles to a Multilateral Instrument on Meaning Human Control: Draft Chair’s Summary of Multisector Expert Discussion on “New Alliances for Meaningful Human Control”’, UN75 Global Governance Forum 2020, New York, September 2020, V1.o, <https://ny.fes.de/fileadmin/user_upload/FES_Chair_summary_v1_-_LAWS_Partnership_VL.pdf>, accessed 6 September 2021.
24. Fjelland, ‘Why General Artificial Intelligence Will Not Be Realized’.

Section III. Technology and Communication in Future Nuclear Deterrent

VI. Replacement Warhead: Deterrence Without Detonation

Mat Budsworth

ON 6 AUGUST 1945, the world became keenly aware of the destructive power of nuclear warheads. Since then, over 2,000 nuclear tests have been conducted by a handful of countries, all of whom have acquired the coveted ability to successfully build nuclear weapons. The UK's last test occurred in November 1991 at the Nevada Test Site and marked an end to the country's empirical approach to warhead certification. It carried out nuclear tests to understand the reliability, safety and performance of its warheads, but a secondary effect, whether intended or not, was a clear demonstration of nuclear weapons capability. Absent the ability to perform full-scale nuclear tests, and in the context of a demanding replacement warhead programme, is the credibility of the UK's nuclear capability at risk? This paper seeks to explore some key themes in answer to this question.

The Comprehensive Test Ban Treaty (CTBT) opened for signature in 1996 and, while the treaty has not entered into force, it has been successful in effectively ending the practice of full-scale nuclear testing. One of the goals of the CTBT has been to significantly increase the difficulty of bringing a nuclear warhead into service by banning the primary method of testing.[1] However, it has also nullified the ability of nuclear weapon states to demonstrate unequivocally their capability to produce working nuclear weapons.

In February 2020, UK Defence Secretary Ben Wallace announced a warhead programme for the UK's nuclear deterrent.[2] This means that the UK will be moving away from a product that was designed, certified and brought into service during the era of full-scale nuclear testing to one that will be deployed in the era of the CTBT. This paper seeks to address the implications of this transition on the effectiveness of the UK replacement warhead as a deterrent. Given

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1. CTBTO Preparatory Commission, 'Objectives and Activities: Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization', 2007, p. 2, <https://www.ctbto.org/fileadmin/content/reference/outreach/objective_and_activities_2007_web.pdf>, accessed 6 September 2021.
2. Ministry of Defence, Defence Nuclear Organisation and Ben Wallace, 'Defence Secretary Announces Programme to Replace the UK's Nuclear Warhead', 25 February 2020, <https://www.gov.uk/government/news/defence-secretary-announces-programme-to-replace-the-uks-nuclear-warhead>, accessed 22 July 2021.

that effective deterrence is predicated on adversary perceptions,[3] the question is then: absent full-scale nuclear testing, can the UK's allies and adversaries remain assured of its nuclear capabilities as it moves towards deployment of its replacement warhead?

It should be noted that the inability to perform full-scale nuclear warhead tests should not affect the perceived credibility of other aspects of the UK nuclear deterrent, for example, the weapon delivery system. As such, this paper does not discuss the perceived effectiveness of any aspect of the future UK nuclear deterrent system other than the warhead.

Perceptions and deterrent effects are also challenging to quantify. Consequently, this paper attempts to highlight several key aspects that might have a positive or negative impact on the credibility of the UK's nuclear warhead capability.

Science-Based Certification

The process of warhead certification without full-scale nuclear testing, referred to as science-based certification (SBC), relies on high-performance computing, bespoke codes and small-scale tests to simulate the conditions experienced throughout the nuclear weapon life-cycle. Computational predictive capabilities are validated against historic underground test data and experimentally obtained results from science facilities.[4]

It is reasonable to suggest that possession and operation of these facilities and tools aids credibility, albeit by an unquantifiable amount. The UK has also, in effect, been performing SBC for many years.[5]

Furthermore, bringing a new system into service does not necessarily mean bringing an entirely different system into service, and the overlap in similarities between the new design and the previously tested design would never be revealed. This ambiguity benefits any state with testing history, such as the UK, and aids the credibility of their new warhead. It is only the timescale between the last test and the new system that adds a layer of uncertainty, with loss of credibility necessarily predicated on the assumption that, in the intervening time, the UK has lost the ability to produce and certify warheads.

It is essential that many of the technical details surrounding warhead certification remain highly opaque, due to the sensitive and potentially proliferative nature of the work, but this does not mean that the UK cannot leverage its SBC process to further enhance deterrent effects.

3. House of Commons Defence Committee, 'Deterrence in the Twenty-First Century', 11 March 2014, <https://publications.parliament.uk/pa/cm201314/cmselect/cmdfence/1066/106602.htm>, accessed 6 September 2021.
4. Andrew Randewich et al., 'Inertial Confinement Fusion: A Defence Context', *Philosophical Transactions of the Royal Society A* (Vol. 378, No. 2184, 2020).
5. Warheads undergo ageing effects, and the UK Atomic Weapons Establishment (AWE) certifies against these effects through its science-based approach.

The Atomic Weapons Establishment (AWE) can, and already does, publish some technical output from its SBC programme – high-quality, innovative science can bolster technical credibility. Although China, for example, publishes very little about its nuclear weapon programme, its capabilities are still considered credible, so the benefit of doing so is questionable. Strategically published work has the potential to enhance deterrence effects, and there may be specific but subtle messaging that could be communicated by adopting a more comprehensive technical publications strategy. To the general public, it might not change perceptions, but the agencies of states at whom deterrence is aimed might pay closer attention.

The Comprehensive Test Ban Treaty

The UK remains committed to the CTBT and is a strong advocate for its ratification and entry into force. This commitment clearly demonstrates the UK's support for a world without full-scale nuclear testing, but it also communicates a more subtle message: confidence in its own ability to certify warheads for service without full-scale testing and in its own science-based approach. This is an important implication of the UK's position and has the potential to influence external perceptions. Continuous and consistent reaffirmation of the UK's commitment might help consolidate this message.

Conversely, if the UK were to resume full-scale testing, international perception might be that it has lost confidence in its own science-based approach. Perceptions can of course be managed through careful and strategic communications, but credibility might be compromised if the UK were to return to a non-testing regime. A resumption of testing might also have wider implications, giving the green light to other nuclear weapon states and would-be proliferators to reignite their own testing regimes.

Special Relationship

In 1958, the UK and the US signed the Mutual Defence Agreement (MDA), a bilateral treaty on nuclear weapons cooperation.[6] The two countries have worked closely together ever since, pooling expertise, resources and capabilities across their respective nuclear weapon enterprises. This pooling not only allows the two countries to maintain a more cost-effective deterrent, but also presents the opportunity for scientific and technical collaboration. Bringing together experts of different strengths, experiences and perspectives with proven track records tends to improve the quality, and hence perception, of their output.

The MDA also provides the framework for a form of peer review and, given that collaboration and peer review are widely accepted methods of providing credibility to technical work, it is not unreasonable to assert that it also adds credibility to the UK's nuclear deterrent. The extent to which it adds credibility is difficult to measure but, by effectively and consistently communicating the benefits of the agreement to the UK, its deterrent impact could be maximised.

6. '1958 Mutual Defense Agreement (UK and USA)', July 1958.

The mutual benefit provided by the 1958 MDA has been emphasised on many occasions, most recently during the 60th anniversary of the agreement.[7] The US's favourable view of the agreement and the fact that it has been renewed nine times strongly suggests that the UK provides significant value to the partnership and is a sufficiently competent technical partner, assuming of course that the US nuclear capability is credible. The 1958 MDA is based on the foundations of the 1958 amendments to the US Atomic Energy Act, which provides the framework for the US to collaborate with countries who have made 'substantial progress in the development of atomic weapons'.[8] Although vague in wording, this means, at the very least, that the US believes that statement to be true about the UK.

Infrastructure and Investment

While many aspects of AWE business remain necessarily secret, it is ultimately funded by taxpayers' money and therefore the nature and details of some of the infrastructure investments are publicly known.

AWE has, in recent years, been on the receiving end of bad press regarding its handling of major infrastructure investments. Press articles linking delayed and overbudget infrastructure projects to the UK's ability to maintain Continuous At Sea Deterrence (CASD) naturally have created some worrying headlines.[9] It would be risky, and therefore unlikely, however, for an adversarial state to adjust their military calculus as a result of these speculative headlines. The potential consequences of nuclear military miscalculation are disastrous, and press articles alone, in the absence of credible intelligence, are unlikely to cause countries to stray from the side of caution.

The UK government's willingness to provide the required funds for over-budget projects might also demonstrate the strength of its commitment to maintaining CASD. Additionally, delays and overspend are factored into the risk when planning major projects, such that essential capabilities should not be compromised by even significant delays. However, AWE still needs to demonstrate value for money to the Ministry of Defence and to the UK public, otherwise it risks eroding public support for nuclear deterrence.

7. In June 2018, Lisa E Gordon-Hagerty, Administrator at the National Nuclear Security Administration, noted that 'the MDA has proven to be essential in our efforts to ensure that our nuclear weapons capabilities and nuclear propulsion plants are safe, reliable and effective'. See US Department of Energy, 'US–UK Mutual Defense Agreement Marks 50 Years', 26 June 2018, <https://www.energy.gov/articles/us-uk-mutual-defense-agreement-marks-60-years>, accessed 27 July 2021.
8. 'Atomic Energy Act 1954 (US)', 1958 amendment.
9. *The Economist*, 'Botched Nuclear Projects Put the Future of Britain's Defences at Risk', 8 February 2020.

Default Credibility

There is a convincing argument that, despite the challenges of post-CTBT certification, and in the absence of clear verifiable evidence to the contrary, the UK maintains credibility by default, even as it moves towards a post-CTBT deployed system. The UK's baseline credibility is founded on several aspects:

1. The UK has a long testing history. Not only does this provide valuable data for certification, it also shows that the UK has mature nuclear weapon capabilities.
2. The UK is an experienced nuclear weapon state, with 70 years of experience in nuclear weapon production and certification, and has the required infrastructure and expertise.
3. The UK government has consistently reaffirmed its commitment to maintaining a nuclear deterrent and has continued to provide the funding and resources to do so.[10]

Israel is a compelling case study for the 'deterrence by default' argument. Although Israel maintains a policy of deliberate ambiguity, never officially denying nor admitting to having nuclear weapons, and has also denied its involvement in the Vela incident,[11] it is widely believed that it possesses nuclear weapons outside the NPT framework.[12] Conversations and statements given by Edward Teller[13] and Mordechai Vanunu[14] to the CIA and *The Sunday Times* respectively have reinforced suspicions about Israel's nuclear weapons programme. In 1988, former Israeli nuclear technician Vanunu was sentenced to 18 years in prison after he revealed details of Israel's alleged nuclear weapons programme,[15] but these are not the only pieces of evidence that bolster Israel's credibility. It has a domestic fuel cycle, major economic sectors in technology and industrial manufacturing, a relatively highly educated population, and spends heavily on defence. These peripheral factors are not, in themselves, proof of a nuclear weapons capability, but add credibility to the assertion that Israel is nuclear weapons capable.

If Israel is widely believed to be a credible nuclear weapon possessor state, despite no confirmed tests and no admission of possession, it is not contentious to aver that the UK would retain credibility when it puts into service a new warhead certified without full-scale nuclear tests.

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10. J Vitor Tossini, 'Britain and Nuclear Weapons – The Second World War to the 21st Century', *UK Defence Journal,* 21 June 2019.
11. The Vela incident refers to a suspected nuclear weapon test in the South Atlantic on 22 September 1979, when the US Vela 6911 satellite detected a double flash optical signal, normally characteristic of a nuclear weapon explosion. See Leonard Weiss, 'Flash from the Past: Why an Apparent Israeli Nuclear Test in 1979 Matters Today'*, Bulletin of Atomic Scientists*, 8 September 2015.
12. Claire Mills, 'Nuclear Weapons at a Glance: Israel', Briefing Paper Number 9075, House of Commons Library, 9 December 2020, <https://researchbriefings.files.parliament.uk/documents/CBP-9075/CBP-9075.pdf>, accessed 6 September 2021.
13. Peter Hounam, 'The Secrets of Israel's Nuclear Arsenal Revealed', *Sunday Times*, 5 October 1986.
14. Ian Black, 'Mordechai Vanunu Gets 18 Years for Treason – Archive, 1988', *The Guardian*, 28 March 2018.
15. *Ibid.*

Conclusion

This paper has argued that, in the absence of clear evidence to the contrary, the UK retains credibility of its nuclear warhead capabilities, even as it moves to a new untested system (certified without full-scale nuclear tests). The UK has a mature capability, testing history and a long track record of nuclear warhead production. To assume that the UK's replacement warhead is no longer a credible capability, without conclusive evidence to the contrary, would be a highly risky military position to adopt, and lack of testing is not a strong enough piece of evidence to suggest this assumption is correct.

Ultimately, as a rich, technologically advanced nation with a strong nuclear pedigree, the UK has earned credibility that is not easily lost, and the consequences of military miscalculation by those states whom the UK seeks to deter are potentially disastrous. Bringing into service a new product, certified without full-scale nuclear testing, adds a dimension of uncertainty, but in the absence of clear conclusive evidence to suggest that the UK is not nuclear weapons capable, and provided that the UK government remains committed to maintaining a nuclear deterrent, credibility is not in danger anytime soon.

This paper was created for UK PONI and is for discussion purposes only. It does not represent the views of the Atomic Weapons Establishment, the Ministry of Defence or the UK government.

VII. Nuclear Credibility and the Impacts of Subjective Discourse

Mary Hood

THIS YEAR MARKS the 25th anniversary of the Comprehensive Test Ban Treaty (CTBT) opening for signature.[1] Despite not entering into force, the treaty has been adhered to by all recognised nuclear weapon states.[2] Decades without testing means that these states are now seeing the last test-experienced scientists retire and the remaining test-era warheads undergo modification. The UK and the US have also both announced parallel programmes to develop their first new warhead designs since signing the CTBT.[3]

As their nuclear programmes age, the US and the UK must consider how the CTBT has changed domestic assessments of nuclear arsenal credibility. The confidence testing once inspired must now come solely from scientific judgement and non-explosive experimentation. This paper uses principal–agent theory to argue that nuclear test moratoria may undermine domestic assessments of nuclear arsenal credibility by inadvertently increasing the influence of subjective discourse between technical experts and policymakers.[4] In this context, subjective discourse is defined as 'any exchange of ideas influenced by human biases, emotions, experiences, needs and so on'.[5] There are typically significant information asymmetries between policymakers and technical experts in the nuclear enterprise, which makes interactions and decisions at this interface particularly vulnerable to negative effects from subjective discourse.[6] Subjective

1. Nuclear Threat Initiative, 'Comprehensive Nuclear Test Ban Treaty (CTBT)', last updated 26 May 2021, <https://www.nti.org/learn/treaties-and-regimes/comprehensive-nuclear-test-ban-treaty-ctbt/>, accessed 5 July 2021.
2. Frank N von Hippel, 'The Decision to End US Nuclear Testing', *Arms Control Today*, December 2019. The CTBT has not entered into force because eight required states have not ratified the treaty, including the US and China.
3. Rebecca Hersman, Joseph Rodgers and Bryce Farabaugh, 'US Nuclear Warhead Modernization and "New" Nuclear Weapons', Center for Strategic and International Studies, December 2020.
4. Thank you to Geoffrey Chapman for inspiring the focus on principal–agent theory at the interface between technology and policy and to Ed Read for invaluable help developing this paper and explaining the nuances of the UK nuclear enterprise.
5. Ian Parker, 'Discourse: Definitions and Contradictions', *Philosophical Psychology* (Vol. 3, No. 2–3, 1 January 1990), p. 189.
6. Dietmar Braun and David H Guston, 'Principal-Agent Theory and Research Policy: An Introduction', *Science and Public Policy* (Vol. 30, No. 5, 1 October 2003), pp. 302–08; David H Guston, 'Principal-Agent Theory and the Structure of Science Policy', *Science and Public Policy* (Vol. 23, No. 4,

discourse, if unmitigated, may contribute to misjudgements of nuclear arsenal credibility and lead to poor decision-making within the nuclear complex. Although not a new problem, test moratoria eliminate testing as the most natural mitigator of subjective discourse effects and demand thoughtful policy as an alternative.[7] This paper begins by examining credibility and principal–agent theory in a nuclear weapons context. The manifestation of subjective discourse in US and UK nuclear enterprises is then evaluated before mitigation measures are discussed and a conclusion is presented.

Credibility

Credibility is a key concept in the classical theory of deterrence, and can be defined as 'the extent to which a nation's threat to retaliate … is believable'.[8] Deterrence credibility is primarily a political phenomenon comprised of two components: *credibility of intent*; and *credibility of capability* (also referred to in public policy as political feasibility and technical feasibility).[9] The absence of live weapons testing affects both types of credibility, but this paper focuses on its effects on the credibility of capability of a state's nuclear weapons stockpile. Credibility of capability is assessed at two critical interfaces: between technical experts and policymakers; and between political leaders of different states.[10] Regardless of the true technical reliability of a state's nuclear arsenal, the relevant determination of its credibility is whether political leaders, both domestically and internationally, have confidence that the nuclear arsenal is reliable.[11]

Principal–Agent Theory in Nuclear Enterprises

Principal–agent theory is a broadly applied theory originating in economics that addresses organisational relationships with information asymmetries.[12] Information asymmetries, in which

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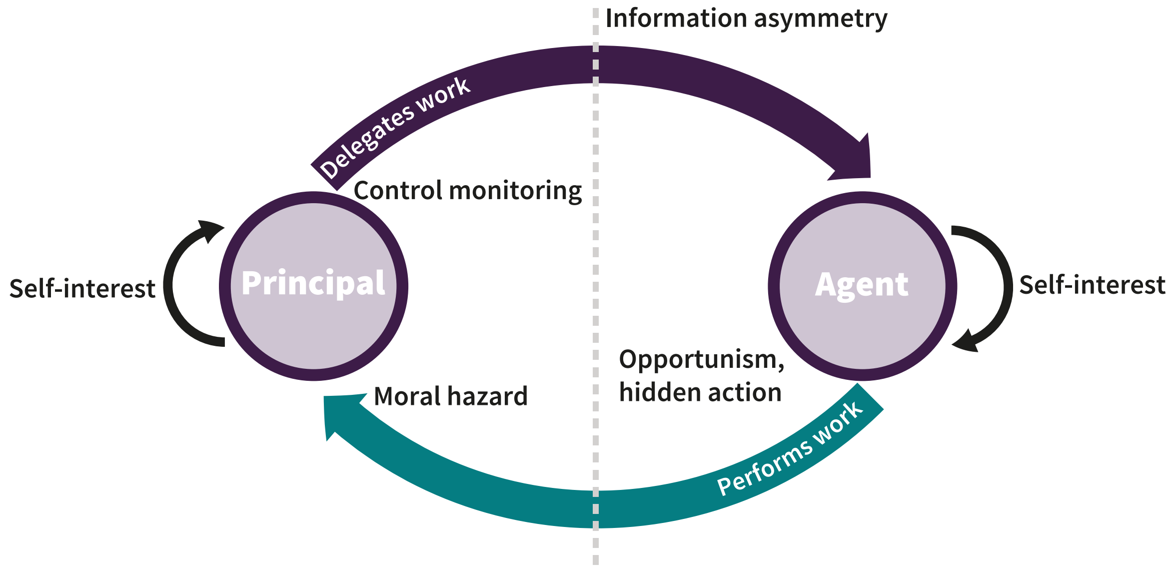
1 August 1996), pp. 229–40; Thomas F Gieryn, *Cultural Boundaries of Science: Credibility on the Line* (Chicago, IL: University of Chicago Press, 1999).

7. C Paul Robinson, 'Statement of C. Paul Robinson', testimony before the Senate Armed Services Committee, 7 October 1999. Robinson was the Sandia National Laboratory Director during the US Senate CTBT ratification negotiations and testified to the difficulties of eliminating testing.
8. Claudio Cioffi-Revilla, 'A Probability Model of Credibility: Analyzing Strategic Nuclear Deterrence Systems', *Journal of Conflict Resolution* (Vol. 27, No. 1, March 1983), pp. 73–108; Dean Pruitt and Richard Snyder, *Theory and Research on the Causes of War* (Englewood Cliffs, NJ: Prentice-Hall, 1969), p. 107.
9. Duncan MacRae and James Wilde, *Policy Analysis for Public Decisions* (Lanham, MD: University Press of America, 1985), p. 219; John R Raser, *Theories of Deterrence* (Oakville, Ontario: Canadian Peace Research Institute, 1969); J David Singer, 'Threat-Perception and the Armament-Tension Dilemma', *Journal of Conflict Resolution* (Vol. 2, No. 1, 1958), pp. 90–105.
10. Benjamin Sims and Christopher R Henke, 'Repairing Credibility: Repositioning Nuclear Weapons Knowledge After the Cold War', *Social Studies of Science* (Vol. 42, No. 3, June 2012), pp. 324–47.
11. *Ibid.*
12. Kathleen M Eisenhardt, 'Agency Theory: An Assessment and Review', *Academy of Management Review* (Vol. 14, No. 1, January 1989), pp. 57–74.

the agent has expertise and skillsets that the principal lacks, causes two problems – adverse selection and moral hazard. Adverse selection occurs when the principal lacks the requisite knowledge to both select the best agent for the task and the best budgets and programmes suggested to them by the agent.[13] Moral hazard occurs when the principal lacks the ability to discern if the agent is maximising their effort towards furthering the principal's best interests.[14] The principal–agent relationship is shown in Figure 1.

Figure 1: Principal–Agent Interactions



Source: Tim Snippert et al., 'Barriers to Realizing a Stewardship Relation Between Client and Vendor: The Best Value Approach', Construction Management and Economics *(Vol. 33, No. 7, July 2015), p. 572.*

Within the nuclear complex, policymakers are typically the principal, while technical experts are the agent, although there is some bi-directionality in the relationship. The nuclear complex is particularly vulnerable to the problems associated with information asymmetries because of its small communities, niche expertise, secrecy and national importance.

In nuclear programmes, subjective discourse and its effects sit at the intersection of self-interest and information asymmetries. Self-interest is not necessarily malicious but may manifest in subjective discourse as the result of different financial, cultural and political needs and backgrounds.[15] Whether consciously or subconsciously, self-interest influences discourse and permeates the interactions between policymakers and technical experts. The information

13. Braun and Guston, 'Principal-Agent Theory and Research Policy', pp. 302–08.
14. Braun and Guston, 'Principal-Agent Theory and Research Policy'.
15. Douglas A Bosse and Robert A Phillips, 'Agency Theory and Bounded Self-Interest', *Academy of Management Review* (Vol. 41, No. 2, April 2016), pp. 276–97.

asymmetry, once mitigated by demonstrable tests of capability, increases the likelihood that self-interested discourse goes unaddressed in discussions of reliability, budget, design and planning.

Drivers of Subjective Discourse: Financial, Cultural and Political

The potential drivers of subjective discourse are diverse, occurring at both the personal and organisational levels. Significant subjective discourse within the US and the UK nuclear complexes are driven by some combination of financial, cultural or political factors. Each factor is considered briefly here in turn, recognising that factors can overlap and that discourse is inherently more complicated than can be covered here.

Financial

Government budgeting, combined with large organisations and multi-year projects, creates an environment that is particularly susceptible to financially motivated discourse.[16] Politicians must manage budgets against lobbying pressures and a variety of monetary demands; laboratory directors want to retain scientists and fund experimentation; and private companies have to balance profitability with organisational needs. Financial incentives have swayed significant decisions within the US and the UK nuclear complexes. In the US, for example, laboratory directors expressed support for the new Stockpile Stewardship Program (SSP) that was introduced following the 1992 unilateral test moratorium.[17] The multi-billion dollar price tag of the SSP placated laboratory directors, many of whom privately disagreed with the decision to end testing but feared for their laboratories and jobs if they did not support the change.[18] The SSP has remained the underpinning of the US nuclear programme for decades, but some question if it was the best choice to maintain nuclear reliability.[19] In the UK, the private operation of the Atomic Weapons Establishment (AWE) has drawn criticism as being opaque and profit driven.[20] Although it has not been officially recognised, some have suggested that massive budget overspend and a costly rewards structure contributed to the UK government's decision

16. Allen Schick, *The Federal Budget: Politics, Policy, Process* (Washington, DC: Brookings Institution Press, 2008), pp. 62–66.
17. The Stockpile Stewardship Program was a $4.5-billion per year programme to improve scientific understanding and experimental capabilities of the US nuclear weapons establishment in order to maintain stockpile reliability and safety in the absence of testing. For further information, see Sims and Henke, 'Repairing Credibility', pp. 324–47.
18. Hugh Gusterson, 'The Virtual Nuclear Weapons Laboratory in the New World Order', *American Ethnologist* (Vol. 28, No. 2, 2001), pp. 417–37.
19. John C Hopkins and David H Sharp, 'The Scientific Foundation for Assessing the Nuclear Performance of Weapons in the US Stockpile Is Eroding', *Issues in Science and Technology* (Vol. 35, No. 2, 2019), pp. 23–25; Donald MacKenzie and Graham Spinardi, 'Tacit Knowledge, Weapons Design, and the Uninvention of Nuclear Weapons', *American Journal of Sociology* (Vol. 101, No. 1, 1995), pp. 44–99.
20. Tom Youngman, 'Factsheet: Financing the Atomic Weapons Establishment', Nuclear Information Service, April 2017, <https://www.nuclearinfo.org/wp-content/uploads/2020/09/NIS-Factsheet-

to end its private operation.[21] While tests once signposted budget decisions, policymakers now increasingly rely on the assurances of those within the community that funds are being used effectively. Even if profiteering is not the intention, merely the appearance of it may undermine trust and credibility between technical experts and policymakers.

Cultural

Cultural influences are a salient and sometimes overlooked driver of subjective discourse. Culturally driven discourse may be particularly influential in relationships with information asymmetries because it can be difficult to parse how recommendations and beliefs are shaped by cultural influences. An example is how the technical community's understanding of their own knowledge and role changed over time. Many nuclear scientists in the US and the UK vehemently disagreed with the CTBT because they believed it would be difficult or impossible to maintain a safe and reliable stockpile without testing.[22] Research evaluating these claims found mixed evidence, with some support for the potential loss of critical tacit knowledge contrasting with evidence that test-experienced scientists might have simply felt the need to self-justify the criticality of their contribution to the nuclear complex.[23] As test-experienced scientists have retired and new technology has been developed, many within the nuclear community now take pride in their stated ability to modify, design and certify nuclear weapons without the need for testing.[24] Given the influence of organisational culture, educational background and experience, it may be difficult to identify the extent to which statements of reliability or capability from the technical community are swayed by culture.

Political

Political motivations are particularly acute within nuclear complexes given their national and strategic importance. The US and the UK face not only domestic pressure to maintain a credible nuclear threat, but their extended deterrence commitments mean that allies also rely on the

AWE-finances_0.pdf>, accessed 25 August 2021; Tom Plant and Matthew Harries, 'No Go for GOCO: The UK Renationalises its Nuclear Warhead Factory', *RUSI Commentary*, 6 November 2020.

21. Youngman, 'Factsheet: Financing the Atomic Weapons Establishment'; Plant and Harries, 'No Go for GOCO'.
22. Jon Kyl, 'Maintaining Peace Through Strength: A Rejection of the Comprehensive Test Ban Treaty', *Harvard Journal on Legislation* (Vol. 37, No. 2, 2000), pp. 325–44; Robinson, 'Statement of C Paul Robinson'; author interviews with current and former members of the Atomic Weapons Establishment, Defence Nuclear Organisation, US Air Force and US national laboratories.
23. MacKenzie and Spinardi, 'Tacit Knowledge, Weapons Design, and the Uninvention of Nuclear Weapons', pp. 44–99.
24. National Research Council, *The Comprehensive Nuclear Test Ban Treaty: Technical Issues for the United States* (Washington, DC: National Academies Press, 2012); Sidney Drell, Raymond Jeanloz and Bob Peurifoy, 'Maintaining a Nuclear Deterrent Under the Test Ban Treaty', *Science* (Vol. 283, No. 5405, February 1999), pp. 1119–20; Kaegan McGrath, 'Verifiability, Reliability, and National Security', *Nonproliferation Review* (Vol. 16, No. 3, November 2009), pp. 407–33.

credibility of their nuclear forces. Because the ultimate authority over the nuclear complex lies with the president or the prime minister, new administrations with different priorities can alter the direction and funding of nuclear programmes.[25] In the US in particular, differences of opinion over the importance of test, disarmament and non-proliferation have resulted in heavily political discourse. A prominent US example was the support lent to the Reliable Replacement Warhead (RRW) programme by Congressmen David Hobson in the 1990s. Hobson supported the RRW not necessarily because he liked it, but because he saw it as a way to divert funding from another programme he actively opposed.[26] In the UK, successive prime ministers' reluctance to make a decision about the development of a new warhead resulted in higher costs and tighter timelines for the technical community.[27] Such political machinations, particularly if they are obscured from the technical community, may result in poorly chosen and allocated projects as well as an undermining of trust between policymakers and technical experts.

Control and Monitoring Mechanisms

In his application of principal–agent theory to civil–military relations, Peter D Feaver highlights several mechanisms of control and monitoring that a principal may use to reduce information asymmetries.[28] There are three mechanisms that are potentially useful within the nuclear establishments of the UK and the US: screening and selection; 'fire alarms'; and 'police patrols'.

Screening and selection is a proactive control mechanism that involves cultivating better methods for finding and choosing appropriate agents.[29] Beyond the nuclear institution, general higher education practices that include less pressure to specialise early and more interdisciplinary education opportunities may better prepare potential jobseekers for the complexity of science policy positions. Internal to the nuclear complex, improved talent management and retention may be beneficial. The US practice of politically appointing leaders of organisations such as the Department of Energy or the National Nuclear Security Administration (NNSA) occasionally leads to the selection of individuals with ill-fitting backgrounds, while the UK has repeatedly identified issues with filling skills gaps within its nuclear enterprise.[30]

25. Claire Mills, 'Replacing the UK's Nuclear Deterrent: The Long-Awaited Warhead Decision', Briefing Paper 8941, House of Commons Library, 2 March 2021; US Department of Defense, Office of the Secretary of Defense, 'Nuclear Posture Review 2018', February 2018; US Department of Defense, Office of the Secretary of Defense, 'Nuclear Posture Review Report', April 2010; Michaela Dodge, 'The Trump Administration's Nuclear Weapons Policy: First Steps', The Heritage Foundation, 30 November 2016, <https://www.heritage.org/defense/report/the-trump-administrations-nuclear-weapons-policy-first-steps>, accessed 17 July 2021.
26. Sims and Henke, 'Repairing Credibility', pp. 324–47.
27. Plant and Harries, 'No Go for GOCO'; Mills, 'Replacing the UK's Nuclear Deterrent'.
28. Peter D Feaver, *Armed Servants: Agency, Oversight, and Civil-Military Relations* (Cambridge, MA: Harvard University Press, 2003).
29. *Ibid.,* pp. 78–80.
30. The History Makers, 'The Honorable Hazel O'Leary's Biography', 15 March 2007, <https://www.thehistorymakers.org/biography/honorable-hazel-oleary>, accessed 1 October 2021; National

A second mechanism of control and monitoring is ‘fire alarms’,[31] third parties such as watchdogs and journalists who, by the nature of their work, alert the principal of potential wrongdoing. However, traditional fire alarms are not always feasible within nuclear complexes because of secrecy. Expanding the theory slightly to accommodate the uniqueness of the nuclear establishment, fire alarms might include governmentally institutionalised internal ‘alarms’ that flag atypical events, such as safety incidents, missed project milestones or budget problems.[32]

Finally, ‘police patrols’ are the most intrusive method of monitoring and must be balanced against the risk of micromanaging.[33] Standing oversight committees, such as the UK’s recently developed Defence Nuclear Organisation (DNO), as well as regular audits and reports, are examples of police patrols.[34] Critical to police patrols like the DNO is the ability to straddle the information asymmetry through appropriate expertise and to maintain neutrality. Without these two components, ‘middleman’ organisations such as the DNO or the NNSA are liable to become another entity involved in subjective discourse and entwined in the traditional principal–agent problems.

Conclusion

The ability to maintain credibility of capability under test moratoria is still debated. Despite this, relatively little literature is devoted to understanding how sociocultural influences impact nuclear programmes, particularly since the widespread implementation of test moratoria. This paper addresses one aspect of that issue by recognising that test moratoria make the interface between technical experts and policymakers particularly vulnerable to self-interested discourse. While a return to testing is not necessarily the solution, a careful evaluation of the drivers of subjective discourse and ways to mitigate them are critical if the US and the UK hope to avoid potential missteps as they prepare to add untested warhead designs to their nuclear arsenals.

Audit Office, *‘The Defence Nuclear Enterprise: A Landscape Review’*, HC 1003, 22 May 2018; Ministry of Defence, ‘The United Kingdom’s Future Nuclear Deterrent: The 2018 Update to Parliament’, 20 December 2018.

31. Mathew D McCubbins and Thomas Schwartz, ‘Congressional Oversight Overlooked: Police Patrols Versus Fire Alarms’, *American Journal of Political Science* (Vol. 28, No. 1, 1984), p. 166; Feaver, *Armed Servants*, pp. 80–83.
32. The decision to prematurely end the private contracting of the AWE may have been affected by safety accidents and fiscal mismanagement, which, if institutionalised, could be considered fire alarms. See Plant and Harries, ‘No Go for GOCO’.
33. McCubbins and Schwartz, ‘Congressional Oversight Overlooked’, p. 166; Feaver, *Armed Servants*, p. 84.
34. UK Government, ‘Defence Nuclear Organisation: About Us’, <https://www.gov.uk/government/organisations/defence-nuclear-organisation/about>, accessed 15 July 2021.

VIII. A Quantum ‘State’ of Mind: Threats Posed by Bose–Einstein Condensate Gravity Sensors

George Parkes and Joseph Campion

THE EARTH’S GRAVITATIONAL field is not constant over its surface. Its strength alters with changes in the thickness of the Earth’s crust or the presence of large geological features, such as mountain ranges. The accurate measurement of acceleration, including that due to gravity, is crucial to the accuracy of nuclear weapon systems, both at the point of launch and throughout the powered and ballistic flight phases of missiles.

Bose–Einstein condensates (BECs) are a quantum state of matter that can be used in ultrasensitive gravity sensors. Both the Defence Science and Technology Laboratory[1] and the EU[2] have highlighted this technology as one that will have significant impacts in the field of gravimetry. This new form of sensor is several orders of magnitude more sensitive than existing technology. This has the potential to affect weapon system accuracy and submarine navigation, and potentially opens more doors to the detection of stealth assets.

This paper aims to give an introduction to the underlying physics, engineering, applications and potential implications of a quantum technology that is likely to see operational deployment in the near future.

The Physics: Wave–Particle Duality

Quantum theory relates to the ‘quantisation’ of energy packets and addresses the innate randomness of our universe. As such, it is best described using statistics and probabilities. A

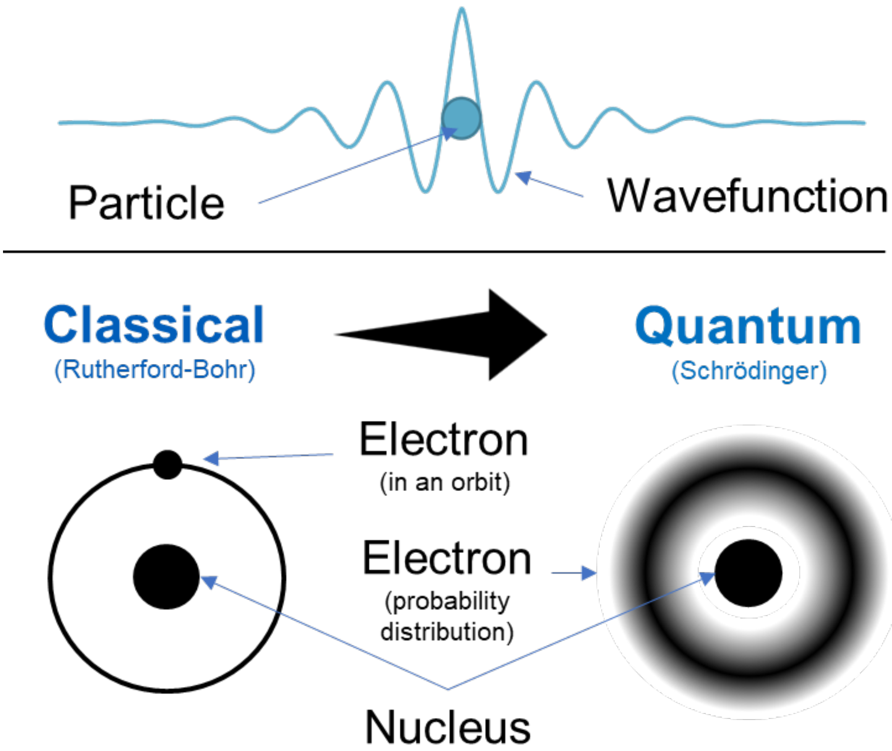
1. David Delpy, ‘A Perspective of UK Quantum Technology Prepared by and for the UK Quantum Technology Community’, DSTL/PUB098369, Defence Science and Technology Laboratory, <https://uknqt.ukri.org/files/ukquantumtechnologylandscape2016/>, accessed 14 July 2021.
2. Martino Travagnin, *Cold Atom Interferometry Sensors: Physics and Technologies* (Luxembourg: Publications Office of the European Union, 2020).

key concept is wave–particle duality. Experiments have shown that matter and energy can be described as both particles and waves.[3]

These concepts can be explained using the analogy of throwing a pebble into a pond. The particle description deals with the pebble that has a defined mass and path to the water. The wave description deals with ripples on the surface of water when dropping in a pebble. With multiple pebbles, the sets of ripples can interfere with one another and create patterns that give information, such as pebble drop position and timing. In truth, these are both views of the same underlying reality.

The classical Bohr model of the hydrogen atom is a proton (nucleus) orbited by an electron. When described using quantum mechanics, the electron's position is represented mathematically as a wave function, which can be used to calculate the probability of finding the electron at a given location around the nucleus. Figure 1 gives a visualisation of the differences between the classical and quantum hydrogen atom.

Figure 1: Simplified Graphical Representation of a Classical and Quantum Hydrogen Atom



Source: Author generated.

3. Andrew Murray, 'Double Slits with Single Atoms', *Physics World*, 18 February 2020, <https://physicsworld.com/a/double-slits-with-single-atoms/>, accessed 14 July 2021.

The quantum atom still has a nucleus, but the electron's position is now described as a probability function instead of a defined orbit line. Quantum theory tells us that there is a probability 'cloud' that surrounds the proton within which the electron is statistically likely to lie.

States of Matter, Energy Levels and Bose–Einstein Condensation

Typically, there are four states of matter – solids, liquids, gases and plasmas. Under extreme conditions, additional states of matter, such as BECs, can exist. A BEC is formed as a result of cooling a Boson[4] gas to temperatures up to almost absolute zero (-273.15°C), where all particles in the BEC share a single quantum ground state.

Quantum system wave functions have amplitude and carry energy. The amount of energy in a quantum system, such as an individual particle, is quantised into discrete energy levels, which can be influenced by external factors such as temperature. Influences on the overall energy of a quantum system are typically a case of moving up or down energy levels. An increase in temperature will heighten the number of occupied energy levels. Conversely, lowering the temperature will cause the overall number of occupied energy levels to fall. Lowering the temperature close to the physical limit causes the large majority of atoms to exist in the lowest energy state (ground state).

Quantum effects such as wave function interference, typically observable only on the quantum scale, can now be observed macroscopically. This is the point where a Boson gas has formed a new state of matter, a BEC. The BEC formation can be compared to throwing a handful of pebbles into a lake, the resulting ripples interfering with many others. From afar, no specific patterns would be visible. The state of matter conversion can be thought of as the handful of pebbles 'condensing' into a single large rock, which when thrown creates a single set of larger ripples, more easily observable from a distance.

Application in Gravity Sensors

Sensors used to detect differences in the Earth's gravitational field on and around its surface currently exist in different forms, many using classical mechanics and falling masses to calculate the local gravity. BECs are a new addition to this field,[5] with the most practical using a chip-based system in a vacuum.

A Boson gas is cooled to form a BEC, which is then released into a vacuum and deflected by lasers along multiple paths. The interference patterns which form between the two paths can be measured when they converge at a detector. The readings provide the information to calculate very precise estimates of local gravity. The interference pattern is highly sensitive to the relative

4. A classification of fundamental particle that obeys Bose–Einstein statistics.
5. Nina Heine et al., 'A Transportable Quantum Gravimeter Employing Delta-Kick Collimated Bose–Einstein Condensates', *European Physical Journal D* (Vol. 74, No. 174, 2020).

positions of the atoms and provides much higher precision data over merely measuring the position of a falling mass.

The time taken for the atoms to fall is in the order of milliseconds, which can be repeated frequently, providing the potential for high-fidelity time series data. BEC gravimeters have the potential to take acceleration measurements to an accuracy of one part in 10^9, which is one to two orders of magnitude better than existing technology. Furthermore, these gravimeters are lightweight and could potentially fit inside a backpack, making them easily deployable.[6]

Application of BECs to Nuclear Weapons Delivery Systems and Platforms

Understanding the local gravity field is important to the accuracy of ballistic weapon systems. The mathematical models used to calculate missile trajectories include adjustments for local gravitational disturbances throughout the missile's flight. Therefore, increasing the accuracy with which gravity is measured and mapped results in an increased weapon system accuracy. Accurate ballistic systems already do this and, as beyond a certain threshold other sources of error – such as aerodynamic effects or errors in initial conditions such as weapon position and velocity – will dominate, there are limited advantages to using a BEC sensor for this purpose.

For trajectory modelling, only larger fluctuations in local gravity will have a significant effect on the ballistic profile of the weapon. However, whilst the fluctuations caused by smaller features may not be a concern for weapon system accuracy, the ability to accurately map these enables a stealthy method of navigation.

Accurate inertial navigation systems (INS), such as those used by submarines and within missile guidance systems, track unit movement by measuring accelerations. However, they also require occasional positional updates to correct for measurement errors that accumulate over time.

There are currently two ways in which INS errors can be corrected through positional fixes: GPS; and bathymetry. A GPS fix is highly accurate; however, it requires connection with satellites in orbit, which are vulnerable to jamming/spoofing or anti-satellite weaponry. GPS-denied environments are of increasing concern for navigation.[7] A submarine also needs to raise a mast, which could highlight its position to enemy satellites. Another method is to use bathymetry, which looks at the topography of the sea floor to indicate position. Whilst this allows a submarine to remain submerged, it does typically require the use of sonar systems to take readings, which necessitate broadcasts into the water. A gravity alternative would be

6. Hamish Johnston, 'Gravity Measured Using a Bose–Einstein Condensate on a Chip', *Physics World*, 22 November 2016, <https://physicsworld.com/a/gravity-measured-using-a-bose-einstein-condensate-on-a-chip/>, accessed 14 July 2021.
7. Alan Grant et al., 'GPS Jamming and the Impact on Maritime Navigation', *Journal of Navigation* (Vol. 62, No. 2, 2009), pp. 173–87.

completely passive.[8] The unit could remain submerged and completely silent without risk of data spoofing or detection. This would provide a significant benefit to platform vulnerability and give greater operational freedom to an asset.

These BEC sensors measure acceleration. For gravity sensing, this is usually an issue – removing noise from vibrations and motion requires significant effort and can lead to inaccurate readings and measurement uncertainty. However, accelerations (minus a known local gravity) can be measured and used in an INS. Highly precise measurements from a BEC sensor could be used as a highly accurate accelerometer which, when coupled with a highly accurate gyro system, would provide a highly accurate INS. This again could have benefits to operational freedom and system accuracy.

Application of BECs to Detection

In addition to improving weapon system accuracy, BEC-based gravitational sensors could also be used for the detection of stealthy assets. Highly sensitive and precise gravitational sensors can detect significantly smaller mass differences than existing sensors. This also applies to the absence of mass, which is the case for underground facilities. Detection of underground voids with gravity is not a new concept,[9] and traditional sensors can be used for this purpose. However, BEC sensors have several advantages over their traditional counterparts. The first is precision. The aforementioned increase in precision correlates to an increase in the effective range by around 3–5 times. Additionally, it is possible to measure the local electromagnetic (EM) field using BECs.[10] This would enable the detection of anomalies in the local EM field that are produced by electromagnetically conductive objects, such as steel rebar, which may be used to reinforce concrete in the facilities' superstructure.

Another benefit to the use of the gravity anomaly detection over other intelligence sources is that the use of BEC does not require any form of broadcast. This means that current methods of detecting surveillance activities, through the measurement of equipment broadcasts, would not identify the use of gravitational sensors. Additionally, unlike EM, it is not possible to artificially manipulate gravitational fields to the extent to which it would be possible to completely hide underground facilities or, possibly, structures under the water. Therefore, jamming and/or spoofing the fields BEC sensors detect would be expensive and highly likely to fail, with the

8. No broadcasts are required to obtain the measurements, the measurements taken have no effect on the thing being measured.
9. T Mochales et al., 'Detection of Underground Cavities by Combining Gravity, Magnetic and Ground Penetrating Radar Surveys: A Case Study from the Zaragoza Area, NE Spain', *Environmental Geology* (Vol. 53, 2008), pp. 1067–77; Lockheed Martin, 'Cutting-Edge Resource and Exploration Technologies: Gravity Gradiometry', <https://www.lockheedmartin.com/en-us/products/gravity-gradiometry.html>, accessed 14 July 2021.
10. K S Hardman et al., 'Simultaneous Precision Gravimetry and Magnetic Gradiometry with a Bose-Einstein Condensate: A High Precision, Quantum Sensor', *Physical Review Letters* (Vol. 117, No. 13, 2016).

potential exception of directly interfering with the sensors' internal electronics. However, there are currently difficulties with merging the output of multiple BEC-based gravitational sensors.[11]

As with other methods of intelligence gathering, it is unlikely that BEC-based gravitational sensors would be used in isolation. An ideal implementation would be to use multiple sensors and methods of measurement to improve the reliability of the intelligence gathered. Combined with AI technology, it would be possible to use these highly sensitive gravitational sensors to identify anomalies resulting from the presence of underground facilities. The combination of intelligence from highly sensitive detection with improvements in weapon accuracy would provide a state with confidence in their ability to neutralise a facility (with potentially fewer weapons). This particular use is unlikely to significantly challenge current regimes of deterrence.

The major application that could upset established power dynamics would be if a state could use this technology to detect underwater targets, such as a submarine. This capability could undermine confidence in a state's second-strike capabilities. However, the current state of development limits the viability of this application in the near future. The very small variations would only be detectable at a very limited range. Therefore, the ability to detect submarines would not be significantly different. There would be other significant engineering challenges to achieve this goal. In time, further advances may drive different types of submarine design and operating tactics. As this technology develops, this type of detection should be considered as a potential threat.

Conclusions

While there is clear potential for the use of BEC-based gravitational sensors for improving targeting, navigation and intelligence gathering for underground facilities, the current state of development of this technology limits the viability of its application to submarine detection. There are currently significant engineering challenges that need to be addressed before this BEC-based gravitation sensing can be used effectively for the purposes of detection. The application of this technology in the near future to submarine navigation is likely to increase the stealth of submarines rather than undermine it and is therefore unlikely to upset established power dynamics. However, as this technology develops and the sensitivity of the equipment improves further, it should also be considered as a potential threat to the security of defence capabilities.

Thanks go to those who contributed to the production and review process: Tom Plant, Paul Jagger, Simon Weatherburn, Iain Petherick, Alison Nightingale and Ana Alecsandru.

11. Grant et al., 'GPS Jamming and the Impact on Maritime Navigation'.

Section IV. Hypersonics and Strategic Stability

IX. Hypersonic Missile Defence: Detecting the Undetectable

Daniel Cook, Aaron Kennedy, Jonathan Balakumar and Jonathan Roberts

LOCKHEED MARTIN UK Ampthill research presented previously outlined a method of engaging hypersonic weapons, concluding that directed energy was a potential solution to stopping the 'unstoppable' threats.[1] This paper shifts the focus to hypersonic visibility by using modelling to investigate the detection of hypersonic weapons.

Hypersonic missiles are emerging threats that combine manoeuvrability with speeds in excess of Mach 5.[2] The unpredictability of hypersonic weapons makes them a 'game-changing' asset[3] with their ability to manoeuvre and fly at low altitudes, circumventing detection systems that are designed for traditional ballistic threats.[4]

The research for this paper examined NATO defensive infrastructure performance against hypersonic weapons and the warning time that would be available as well as beneficial future technologies. This topic was explored due to the importance of assessing NATO's preparedness for new threats entering the near peer adversarial arsenals.

NATO Radar

Radio Detection And Ranging (RADAR) is an electromagnetic detection system that analyses echoes of radio waves to determine the distance, azimuth, elevation and velocity of objects. This paper focuses on its application to ballistic missile defence (BMD), which takes multiple forms, including a range from ship-based sensors such as the Aegis-equipped *Arleigh Burke*-class

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1. Aaron Kennedy et al., 'Hypersonic Missile Defence: Stopping the Unstoppable', 2020 UK PONI Papers, RUSI, October 2020, <https://rusi.org/explore-our-research/publications/conference-reports/the-2020-uk-poni-papers>, accessed 15 September 2021.
2. Kelley M Sayler, 'Hypersonic Weapons: Background and Issues for Congress', Congressional Research Service, updated 9 July 2021, <https://fas.org/sgp/crs/weapons/R45811.pdf>, accessed 15 September 2021; Jill Hruby, Mark Melamed and Lynn Rusten, 'Russia's New Nuclear Weapon Delivery Systems: An Open-Source Technical Review', NTI, 13 November 2019, <https://www.nti.org/analysis/reports/russias-new-nuclear-weapon-delivery-systems-open-source-technical-review/>, accessed 15 September 2021.
3. Richard H Speier et al., *Hypersonic Missile Nonproliferation: Hindering the Spread of a New Class of Weapons* (Santa Monica, CA: RAND Corporation, 2017).
4. Sayler, 'Hypersonic Weapons'.

destroyers to more permanent dedicated ground-based stations such as the AN/FPS-132 located at RAF Fylingdales in the UK.[5]

Open-source data was used to create a European NATO BMD case study. The types of radar that were used are listed in Table 1 with detection ranges based on a representative threat, but they may not necessarily represent a full or accurate representation of current BMD capability.

Table 1: Radar Types and Locations Used in Simulations

Type of Radar	Location	Detection Range (km)	Type
AN/FPS-132 UEWR	RAF Fylingdales, UK	4,828	Land
AN/SPY Series Radar Aegis Ashore	Redzikowo, Poland and Deveselu, Romania	1,000 (assumed)	Land
AN/TPY-2	Kurecik, Turkey	1,000	Vehicle
AN/SPY Series Aegis Ship	Mediterranean Sea	1,000 (assumed)	Ship

Source: US Department of Defense Missile Defense Agency, 'Elements: Sensors', <https://www.mda.mil/system/sensors.html>, accessed 15 September 2021; Janes, 'Air Defence Radar – AN/TPY-2', 11 November 2020, <https://customer.janes.com/Janes/Display/JREW0126-JC4IL>, accessed 15 September 2021.

Figure 1 shows the radar types' geographical positions and respective coverage. The largest circle highlighted in green is RAF Fylingdales whilst the two yellow circles are the Aegis Ashore sensors located in Romania and Poland, representing permanent ground stations. The X-band radar in Turkey and the Aegis-equipped ship in the Mediterranean, highlighted in blue and orange respectively, are two deployable BMD radars that were added. The locations were derived from open-source data and judgement in order to position them in a representative strategic way to give the BMDs optimal chance of detecting incoming threats. These radars may not always be deployed but were considered fully operational for this study. Other non-open-source radars may exist in undisclosed locations, providing additional coverage.

5. Janes, 'Surveillance Radar – AN/FPS-123(V)3 "Pave PAWS" and AN/FPS-132 Upgraded Early Warning Radar (UEWR)', Janes Database, 15 December 2020, <https://customer.janes.com/Janes/Display/JREWA348-JC4IL>, accessed 15 September 2021.

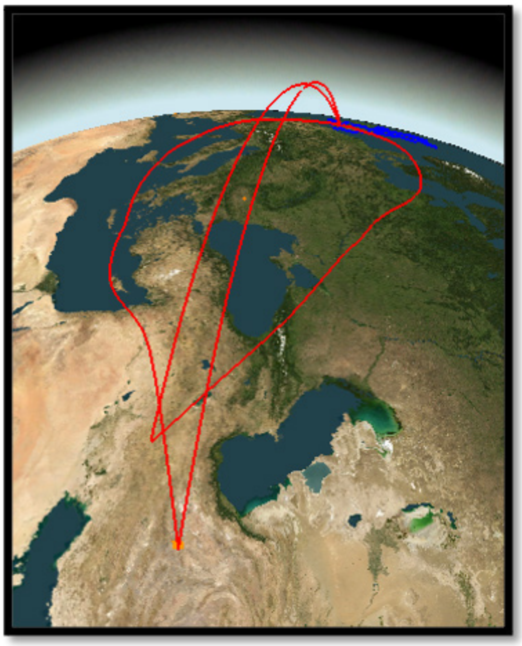
Figure 1: Assumed Radar Locations in Europe for the Simulated Scenarios (Not to Scale)

Source: Author generated. Original map source is 'World Map' by Vemaps.com, <https://vemaps.com/world/wrld-15>, accessed 15 September 2021.

Method, Modelling and Simulation

To model the effectiveness of the NATO infrastructure, a Lockheed Martin proprietary tool suite called SMARTset was used. This allows the user to plan, simulate and evaluate bespoke threat scenarios by building a synthetic environment incorporating user-selected sensors, weapon systems and command nodes.

Figure 2: Four Different Threat Scenarios



Source: Author generated.

A series of scenarios were created to directly compare the detection performance of the NATO BMD radar infrastructure against traditional ballistic and hypersonic threats, specifically hypersonic glide vehicles (HGVs).[6] The simulations (which were deterministic) launched both threats from two locations in the Middle East, angling towards the same target-rich environment in Europe, as seen in Figure 2. In recognition of the unpredictability and flexibility of HGVs, two different HGV trajectories were used to approach the destination and test the defensive infrastructure from different angles.

By using two different threats with the same target range, the radar's coverage was compared in each case, specifically: the first point of detection; the overall time the threat was detected; the last point of detection prior to strike; and an assessment of the warning time available.

For modelling simplicity, the trajectories were deterministic. No radar environmental effects were considered, and a line-of-sight horizon was assumed. In a real-life scenario, a threat detected would require further time to track, discriminate, identify and respond with suitable interceptors. These track accuracy requirements and target discrimination capabilities were not considered and it was assumed that tracking occurs immediately following detection. No satellites or other detection systems were implemented.

6. Hypersonic glide vehicles are rocket-launched weapons which, after the initial rocket boost, glide towards their targets at speeds in excess of Mach 5.

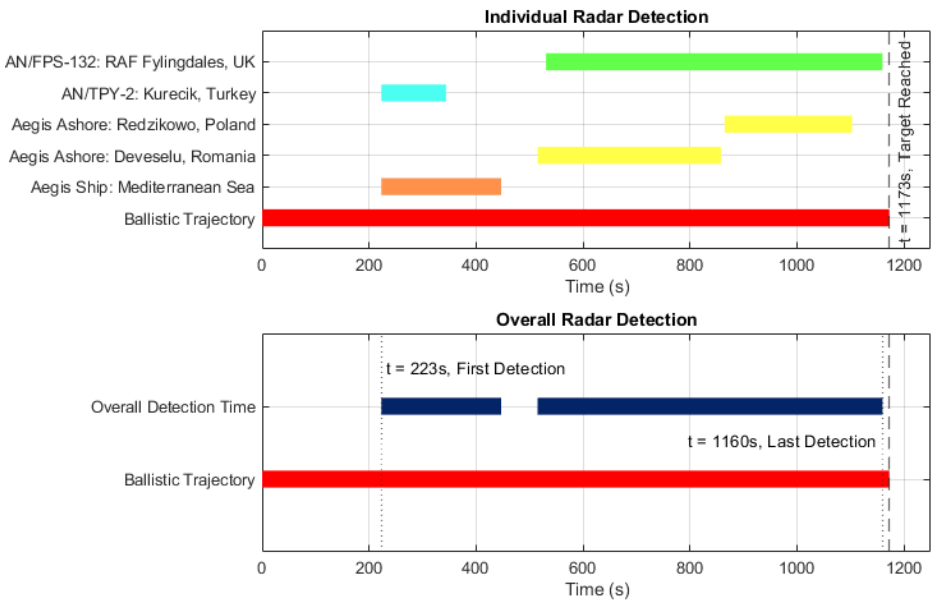
Results and Discussion

The results comparing a ballistic missile (BM) and HGV threats are presented below. Only two of the four cases simulated were explored due to a high level of similarity between the respective threat results when comparing the coverage of the BM and HGV from the different launch locations. Therefore, the results presented cover a single BM and HGV launched from the same location.

Ballistic Missile Case

The results for the BM are illustrated in Figure 3.

Figure 3: Ballistic Missile Threat Results



Source: Author generated.

The BM had a total flight time of approximately 19 minutes to reach the target. The BM was within range of the radars for a large proportion of the trajectory and all five detected it. The first detection occurred in under four minutes and the last point of detection was just over 10 seconds before impact. In total, the BM was under detection for 869 seconds (14.5 minutes) or 74% of its flight. However, gaps in coverage were shown to exist between 447 (7.5 minutes) and 515 seconds (8.5 minutes) as well as the initial 20% of the flight when the BM remained undetected due to being beyond the assumed range of the sensors.

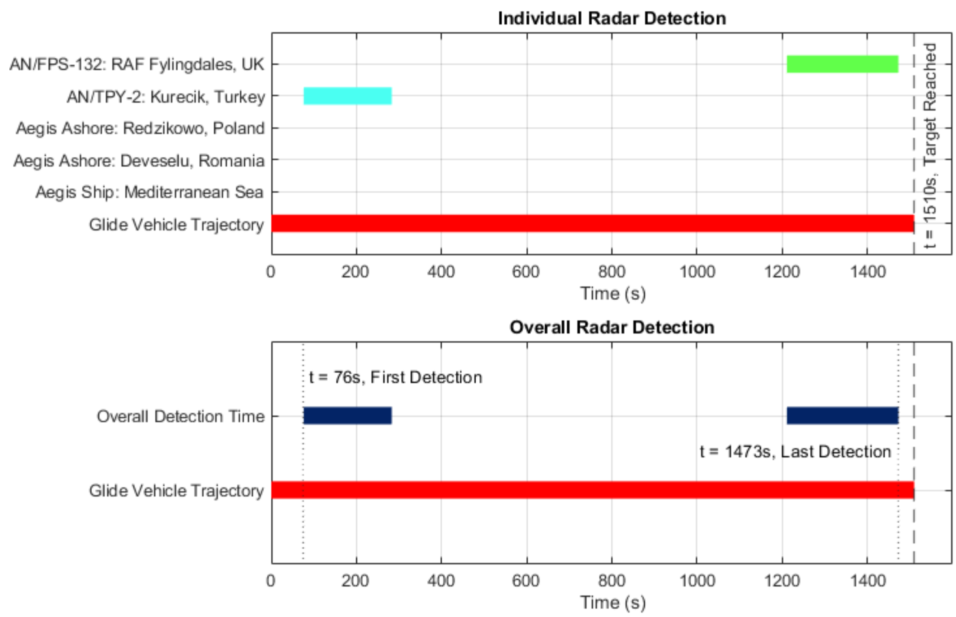
The deployment of the Aegis ship and the X-band radar benefited the coverage by providing earlier detection and reducing the gaps. With the assumption of immediate track and identification, around 15 minutes of awareness from initial detection to impact was provided. Without the Aegis ship and X-band radar, this time was reduced to approximately 11 minutes.

Successful identification and defence against threats is considered much more likely with long-range persistent tracking.[7] This case highlighted the current defensive infrastructure's capability against a BM but suggested there are still limitations in continuous detection and tracking, especially soon after launch. It also showed some dependence on non-permanent stations being deployed at the right time and in the right place to improve the coverage. Without them, warning time would be reduced.

Hypersonic Glide Vehicle Case

In contrast, the results in the case of the HGV are illustrated in Figure 4.

Figure 4: Hypersonic Glide Vehicle Threat Results



Source: Author generated.

The HGV took approximately 25 minutes to reach the target. The difference in flight time between the BM and the HGV was partly due to the HGV's less direct path, which also contributed to an

7. Missile Defense Agency, 'Long Range Discrimination Radar (LRDR), Clear Air Force Station (AFS), Alaska', Fact Sheet, 24 February 2021, <https://www.mda.mil/global/documents/pdf/lrdr.pdf>, accessed 15 September 2021; US Department of Defense Missile Defense Agency, 'LRDR Work Continues Through Covid-19 for Initial Fielding in 2021', 24 February 2021, <https://www.mda.mil/news/21news0003.html>, accessed 15 September 2021.

increased duration of atmospheric drag that subsequently slowed it post-burnout. Notably, the HGV completely evaded the three Aegis radars, as shown in Figure 4.

The initial detection window was marginally shorter than the BM. This early detection was advantageous but there was then a gap in coverage of approximately 15 minutes before the HGV was detected again by the RAF Fylingdales radar due to being beyond the assumed range of the sensors. In that time, the HGV could have travelled at least 1,500 km, just under a quarter of the Earth's radius, inducing a large uncertainty in the target destination.

The total coverage time for the HGV was 469 seconds (eight minutes). This is considerably less than for the BM and accounted for less than a third of the HGV's trajectory (31%). This supported the warnings of shortfalls in the performance of current defences against emerging hypersonic threats.[8]

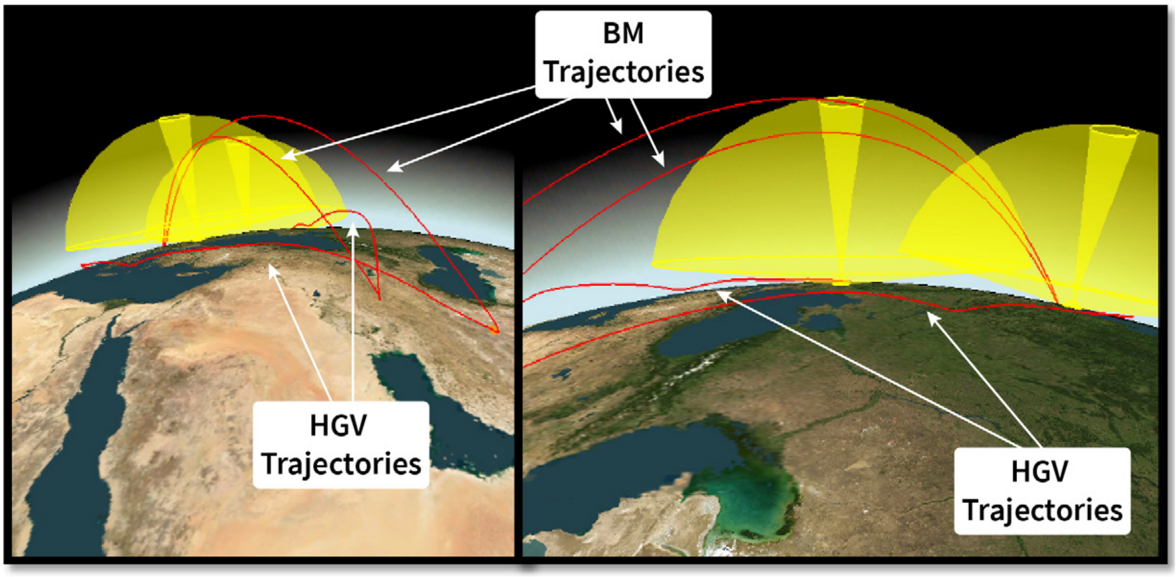
Again with the assumption of immediate tracking and identification, only five minutes was provided for the second and final continuous detection window. The last point of detection occurred 37 seconds before impact. In that time, even at Mach 5 the HGV could have travelled at least 63 km undetected (approximately the length of London) in any direction, yielding a target radius of 126 km without taking into account any payload considerations. Even neglecting the coverage gap between final detection and impact, this five-minute period may not provide enough time to respond.

The detection times were also affected by the line-of-sight radar horizon assumption which had the effect of increasing the shadow zone,[9] due to neglecting the radar beam refraction as it propagated through the atmosphere.[10] Therefore, while this vulnerability existed in the model, the shadow zone would be smaller in practice. This was considered to not fundamentally change the outcome of the results, although further work should be undertaken to establish its full effect. Further analysis of the model identified the HGV trajectory traversing through the shadow zone, below the Aegis sensor's field of view. Figure 5 shows this with the labelled HGV trajectories traversing below the yellow detection domes compared with the BM trajectories

8. Kelley M Sayler and Stephen M McCall, 'Hypersonic Missile Defence: Issues for Congress', Congressional Research Service, updated 11 June 2020, <https://fas.org/sgp/crs/weapons/IF11623.pdf>, accessed 15 September 2021; Andreas Schmidt, 'Hypersonic Threats: Hype or Game Changer for NATO's Deterrence?', *Transforming Joint Air and Space Power*, *The Journal of the JAPCC* (Edition 31, Winter/Spring 2021), <https://www.japcc.org/hypersonic-threats/>, accessed 15 September 2021.
9. A shadow zone is an area/zone where a radar cannot detect objects, for instance below the radar horizon due to curvature of the Earth or from other obstructions such as mountains or buildings.
10. Joris Derksen, 'Radar Performance Modelling: A Study of Radar Performance Assessment Accuracy Sensitivity to the Resolution of Atmospheric Input Data – Case Studies of North Sea Environments', MSc Thesis, Delft University of Technology, 16 March 2016, <https://repository.tudelft.nl/islandora/object/uuid:9e646012-038a-4ac5-8c45-6fed9c6361c8/datastream/OBJ/download>, accessed 15 September 2021.

which pass through the domes. This demonstrated how an HGV's characteristics can exploit gaps in coverage.

Figure 5: HGV Trajectories in the Radar Shadow Zone



Source: Author generated.

Like the BM case, the coverage of the HGV benefited from the deployment of the X-band radar. Without it, initial detection would not have occurred until around 20 minutes, increasing the coverage gap and delaying detection. The lack of coverage indicated a significant vulnerability of defensive infrastructure against HGVs.

Future Technologies

The main problem with the existing radar infrastructure, as highlighted by the modelling above, was the limitation in coverage of terrestrial radar due to shadow zones caused by the curvature of the Earth. Over-the-horizon radar (OTHR) technology could provide a viable terrestrial solution to overcome this limitation. The most common OTHR extends detection coverage into the shadow zones by reflecting radio waves off the ionosphere.[11] Despite the technical challenges, OTHR systems have been developed since the 1940s and many different systems are in use or under development.[12] Advanced radars based on solid state S-band technologies, which are suited to long-range and persistent discrimination and tracking, can help address this.

11. Bin Yi Liu, 'HF Over-the-Horizon Radar System Performance Analysis', thesis, Naval Postgraduate School, September 2007, <https://core.ac.uk/download/pdf/36697003.pdf>, accessed 15 September 2021.
12. Global Security, 'Project 2319 Tianbo (Sky Wave) Over-the-Horizon Backscatter Radar (OTH-B)', <https://www.globalsecurity.org/wmd/world/china/oth-b.htm>, accessed 15 September 2021.

The UK BMD Ground Radar is an example of a next-generation ground radar that will provide improved capability in relation to evolving missile threats, including hypersonics, for the UK and Euro-Atlantic.[13]

A complementary approach is to use space-based infrared sensors. Infrared sensing is possible due to the high amount of infrared energy emitted by HGVs as they glide through the atmosphere, resulting in significant heat signatures.[14] Geosynchronous satellite detection systems have been used for decades in BMDs[15] and continue to be developed, such as the US's Space-Based Infrared System[16] that aims to provide 24/7 early missile warning and battlespace awareness.[17] However, these systems are not considered sufficient for tracking HGVs in their mid-course glide phase.[18] This is due in part to hypersonic targets being much dimmer than the typical threats such as ballistic missiles at launch making them more challenging to detect.[19] Another reason is the unpredictability of HGVs – the relatively low resolution offered by geosynchronous satellites is sufficient when detection is only needed at launch. For example, a conventional BM's flightpath can be predicted, whereas for an HGV, continuous monitoring is required for precise tracking.[20]

Low Earth Orbit (LEO) is considered an optimum altitude range to track hypersonics, although a constellation of many satellites is required for complete global coverage.[21] An LEO system currently under development by the US is the Hypersonic and Ballistic Tracking Space Sensor that will consist of hundreds of satellites and provide increased tracking.[22]

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13. George Allison, 'UK Looks to Industry for New Ground-Based Ballistic Missile Defence Radar Capability', *UK Defence Journal*, 18 July 2017.
14. Qinglin Niu et al., 'Infrared Radiation Characteristics of a Hypersonic Vehicle Under Time-Varying Angles of Attack', *Chinese Journal of Aeronautics* (Vol. 32. No. 4. 2019), pp. 861–74.
15. Pavel Podvig, 'History and the Current Status of the Russian Early-Warning System', *Science and Global Security* (Vol. 10, 2002), pp. 21–60.
16. The Space-Based Infrared System uses powerful overhead infrared surveillance to provide early missile warning for the US military and is considered one of the nation's highest-priority space programmes.
17. Lockheed Martin, 'Space Based Infrared Surveillance SBIRS', <https://www.lockheedmartin.com/en-us/products/sbirs.html>, accessed 15 September 2021.
18. Congressional Research Service, 'Hypersonic Missile Defence: Issues for Congress', Federation of American Scientists, 11 June 2020, <https://fas.org/sgp/crs/weapons/IF11623.pdf>, accessed 15 September 2021.
19. *Ibid.*
20. Missile Defense Advocacy Alliance, 'Hypersonic and Ballistic Tracking Space Sensor (HBTSS)', updated 2 July 2020, <https://missiledefenseadvocacy.org/defense-systems/hypersonic-and-ballistic-tracking-space-sensor-hbtss/>, accessed 15 September 2021.
21. Sandra Erwin, 'Space Development Agency to Deploy Hypersonic Missile Defense Satellites by 2022', *SpaceNews*, 7 June 2020, <https://spacenews.com/space-development-agency-to-deploy-hypersonic-missile-defense-satellites-by-2022/>, accessed 15 September 2021; Loren Thompson, 'Raytheon Defines First Principles for Building a Space Sensor Layer', *Forbes*, 2 October 2020.
22. Missile Defense Advocacy Alliance, 'Hypersonic and Ballistic Tracking Space Sensor (HBTSS)'.

Conclusion

During the research for this paper, the authors investigated and gained an understanding of current NATO defensive infrastructure using open-source information. Case studies were modelled to compare the performance of NATO BMD radars against BMs and HGVs. The modelling suggested there are coverage gaps in both cases but especially against HGVs. In addition, the research showed a potentially narrow continuous detection window prior to impact of less than five minutes for HGVs. This highlights a potentially limited time frame to respond appropriately and effectively to such a threat.

These results suggest the need for new solutions to improve overall coverage and provide increased protection. Satellite-based systems could offer significant improvements in detection coverage whilst the defensive infrastructure could also benefit from additional modernised terrestrial radar assets. A combination of both would likely increase the probability of detecting the 'undetectable', but further work should be conducted to determine the optimum defensive infrastructure.

X. Hypersonic Boost-Glide Vehicles and Their Implications for Crisis Stability: A Technical and Doctrinal Analysis

Timothy Wright

HYPERSONIC BOOST-GLIDE VEHICLES (HGVs) are currently being developed by the world's three largest possessors of nuclear warheads – China, Russia and the US – among others.[1] Both China and Russia began introducing HGVs into service from 2019, while the US is expected to follow by 2023. However, each have operationalised their vehicles differently, creating nuances in the technical characteristics of their separate programmes, as well as their resultant force posture and structure. As these technical and doctrinal details differ, so too might their impact on crisis stability.

Strategic Stability and the Impact of Technology

An extensive discussion on the various interpretations of strategic stability, which forms the broader framework in which crisis stability originates, is beyond the scope of this paper.[2] However, a working definition provides useful context and clarity as to what strategic stability is and how HGVs might impact it. Using a narrow interpretation, strategic stability can be understood as the lack of incentives to use nuclear weapons first due to fears that an adversary will pre-emptively use them (crisis stability) and the lack of incentives to build up nuclear forces through quantitative or qualitative improvements (arms race stability).[3] During the Cold War, for instance, technological advancements in missile technologies, such as multiple independent re-entry vehicles (commonly known as 'MIRVs'), had lasting implications for stability.[4] The

1. Arms Control Association, 'Nuclear Weapons: Who Has What at a Glance', August 2020, <https://www.armscontrol.org/factsheets/Nuclearweaponswhohaswhat>, accessed 20 July 2021.
2. For an extensive overview of the various interpretations of strategic stability, see Elbridge A Colby and Michael S Gerson (eds), *Strategic Stability: Contending Interpretations* (Washington, DC and Carlisle, PA: Strategic Studies Institute and US Army War College Press, 2013).
3. James M Acton, 'Reclaiming Strategic Stability', Carnegie Endowment for International Peace, February 2013, <https://carnegieendowment.org/2013/02/05/reclaiming-strategic-stability-pub-51032>, accessed 20 July 2021.
4. Herbert F York, 'ABM, MIRV [Multiple Independent Re-Entry Vehicle], and the Arms Race', *Science* (Vol. 169, No. 3942, 1970), pp. 257–60.

evolution from missiles armed with a single warhead to being able to carry multiples resulted in arms race instabilities – this was evident through the expansion of nuclear arsenals in the 1960s and 1970s [5] and crisis instabilities brought about by the development of Soviet and US counterforce strategies resulting from mutual fears of a disarming first strike.[6]

Just as advancements in missile technology during the Cold War resulted in strategists to reflect the potential consequences of these developments and policymakers to develop new measures in response,[7] contemporary experts similarly argue that new technologies, including hypersonic weapons, will 'increasingly shape the nuclear order, particularly in relation to questions of stability and risk',[8] which requires an 'urgent reassessment of the way nuclear order and nuclear risks are conceptualised'.[9] By unpacking and understanding how seemingly similar technologies might impact crisis dynamics differently, policymakers might be better informed of how to tailor and adapt existing and potential arms control mechanisms to better capture their most destabilising effects.

Hypersonic Boost-Glide Vehicles

Like traditional ballistic missiles, HGVs use rocket boosters for acceleration beyond the upper atmosphere. Unlike ballistic missile payloads, however, which generally travel along arced trajectories in space, HGVs travel toward their targets at hypersonic (Mach 5+) speeds on flight paths within the Earth's upper atmosphere.

Considering ongoing research into and development of HGVs, these systems are sometimes referenced as an 'emerging' or 'disruptive' technology with game-changing implications.[10] Some scholars reject this categorisation, considering the lack of consensus on what these

5. Sameer Lalwani and Travis Wheeler, 'The Second Coming of MIRVs: The Future of Strategic Arms Competition', *War on the Rocks*, 23 August 2016.
6. Alexey Arbatov and Vladimir Dvorkin, 'The Impact of MIRVs and Counterforce Targeting on the US-Soviet Strategic Relationship', in Michael Krepon, Travis Wheeler and Shane Mason (eds), 'The Lure & Pitfalls of MIRVs: From the First to the Second Nuclear Age', Stimson Center, 2016, pp. 55–93.
7. Bernard Brodie, 'Nuclear Weapons: Strategic or Tactical?', *Foreign Affairs* (No. 32, Vol. 2, January 1954); Thomas C Schelling, *The Strategy of Conflict* (Cambridge, MA: Harvard University Press, 1981).
8. Andrew Futter and Benjamin Zala, 'Strategic Non-Nuclear Weapons and the Onset of a Third Nuclear Age', *European Journal of International Security* (Vol. 31, No. 3, 2021), p. 257.
9. *Ibid.*
10. Steven Simon, 'Hypersonic Missiles Are a Game Changer', *New York Times*, 2 January 2020.

terms mean, while others point out longstanding interest and research into developing these systems.[11] Some experts also contend that hypersonic missile technology is overblown.[12]

Nonetheless, China, Russia and the US attach significant importance and prestige to the acquisition of HGVs. For instance, during his 2018 presidential address, Russian President Vladimir Putin linked the development of Russia's HGV, the *Avangard*, with an unrestrained and resurgent Russia that was ahead of its rivals.[13] Similarly, Chinese state media has noted the importance of its HGV programme, the DF-17, in playing 'a vital role in safeguarding China's territorial integrity'.[14] China, Russia and the US have devoted considerable resources to the development of HGVs. The cost of the US's various hypersonic missile programmes, for instance, is estimated at almost $15 billion between 2015 and 2024.[15] Detailed costs of Russia and China's respective HGV programmes are unavailable publicly, but China is estimated as having the world's largest and best-funded research programme.[16]

Despite these investments, policymakers also recognise the risk that these systems may have on stability and have made tentative steps to find ways to address possible adverse consequences. Following the bilateral Russia–US Geneva Summit in June 2021, US President Joe Biden announced that US and Russian diplomats were launching a bilateral strategic stability dialogue 'to work on a mechanism that can lead to control of new and dangerous and sophisticated weapons … that reduce the times of response, [and] raise the prospects of accidental war. And we went into some detail of what those weapons systems were'.[17] While HGVs were not

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11. Andrew Futter, 'Explaining the Nuclear Challenges Posed by Emerging and Disruptive Technology: A Primer for European Policymakers and Professionals', Non-Proliferation and Disarmament Papers, EU Non-Proliferation and Disarmament Consortium (No. 73, March 2021); see, for instance, Russia's Albatross HGV programme, which began in the late 1970s. Vladimir Dvorkin, 'Hypersonic Threats: The Need for a Realistic Assessment', Carnegie Moscow Center, August 2016, <https://carnegie.ru/2016/08/09/hypersonic-threats-need-for-realistic-assessment-pub-64281>, accessed 20 July 2021.
12. Robert S Wilson, 'The Hypersonic Missile Debate', Aerospace Corporation's Center for Space Policy and Strategy, January 2021, <https://aerospace.org/sites/default/files/2021-01/Wilson_HypersonicMissileDebate_20210112_1.pdf>, accessed 20 July 2021.
13. President of Russia, 'Presidential Address to the Federal Assembly', 1 March 2018, <http://en.kremlin.ru/events/president/news/56957>, accessed 21 July 2021.
14. Yang Sheng and Liu Xuanzun, 'DF-17 Ballistic Missile Makes Debut at National Day Parade', *Global Times*, 1 October 2019, <https://www.globaltimes.cn/content/1165933.shtml>, accessed 20 July 2021.
15. Government Accountability Office, 'Hypersonic Weapons: DOD Should Clarify Roles and Responsibilities to Ensure Coordination Across Development Efforts', 22 March 2021, <https://www.gao.gov/products/gao-21-378>, accessed 21 July 2021.
16. International Institute for Strategic Studies (IISS), 'Hypersonic Weapons and Strategic Stability', *Strategic Comments* (Vol. 26, March 2020).
17. White House, 'Remarks by President Biden in Press Conference', 16 June 2021, <https://www.whitehouse.gov/briefing-room/speeches-remarks/2021/06/16/remarks-by-president-biden-in-

explicitly named, considering the very high speed at which they travel and the resultant reduced reaction times for defenders to react and respond appropriately, it is likely that the systems were an important part of the discussions.[18]

But while HGVs share some universal design characteristics – for instance, the ability to travel at hypersonic speeds and manoeuvre laterally and vertically – China, Russia and the US's respective programmes are dissimilar in terms of other current or expected attributes, including range, warhead, mission profile, and force structure and doctrine. Unpacking, comparing and contrasting these differences can potentially reveal whether some systems might have greater implications for crisis stability than others.

Analysing China, Russia and the US's Hypersonic Programmes

China was the first state to declare an operational HGV and publicly unveiled its DF-17 (CH-SS-X-22) in October 2019. The DF-17 is operated solely by the People's Liberation Army Rocket Force (PLARF) across two brigades in eastern China.[19] The system is transported atop a mobile transporter-erector-launcher (TEL), can allegedly travel between Mach 5 and 10 and has an estimated maximum range of 1,800–2,500 km.[20] China is opaque about the DF-17's warhead. While its Ministry of Defence claims it is armed with a conventional warhead, state media has referred to the DF-17 as part of China's 'strategic attack forces', which would suggest it also has a nuclear role.[21] US officials have also proposed that the DF-17 could use either nuclear or conventional warheads.[22] This uncertainty is not unusual, as the PLARF relies on dual-capable missiles to enhance its regional deterrence. Analysts have suggested that the DF-17's force posture is to strike Taiwan and regional US bases within the First Island Chain and perform a regional anti-access/area-denial (A2/AD) role in the event of a conflict between Beijing, Taipei and Washington.[23] If the DF-17 were armed with a nuclear warhead, its use would presumably

press-conference-4/>, accessed 20 July 2021.

18. Douglas Barrie, 'Trends in Missile Technologies', IISS, 11 March 2019, <https://www.iiss.org/blogs/analysis/2019/03/trends-in-missile-technologies>, accessed 20 July 2021.
19. Hans M Kristensen and Matt Korda, 'Chinese Nuclear Forces, 2020', *Bulletin of the Atomic Scientists* (Vol. 76, No. 6, 2020), pp. 443–57.
20. Ankit Panda, 'Questions About China's DF-17 and a Nuclear Capability', *The Diplomat*, 16 February 2020.
21. Sheng and Xuanzun, 'DF-17 Ballistic Missile Makes Debut at National Day Parade'; New China TV, 'China Holds Grand Gathering, Parade on 70th National Day', 1 October 2019, <https://www.youtube.com/watch?v=dit7zmnzAh0>, accessed 20 July 2021.
22. Charles Richard, 'Statement of Charles A. Richard, Commander, United States Strategic Command Before the Senate Committee on Armed Services', US Senate Committee on Armed Services, 13 February 2020, <https://www.armed-services.senate.gov/imo/media/doc/Richard_02-13-20.pdf>, accessed 21 July 2021.
23. Ma Xiu and Peter W Singer, 'What Do We Know About China's Newest Missiles?', *Defense One*, 19 March 2021, <https://www.defenseone.com/ideas/2021/03/what-do-we-know-about-chinas-newest-missiles/172782/>, accessed 19 July 2021.

be guided by China's no-first-use (NFU) policy, whereby Beijing pledges it will not use nuclear weapons unless it is targeted first.[24] Despite Chinese officials' insistence that China's NFU policy is perennial,[25] Western scholars and practitioners are generally sceptical of such promises.[26] There are some suggestions from US government reports that China could use its recently developed DF-41 intercontinental ballistic missile (ICBM) as a launcher for the DF-17 to provide the HGV with an intercontinental range.[27] Beijing does not seem, at least for now, interested in modifying the DF-17 so that it may be launched from air or maritime platforms.

Russia also deployed its first HGV in 2019, the *Avangard* (RS-SS-19 Mod 4). Two regiments of *Avangard* consisting of two launchers apiece are deployed in silos as part of the 13th Missile Division at Dombarovsky, forming part of Russia's Strategic Rocket Forces. Russia's Ministry of Defence expects deployment of two systems a year to continue until 2027, for a total of 12 launchers.[28] While the system is also ground-launched like China's DF-17, it differs in many other respects. The *Avangard* is claimed to have a range of at least 6,000 km, due to it being transported atop a modified siloed RS-SS-19 ICBM. This enables it to strike targets beyond its immediate region. It is likely that this range will be further increased once a new ICBM launcher, the *Sarmat* (RS-SS-X-28), is introduced into service in 2022.[29] The *Avangard*'s greater ballistic trajectory also means it can travel at faster speeds than China's DF-17, allegedly up to Mach 20.[30] It is also expressly fitted with a nuclear warhead, which reportedly has a 150-kt yield.[31] Due to its nuclear warhead, *Avangard*'s doctrinal use fits within Russia's updated 2020 nuclear

24. State Council, People's Republic of China, 'China's National Defense in the New Era', 24 July 2019, <http://english.www.gov.cn/archive/whitepaper/201907/24/content_WS5d3941ddc6d08408f502283d.html>, accessed 19 July 2021.
25. Fu Cong, 'Statement by Director-General FU Cong at the EU Non-Proliferation and Disarmament Conference', Ministry of Foreign Affairs of the People's Republic of China, 13 November 2020, <https://www.fmprc.gov.cn/mfa_eng/wjb_663304/zzjg_663340/jks_665232/kjfywj_665252/t1832223.shtml>, accessed 21 July 2021.
26. Michael Quinlan, 'Thinking About Nuclear Weapons', *RUSI Whitehall Paper* (No. 41, 1997), <http://fisherp.scripts.mit.edu/wordpress/wp-content/uploads/2017/03/Thinking-about-Nuclear-Weapons-RUSI-WHP41_QUINLAN1.pdf>, accessed 20 July 2021.
27. U.S.-China Economic and Security Review Commission, '2018 Report to Congress of the U.S.-China Economic and Security Review Commission', November 2018, p. 235, <https://www.uscc.gov/sites/default/files/annual_reports/2018%20Annual%20Report%20to%20Congress.pdf>, accessed 14 September 2021.
28. Russian Federation, 'Expanded Meeting of the Defence Ministry Board', 21 December 2020, <http://en.kremlin.ru/events/president/news/64684>, accessed 21 July 2021.
29. *Ibid.*
30. Pavel Podvig, 'Avangard System Is Tested, Said to Be Fully Ready for Deployment', *Russian Strategic Nuclear Forces*, 26 December 2018, <http://russianforces.org/blog/2018/12/avangard_system_is_tested_said.shtml>, accessed 20 July 2021.
31. Jill Hruby, 'NTI Releases Assessment of New Russian Nuclear Weapon Delivery Systems', NTI, 13 November 2019, <https://www.nti.org/newsroom/news/nti-releases-assessment-new-russian-nuclear-weapon-delivery-systems>, accessed 20 July 2021.

doctrine, which outlines that nuclear weapons will only be used in specific circumstances, such as where the existence of the Russian state were threatened or if nuclear weapons had been used against Russia.[32]

The US is yet to deploy an HGV, but it has several programmes at various stages of development with different branches of the US armed forces. Together, these constitute the Conventional Prompt Global Strike (CPGS) programme.[33] The Common-Hypersonic Glide Body (C-HGB) serves as the base for separate US Army and Navy HGV programmes which share many common characteristics. Like China's DF-17, the US Army's long-range hypersonic weapon (LRHW) will also use a road-mobile TEL, each armed with two HGVs capable of travelling up to Mach 17 to an estimated range of 1,600 km.[34] The US Navy's programme using the C-HGB, Conventional Prompt Strike, will be deployed aboard *Virginia*-class nuclear-powered guided missile submarines in 2025.[35] The system might also possibly be deployed aboard nuclear-armed *Ohio*-class ballistic missile submarines in the future.[36] Deployment aboard these mobile maritime platforms will provide the US Navy with the capability to deploy the system in different theatres. The C-HGB's range is expected to be similar to the US Army's LRHW system. Like Moscow, Washington has expressly identified the warhead type that the C-HGB will use, although in this case it will be conventionally armed. Although the CPGS programme has been criticised as being a 'missile in search of a mission',[37] US officials have stated its hypersonic weapons would be used to 'hold high-value, time-sensitive and other targets at risk without crossing the nuclear threshold' which will 'enable responsive long-range, conventional strike options against distant and defended threats when other forces are unavailable, denied access, or not preferred'.[38]

32. Russian Federation, 'Basic Principles of State Policy of the Russian Federation on Nuclear Deterrence', 8 June 2020, <https://www.mid.ru/en/web/guest/foreign_policy/international_safety/disarmament/-/asset_publisher/rp0fiUBmANaH/content/id/4152094>, accessed 20 July 2021.
33. Kelley M Sayler, 'Hypersonic Weapons: Background and Issues for Congress', Congressional Research Service, 1 December 2020, <https://fas.org/sgp/crs/weapons/R45811.pdf>, accessed 20 July 2021.
34. Joseph Trevithick, 'Army Shows First-Ever Footage Of New Hypersonic Missile In Flight And Impacting', *The Warzone*, 4 August 2020.
35. Government Accountability Office, 'Hypersonic Weapons: Report to Congressional Addresses', March 2021, <https://www.gao.gov/assets/gao-21-378.pdf>, accessed 21 July 2021.
36. Megan Eckstein, 'Navy Confirms Global Strike Hypersonic Weapon Will First Deploy on Virginia Attack Subs', *USNI News*, 18 February 2020, <https://news.usni.org/2020/02/18/navy-confirms-global-strike-hypersonic-weapon-will-first-deploy-on-virginia-attack-subs>, accessed 21 July 2021.
37. James M Acton, 'Silver Bullet? Asking the Right Questions About Conventional Prompt Global Strike', Carnegie Endowment for International Peace, 3 September 2013, p. 11, <https://carnegieendowment.org/files/cpgs.pdf>, accessed 14 September 2021.
38. Richard, 'Statement of Charles A. Richard, Commander, United States Strategic Command Before the Senate Committee on Armed Services', p. 25.

Implications for Crisis Stability

Considering the technical and doctrinal nuances between China, Russia and the US's HGV programmes, a comparative analysis reveals that some systems will have greater implications on crisis stability than others. For instance, warhead clarity eliminates possibilities for inadvertent escalation, which is magnified if there are pre- and post-launch warhead ambiguities.[39] Unlike Russian and US systems, which have expressly identified warheads, however, China's ambiguous DF-17 could result in unintentional escalatory pathways in a crisis, as targets would be uncertain if the incoming system was nuclear armed. If military and civilian decision-makers assumed a worst-case analysis of the system's warhead, this could lead to unintentional nuclear escalation. Entangled force structures also could result in possible escalatory pathways. The PLARF's partially mixed force structure already creates possible risks of an adversary inadvertently and mistakenly targeting nuclear assets.[40] The possibility of the US C-HGB being deployed aboard *Ohio*-class nuclear platforms also raises the issue of escalation through entanglement.[41] Force postures also might potentially result in crisis instabilities. Although nuclear armed, Russia's *Avangard* essentially functions much like an ICBM in terms of capabilities and posture. Thus, it acts as a classical means of deterrence, with limited implications for crisis stability. Conversely, although the US's CPGS systems will be conventionally armed, the US's open-ended counterforce doctrine vis-à-vis their expected use against 'high-payoff targets'[42] could create uncertainty and escalation risks if a targeted state believed that an adversary's detected HGVs might be targeting their nuclear forces or command and control. As counterforce systems can erode confidence in strategic deterrence stability, as they may be used to target nuclear weapons and elements of their command-and-control infrastructure,[43] decision-makers might inadvertently escalate by pre-emptively using their nuclear weapons in a crisis to avoid their possible destruction.

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39. James M Acton, 'Is it a Nuke? Pre-Launch Ambiguity and Inadvertent Escalation', Carnegie Endowment for International Peace, 9 April 2020, <https://carnegieendowment.org/2020/04/09/introduction-pub-81447>, accessed 21 July 2021.
40. Jeffrey Lewis, David Joël La Boon and Decker Eveleth, 'China's Growing Missile Arsenal and the Risk of a "Taiwan Missile Crisis"', NTI, 18 November 2020, <https://www.nti.org/analysis/articles/chinas-growing-missile-arsenal-and-the-risk-of-a-taiwan-missile-crisis/>, accessed 21 July 2021.
41. James M Acton, 'Escalation Through Entanglement: How the Vulnerability of Command-and-Control Systems Raises the Risks of an Inadvertent Nuclear War', *International Security* (Vol. 43, No. 1, 2018), pp. 56–99.
42. Amy Woolf, 'Conventional Prompt Global Strike and Long-Range Ballistic Missiles: Background and Issues', Congressional Research Service, last updated 16 July 2021, <https://fas.org/sgp/crs/nuke/R41464.pdf>, accessed 21 July 2021.
43. Kier A Lieber and Daryl G Press, 'The New Era of Counterforce: Technological Change and the Future of Nuclear Deterrence', *International Security* (Vol. 41, No. 4, 2017), pp. 9–49.

Section V. Regional Deterrence Dynamics

XI. Strategic Signals Versus Noisy Signals: North Korea's Deterrence Posture

Elisabeth I-Mi Suh

NORTH KOREA COMMUNICATES primarily via its state media outlets. One of its key outlets, the Korean Central News Agency (KCNA), issues an average of 24 articles per day, with five articles explicitly mentioning nuclear weapons, deterrence, sanctions or military drills.[1] Yet, the number of official statements does not diminish the common perception of North Korea as a 'hermit kingdom', a reclusive state that controls the inflow and outflow of information about itself. As a result, official language from Pyongyang is either taken literally or dismissed as mere bluffing. In examining and understanding North Korea's official language, this paper has two main objectives: first, it suggests a method of distinguishing between noisy and strategic signals; and second, it provides examples of Pyongyang's strategic signalling between 2016 and 2018.

Signalling as Communication with Strategic Purpose

The term 'signal' refers broadly to explicit and implicit messages in non-verbal and verbal communication.[2] This paper conceptualises 'signalling' as a form of communication with strategic purpose: it provides a method of influencing the intended target state by conveying information; and the signalling state can aim to exert influence by transmitting information that is relevant to the target state. The reference point for relevance is the target state's strategic calculus. Signalling thus takes place in the context of inter-state bargaining, often against the backdrop of a protracted conflict situation.

This definition of signalling includes a form of signals that this paper terms 'noisy' signals, which still convey information that is strategically relevant to the target state at first sight, but aim to befuddle, distract or foster existing narratives. 'Strategic' signals aim to influence the target state's strategic calculus and to improve the signalling state's bargaining position vis-à-vis the target state. These attributes of noisy and strategic stand at opposite ends of a continuum.

1. The data and the following analysis stem from the author's PhD dissertation research of North Korea's official signalling between 1992 and 2018.
2. For a discussion of definitions and literature on signalling, see Erik A Garetzke et al., 'Signaling in Foreign Policy', in Cameron G Thies (ed.), *The Oxford Encyclopedia of Foreign Policy Analysis*, Volume 2 (Oxford: Oxford University Press, 2018).

The research for this paper uses five basic questions for analysing texts from KCNA (see Table 1).[3] These questions on content, framing, authority, frequency and timing are not a checklist but help to structure the judgement call of where to locate signals along the continuum of noisiness. The ideal type of strategic signal – for example, a clear-cut, once-in-a-lifetime statement by the supreme leader disclosing North Korea's uranium enrichment facilities and outlining the conditions for inspections – is all but impossible. This analysis of signals along the continuum of noisiness is instead a judgement call considering the degree of each signal's respective characteristic.

Table 1: Five Questions to Delineate the Continuum of Noisiness in Signalling

Question	Noisy Signal	Strategic Signal
Content: What information does this signal convey?	Lower levels of relevance	Higher levels of relevance to strategic calculus
Framing: How is this information framed or presented?	Higher levels of ambiguity or befuddlement	Lower levels of ambiguity or befuddlement
Level of authority: Who issued this signal, and what level of authority is attributed to it?	Lower levels of authority	Higher levels of authority
Frequency: Has this information been shared before?	Higher levels of frequency	Lower levels of frequency
Context/timing: What context is this linked to? What correlations exist?	No specific links to context	Specific link to certain context

Source: Author generated.

This analysis of signalling in this paper has three major caveats: first, the definition and analysis are based on the reading and interpretation of the author; second, signalling outlines what information the signalling state has chosen to convey and which framing and timing it has chosen, and these aspects of strategic selection and presentation are crucial when analysing the meaning and purpose of signals; and third, signals conveyed through public official communication automatically reach multiple audiences – signalling often targets more than one audience, including not only external audiences such as the signalling state's allies and adversaries, but also internal audiences such as different domestic constituencies. Analysing the content and framing of signals is essential when identifying the intended target audience. Nevertheless, overlap in audiences is inevitable.

Signalling and Deterrence Posture

At the very minimum, effective deterrence requires capabilities to respond and inflict substantial costs, as well as the resolve to employ those capabilities in contingencies. In addition, the

3. These primary documents are from the online archives of KCNA Watch, <https://kcnawatch.org/>.

deterring state aims to convince the adversary to refrain from attack or other malicious acts by communicating its capabilities and resolve. Signalling is thus one building block for deterrence.

This paper focuses on three elements of signalling deterrence posture: resolve; capabilities; and the mission of those capabilities. North Korea issues a vast amount of signals that contribute to its deterrence posture vis-à-vis its main declared adversary, the US. The following sections are based on the author's empirical analysis of KCNA documents issued between 2016 and 2018.

Signalling Resolve – Blurred Lines Between Noisy and Strategic Signals

The vast majority of North Korea's signalling consisted of signals of resolve. Determination and readiness were the most fundamental notions in Pyongyang's rhetoric and are therefore present in every statement, rendering such signalling rather noisy. A salient point was North Korea's consistent narrative of martyrdom that aims at domestic cohesion, loyalty and mobilisation. Links to history were quite common in Pyongyang's official language, but the narrative of the 'self-chosen path' clashed with the argument that US hostile policy compelled North Korea to pursue this nuclear path. Signals of determination and the irreversibility of this path were dominant, while the possibility of path changes conditional on US hostile policy was also linked to these noisy signals.

Also frequent, but more relevant to the US's strategic calculus and contingency planning, were North Korea's signals concerning its military readiness. In line with its general narrative of remaining at war with the US since 1951, Pyongyang portrayed its Korean People's Army as generally being on high alert, maintaining combat preparedness and engaging in constant contingency planning. In relation to specific contexts, such as US–South Korea joint military exercises, North Korea depicted its strategic forces as being on hair-trigger alert, maintaining its deployed nuclear forces at ready-for-launch status. Such statements with specific links stemmed from military personnel and thus presented as rather strategic signals; noisy signals such as threats to view sea blockades as declarations of war were linked to low- to high-level officials with diplomatic backgrounds.[4]

Pyongyang's signals of resolve emphasised its ability, readiness and willingness to respond militarily and enter armed conflict as well as to improve its strategic position regarding the US. Such signals of resolve – often threats to continuously modernise existing weapons systems and aim for state-of-the-art capabilities – tended to be noisy, contributing to the general tenor of determination. More strategic were North Korea's claims of mass producing certain systems that were termed 'operational'. After respective technical advancements were certified through test events, Pyongyang announced the start of serial production of nuclear warheads, short-range ballistic missiles such as Scud C, and medium-range ballistic missiles such as Pukguksong-2. Although the claim of having resources to produce 'as many as wanted' was an exaggeration,

4. 'U.S. War Hysteria Will Only Bring Miserable End of American Empire: Spokesman for KPA General Staff', KCNA, 9 August 2017.

the signal of mass production was linked to the more strategic signals of early deployment and ready-for-launch status of nuclear forces.

Emphasising Diversity to Project Credibility and Survivability of Capabilities

North Korea went to great lengths to present its capabilities and highlight certain qualities. Pyongyang was particularly mindful of exhibiting the reliability of the country's arsenal. Prior to flight tests in 2017, Pyongyang published information on engine tests and simulations of re-entry vehicles, stating that this illustrated guidance and control, re-entry survivability and targeting accuracy of its longer-range ballistic missiles. Respective statements acknowledged that this publicity was tailored to provide 'transparency' and increase credibility.[5] Strikingly, this strategic signalling correlated with the surge of open-source analyses and detailed public discussions about the credibility of Pyongyang's technical advancements.[6]

The publication of pictures showing different warhead designs was another singular strategic signal issued by North Korea in 2016.[7] In addition to its three nuclear tests in 2016 and 2017, Pyongyang intended to demonstrate the diversity of its nuclear weapons capability and stockpiles, operating at least two different bomb designs of variable compositions. It emphasised its nuclear capability of adjusting explosive power to 'tens or hundreds of kilotons', hinting at smaller yields from fission and greater yields from boosted fission or thermonuclear reactions.[8]

The notion of diversity also played a central role in North Korea's signalling concerning its nuclear forces. It frequently projected that it was operating a diverse arsenal of ballistic missiles and pursuing additional delivery systems.[9] This relatively noisy signalling included general claims of short- to long-range missile capabilities launched from air, land, sea and underwater. While its aerial and naval capabilities remain questionable, this signalling was geared towards projecting survivability of its nuclear arsenal by suggesting an intended equivalent to the US nuclear triad.

Calculated Signalling Among Noisy Threats

The degree of noise among North Korea's signals of how it might employ its nuclear weapons also tends to be relatively high. Pyongyang frequently threatened to conduct pre-emptive strikes in response to any activities by the US and its allies that might suggest use of force against North

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5. See, for example, 'Statement of DPRK Foreign Ministry Spokesman', KCNA, 7 July 2017.
6. See, for example, Dave Schmerler, 'N.Korea counters doubts with 'miniaturized' bomb photo', NK News, 10 March 2016, < https://www.nknews.org/2016/03/n-korea-counters-doubts-with-miniaturized-bomb-photo/>.
7. 'Kim Jong Un Guides Work for Mounting Nuclear Warheads on Ballistic Rockets', KCNA, 9 March 2016.
8. 'Kim Jong Un Gives Guidance to Nuclear Weaponization', KCNA, 3 September 2017.
9. See, for example, 'Kim Jong Un Watches Ballistic Rocket Launch Drill of Strategic Force of KPA', KCNA, 11 March 2016.

Korea.[10] These threats were relatively blunt and intended to convince the US of the potential risks of military activities on the Korean peninsula.[11] They were issued in the context of reports on US-South Korean plans for pre-emption and decapitation.[12] The 2017 threat of conducting a 'surprise launch' with intercontinental ballistic missiles was also linked to this context.[13]

The threat of assured escalation was closely connected to Pyongyang's signals of resolve. North Korea claimed that any situation that included the use of military force against it would end in nuclear exchange.[14] Such signalling of asymmetric escalation to the nuclear level remains relatively noisy, as these frequent threats are often sketchy and lacking specific context or clear levels of authority. Signals of reciprocal response were less frequent and more nuanced; the supreme leader signalled that North Korea would respond to nuclear strikes with nuclear strikes, refraining from suggesting escalatory nuclear use.[15]

North Korea mentioned a set of targets that it might strike with conventional and/or nuclear warheads.[16] Pyongyang's belligerent rhetoric of counter-value targeting of Japan, South Korea and the US remained ambiguous and linked to specific political contexts, such as hostile statements by South Korea's president.[17] North Korea's emphasis on counterforce targeting appeared more strategic, linked to specific military contexts and the highest levels of authority. It underscored US military bases in Japan and Guam as targets for strategic counterstrikes. Pyongyang also mentioned US military bases in South Korea as targets, but emphasised the

10. See, for example, 'U.S. Muscle-flexing Can Never Browbeat DPRK: Foreign Ministry Spokesman', KCNA, 22 April 2017.
11. These threats include blunt statements such as that 'the right to make a nuclear pre-emptive strike is by no means a monopoly of the US'. See 'Kim Jong Un Guides Work for Mounting Nuclear Warheads on Ballistic Rockets'.
12. Media reports since 2015 started publicising excerpts of the new US–South Korean operational plan OPLAN 5015. See Michael Peck, 'OPLAN 5015: The Secret Plan for Destroying North Korea (and Start World War III?)', The National Interest, 11 March 2017, < https://nationalinterest.org/blog/the-buzz/oplan-5015-the-secret-plan-destroying-north-korea-start-19747>. In some statements, North Korea explicitly links its threats to OPLAN 5015 as one proof of the pre-emptive threat posed by the US and South Korea. See, for example, 'Crucial Statement of KPA Supreme Command', KCNA, 23 February 2016.
13. 'Kim Jong Un Guides Second Test-fire of ICBM Hwasong-14', KCNA, 29 July 2017.
14. See, for example, 'KPA General Staff Warns Aggressors of Merciless Nuclear Counter-action of Justice', KCNA, 2 March 2017.
15. See, for example, 'Kim Jong Un Makes New Year Address', KCNA, 1 January 2018.
16. For an overview of targets, see Léonie Allard, Mathieu Duchâtel and François Godement, 'Pre-Empting Defeat: In Search of North Korea's Nuclear Doctrine', *European Council on Foreign Relations Policy Brief 237* (November 2017), pp. 4–5.
17. See, for example, 'KPA General Staff Clarifies Its Stand to Retaliate against U.S. and S. Korean Puppet Warmongers' Provocation', KCNA, 22 September 2016.

Pacific in its strategic signalling as the theatre of war, indicating that its use of military force will not remain limited to the Korean peninsula.[18]

Conclusions for North Korea's Deterrence Posture

North Korea's strategic signals about its resolve, capabilities and missions fit with a posture of minimum deterrence as well as one that manipulates significant risk of nuclear exchange and unacceptable consequences. Although Pyongyang postured in its signalling that it is capable of asymmetric escalation and assured retaliation, such postures require higher degrees of survivability and reliability of counterstrike forces in addition to functional command, control and communication in contingencies.[19] Achieving a credible posture of assured retaliation regarding the US is likely North Korea's preference.[20] In the meantime, it can signal a posture of asymmetric retaliation, striking US bases in Japan and Guam in response to strikes on North Korea.

Distinguishing between noisy signals and strategic signals is not clear-cut and is based on judgement calls. Even though the analysis of Pyongyang's signalling does not separate truth from bluff and deception, it helps to better understand the strategic context and purpose of its official rhetoric. It also provides a method for how to handle the vast amount of belligerent language and focus on the nuances of strategic signals.

18. See, for example, 'Kim Jong Un Inspects KPA Strategic Force Command', KCNA, 15 August 2017.
19. For a description of different deterrence postures, see John V Parachini et al., *North Korean Decisionmaking: Economic Opening, Conventional Deterrence Breakdown, and Nuclear Use* (Santa Monica, CA: RAND Corporation, 2020), pp. 66–68, 78–81.
20. Bruce W Bennett et al., *Countering the Risks of North Korean Nuclear Weapons* (Santa Monica, CA: RAND Corporation, 2021), pp. 39–41.

XII. The Middle East WMD-Free Zone: Diplomatic Game or Pathway to Regional Stability?

Tom Hickey

THE LEGACY OF WMD development, proliferation and use casts a long shadow over the Middle East.[1] The establishment of a Middle East WMD-free zone (MEWMDFZ) has been discussed for over 60 years. While all the states of the region agree on the need to address the risk of WMDs, the debate surrounding the creation of a MEWMDFZ is often polarising and underlines the distinct perceptions among the region's states which drive the zone process today. Some of the states see the issue as unrealistic, exploited to drive a political agenda or for diplomatic signalling, while others view it as a fundamental necessity on the path to a more stable and peaceful Middle East.

Understanding the history of the zone process is essential to understanding how progress can be made, while learning from the successes and failures of the past. While there were earlier calls to establish a nuclear weapons-free zone in the region,[2] the process began officially under UN auspices in 1974, when Egypt and Iran co-sponsored a resolution calling for the establishment of a Middle East Nuclear Weapon Free Zone.[3] In 1990, this proposal was expanded by the Egyptian

1. Several states in the Middle East are not party to international agreements, including the Chemical Weapons Convention (CWC), Biological and Toxin Weapons Convention (BWC), Comprehensive Nuclear Test Ban Treaty (CTBT) and the Nuclear Non-Proliferation Treaty (NPT). Chemical weapons have been used in several regional conflicts, while on the nuclear side, four states of the region (Iraq, Libya, Iran, Syria) were reported by the International Atomic Energy Agency (IAEA) to the UN Security Council for nuclear safeguards violations.
2. Earlier proposals originated in the Soviet Union (1958), Israel (1962) and Iran (1970). See *TASS*, '1958 Soviet Proposal for the Creation of a Middle East Nuclear Weapons Free Zone', 22 January 1958, <https://unidir.org/sites/default/files/2021-01/1958%20Soviet%20Proposal.pdf>, accessed 17 September 2021; Historical Jewish Press of the NLI and TAU, 'Israeli Intellectuals Call for Denuclearization of the Middle East', 12 October 1962, p. 9, <https://unidir.org/sites/default/files/2020-06/1962-06-23_Israeli%20intellectuals%20call%20for%20the%20denuclearization%20of%20the%20Middle%20East_0.pdf>, accessed 17 September 2021; UN General Assembly, 'General Debate', Twenty-Fifth Session, 1857th Plenary Meeting, 1 October 1970, <https://unidir.org/sites/default/files/2020-11/A_PV.1857_E.pdf>, accessed 17 September 2021.
3. UN General Assembly, 'Establishment of a Nuclear-Weapon-Free Zone in the Region of the Middle East', 9 December 1974, <https://unidir.org/sites/default/files/2020-06/1974-12-26_UNGA%20

'Mubarak Initiative' to include all WMDs.[4] Following the 1991 Madrid Peace Conference on the Middle East,[5] the Arms Control and Regional Security Working Group (ACRS) was established.[6] It met between 1991 and 1995 and held six plenary sessions on a variety of confidence- and security-building measures.[7]

The 1995 Nuclear Non-Proliferation Treaty (NPT) Review Conference marked a seismic shift in the WMDFZ process. As part of the decision to extend the NPT indefinitely, a resolution, co-sponsored by Russia, the UK and the US, called for 'practical steps' towards 'the establishment of an effectively verifiable Middle East zone free of weapons of mass destruction, nuclear, chemical and biological, and their delivery systems'.[8] The Action Plan adopted at the 2010 NPT Review Conference requested that the three co-sponsors of the 1995 resolution, together with the UN Secretary-General, appoint a facilitator and convene a regional conference on the establishment of the MEWMDFZ, to be held by 2012.[9] Finland was chosen as the host country, with Ambassador Jaako Lajaava as facilitator.

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adopts%20resolution%203263%20on%20the%20Establishment%20of%20a%20nuclear-weapon-free%20zone%20in%20the%20region%20of%20the.pdf>, accessed 24 August 2021.

4. UN Security Council General Assembly, 'Letter Dated 16 April 1990 from the Permanent Representative of Egypt to the United Nations Addressed to the Secretary-General', 18 April 1990, <https://unidir.org/sites/default/files/2020-06/1990-04-18_The%20Mubarak%20Initiative%20is%20communicated%20to%20the%20UNSG.pdf>, accessed 24 August 2021.
5. The 1991 Madrid Peace Conference was a multilateral negotiation co-sponsored by the US and the Soviet Union that brought together Israel, Palestine, Jordan, Lebanon and Syria to address outstanding issues in the region, particularly the Israel–Palestine peace process. The conference resulted in a bilateral track to address relations between Israel and its neighbours, and a multilateral track to discuss mutual areas of concern, including arms control, refugees and economic development.
6. More broadly, the Arms Control and Regional Security Working Group (ACRS) was a good opportunity for building high-level relationships, to have frank discussions on regional security issues, and identify contentious topics and areas where progress could be made. Although the aim was not to have direct negotiations on the Middle East WMD-free zone (MEWMDFZ), the group was particularly notable as it was the first time that Arabs and Israelis sat together at the negotiating table to discuss regional security issues directly, although some of the key regional states did not participate in the process.
7. This included military crisis communications, verification and monitoring, and maritime security.
8. UN 1995 Review and Extension Conference of the Parties to the Treaty on the Non-Proliferation of Nuclear Weapons, 'Resolution on the Middle East', New York, 17 April–12 May 1995, <https://unoda-web.s3-accelerate.amazonaws.com/wp-content/uploads/assets/WMD/Nuclear/1995-NPT/pdf/Resolution_MiddleEast.pdf>, accessed 24 August 2021.
9. 2010 Review Conference of the Parties to the Treaty on the Non-Proliferation of Nuclear Weapons, 'Final Document', 2010, <https://unidir.org/sites/default/files/2020-08/2010%20NPT%20RevCon%20Final%20Document.pdf>, accessed 24 August 2021.

However, in 2012 the conference was postponed indefinitely. The co-convenors cited ‘present conditions in the Middle East’ and a lack of agreement about its scope and mandate among regional states.[10] As a follow-on, Lajaava convened the Glion-Geneva process between 2013 and 2014, a series of informal high-level consultations with the facilitator, 16 Arab states and Israel. Perceptions on the outcome were mixed: while the delegations agreed on the importance of convening a conference, the process also revealed stark differences in positions.[11] Israel wanted to address broader regional security issues, and create a process to address this,[12] while countries such as Egypt viewed this approach as a means to avoid addressing core disarmament commitments. For some states, the zone must be addressed first in order to begin a formal peace and security process in the region.[13]

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10. Statements were issued by the UK, the US and Russia, as well as the UN Secretary General and the facilitator (Finland) regarding the postponement of the conference. See UK Foreign and Commonwealth Office, Middle East Weapons of Mass Destruction Free Zone Conference, 24 November 2012, <https://unidir.org/sites/default/files/2020-07/2012-11-24_UK%20Statement%20on%20postponement%20of%20the%202012%20conference.pdf>, accessed 24 August 2021; US Department of State, Office of the Spokesperson, ‘2012 Conference on a Middle East Zone Free of Weapons of Mass Destruction (MEWMDFZ)’, 23 November 2012, <https://unidir.org/sites/default/files/2020-07/2012-11-23_US%20Statement%20on%20postponement%20of%20the%202012%20conference.pdf>, accessed 24 August 2021; Ministry of Foreign Affairs of the Russian Federation, 24 November 2012, ‘Press Statement on the 2012 Conference on the Establishment of a Middle East Zone Free of Weapons of Mass Destruction’, <https://unidir.org/sites/default/files/2020-07/2012-11-24_Russian%20Statement%20on%20postponement%20of%20the%202012%20conference.pdf>, accessed 24 August 2021; UN, ‘Statement by the Secretary-General on the Convening of a Conference on the Establishment of a Middle East Zone Free of Nuclear Weapons and All Other Weapons of Mass Destruction’, 24 November 2012, <https://unidir.org/sites/default/files/2020-07/2012-11-24_Russian%20Statement%20on%20postponement%20of%20the%202012%20conference.pdf>, accessed 24 August 2021; Ministry of Foreign Affairs Finland, ‘Helsinki Middle East Conference’, press release, 24 November 2012, <https://unidir.org/sites/default/files/2020-07/2012-11-24_Facilitator%27s%20Statement%20on%20postponement%20of%20the%202012%20conference.pdf>, accessed 24 August 2021.
11. Bernd W Kubbig and Marc Finaud, ‘Bridging the Most Fundamental Gap: By Simultaneously Pursuing Disarmament and Regional Security’, Policy Forum No. 3, Academic Peace Orchestra Middle East, September 2017.
12. Eyal Propper and Shimon Stein, ‘The Biden Administration on a WMD-Free Zone in the Middle East: Implications for Israel’, INSS Insight No. 1446, Institute for National Security Studies, 24 March 2021.
13. For example, see Permanent Mission of the Islamic Republic of Iran to the United Nations Office and other International Organizations, ‘Statement by H.E. Ambassador Ali Asghar Soltanieh, Permanent Representative of the Islamic Republic of Iran at the Second Session of the Preparatory Committee of the 2015 NPT Review Conference, Cluster 2: Specific Issue - Regional Issues, Including the Middle East Nuclear Weapon Free Zone’, Geneva, 29 April 2013, <https://www.reachingcriticalwill.org/images/documents/Disarmament-fora/npt/prepcom13/statements/29April_Iran.pdf>, accessed 16 September 2021.

In 2018, frustrated by the lack of progress, the Arab states put forward a decision at the UN General Assembly, calling on the UN Secretary-General to convene a regional conference on the establishment of the MEWMDFZ.[14] This move was strongly criticised by Israel, the US and others as an attempt to force the zone issue while disagreements remained about the scope and format of such a conference among key states.[15] Subsequently, despite the absence of the US and Israel, the first MEWMDFZ conference took place in 2019 and was largely viewed as a success, with relatively realistic goals, resulting in the adoption of a political declaration reaffirming the importance of a MEWMDFZ.[16]

The Rocky Road to a MEWMDFZ

With this historical context in mind, the full range of challenges surrounding the creation of a MEWMDFZ can be better considered. These challenges can be divided into political, technical and legal categories.

Political

Regional geopolitical tensions play a major role in discourse surrounding the MEWMDFZ, with political instability, asymmetries in military capabilities, and threat perceptions and misperceptions leading to a general sense of insecurity among regional states. This insecurity can

14. UN General Assembly, 'Convening a Conference on the Establishment of a Middle East Zone Free of Nuclear Weapons and Other Weapons of Mass Destruction', Decisions 73/546, 22 December 2018, <https://unidir.org/sites/default/files/2020-06/2018-12-22_UNGA%20Decision%20to%20convene%20a%20annual%20conference%20on%20the%20ME%20WMDFZ%20is%20adopted.pdf>, accessed 17 September 2021.
15. See statement by Israel following the adoption of 73/546, First Committee 73rd UN General Assembly, 'Explanation of Vote by Mr. Ofer Moreno Director, Arms Control Department, Division for Strategic Affairs, Ministry of Foreign Affairs, Israel Action on All Draft Resolutions and Decisions Submitted Under Agenda Items', 1–9 November 2018, <https://unidir.org/sites/default/files/2020-11/2018-11_73%20UNGA%201C_ISRAEL_Exaplantion%20of%20vote.pdf>, accessed 17 September 2021. See also Preparatory Committee for the 2020 Review Conference of the Parties to the Treaty on the Non-Proliferation of Nuclear Weapons, 'Establishing Regional Conditions Conducive to a Middle East Free of Weapons of Mass Destruction and Delivery Systems: Working Paper Submitted by the United States of America', second session, Geneva, 23 April–4 May 2018, <https://unidir.org/sites/default/files/2020-06/2018-04-19_US%20working%20paper%20at%20the%202018%20NPT%20PrepCom%20elaborates%20steps%20to%20%27establish%20the%20conditions%27%20of%20a%20ME%20WMDFZ.pdf>, accessed 17 September 2021.
16. UN General Assembly, 'Report of the Conference on the Establishment of a Middle East Zone Free of Nuclear Weapons and Other Weapons of Mass Destruction on the Work of its First Session: Annex', 22 November 2019, <https://unidir.org/sites/default/files/2020-07/2019-11-22_Political%20declaration_The%20Conference%20on%20the%20Establishment%20of%20a%20Middle%20East%20Zone%20Free%20of%20Nuclear%20Weapons%20and%20Other%20WMD%20is.pdf>, accessed 17 September 2021.

be seen as both a driver and enabler of WMD acquisition in the region, since WMDs are perceived to be high-prestige weapons which strengthen national security and promote deterrence.[17]

The role of extra-regional actors in the zone process is also unclear. While the impetus to create a MEWMDFZ must come from the states of the region, it is uncertain whether meaningful progress can be made without external support, facilitation and perhaps enforcement. This is further complicated by the fact that several states, including the US, China and Russia, have strategic partners and interests in the region, influencing security dynamics, and by extension the zone process.

The legitimacy of the current MEWMDFZ conference under UN auspices could be called into question, given that a key state – Israel – is not involved in the negotiating process, potentially jeopardising the conference's long-term credibility. The question of engagement is complicated by the fact that Israel does not consider the current process to be a fair playing field. Arab states may consider this refusal to participate as a clear sign that Israel is unwilling to even discuss disarmament, while Israel believes that the MEWMDFZ is doomed to failure without serious engagement on addressing broader regional security challenges: WMDs should be addressed, but not in isolation. The addition of further complex regional security discussions on top of the already complicated zone process can result in a permanent stalemate on the issue unless the concerns of all sides are adequately addressed.

Technical

In addition to political challenges, there is some uncertainty regarding the scope of a MEWMDFZ. Officially, the geographic scope is considered to be the 22 members of the League of Arab States, Iran and Israel. It does not include Turkey, a state with extensive security interests in the region, and a US nuclear weapons host as part of NATO's nuclear sharing policy, making it difficult to see a MEWMDFZ without some Turkish involvement.[18] In terms of the scope of capabilities to be controlled by a MEWMDFZ, in addition to WMDs, means of delivery – and particularly missiles – also need to be addressed. The definition of 'means of delivery' is largely open to interpretation and could be as narrow as only in the context of means of delivery for WMDs, or more broadly to address delivery vehicles independently, both WMD-capable and conventional. For several states in the region, missiles are a significant security concern, arguably more so than WMDs, although it remains to be seen whether the MEWMDFZ context is the most appropriate forum for addressing this challenge.

Verification remains one of the most important elements of a MEWMDFZ, given the range of capabilities covered, distrust among regional states, and the regional proliferation legacy.

17. Paolo Foradori and Martin B Malin, 'A WMD-Free Zone in the Middle East: Creating the Conditions for Sustained Progress', Discussion Paper, Project on Managing the Atom, Harvard Kennedy School Belfer Center, December 2012.
18. Pierre Goldschmidt, 'A Realistic Approach Toward a Middle East Free of WMD', Carnegie Endowment for International Peace, 7 April 2016.

The role of international organisations will be key to monitoring, particularly the International Atomic Energy Agency (IAEA) and the Organisation for the Prohibition of Chemical Weapons (OPCW). However, biological weapons have no substantial international monitoring body, although there have been proposals to establish such an organisation.[19] Delivery vehicles, particularly missiles, face a similar challenge.[20] It has been suggested that for delivery systems, states can draw from Cold War-era treaties[21] to create a regional verification mechanism.[22] The ability of regional states to deceive verification regimes is also of concern. Taking a nuclear case study, Iraq had a Comprehensive Safeguards Agreement (CSA)[23] with the IAEA in 1991, while maintaining a parallel clandestine nuclear weapons development programme. This was a shock to the reliability of the safeguards concept, but the IAEA has enhanced safeguards greatly since then, particularly with the adoption of the Model Additional Protocol[24] in 1997, although the potential for future cases is still of concern. It is likely that a parallel regional monitoring body – perhaps similar to organisations such as the European Atomic Energy Community (EURATOM), or the Brazilian–Argentine Agency for Accounting and Control of Nuclear Materials (ABACC) – will need to be created to complement the work of international organisations.[25]

Legal

Compliance and enforcement of a MEWMDFZ poses an additional challenge. Trust that other states are abiding by their obligations is essential to the success of the zone, but several questions remain around who should be responsible for ensuring its integrity, and what happens in cases of non-compliance. A further challenge is the prominence of non-state actors in the region who have a significant impact on regional security dynamics but who would not be bound by the

19. J P Zanders, ‘Biological Weapons: A Surprise Proposal from Kazakhstan Worth Exploring’, *The Trench*, 6 October 2020, <https://www.the-trench.org/bw-proposal-from-kazakhstan>, accessed 17 September 2021.
20. While there are examples of missile control regimes, including the Missile Technology Control Regime (<https://mtcr.info/>) or the Hague Code of Conduct Ballistic Missile Proliferation (HCoC), these are seen as either exclusionary or not comprehensive enough, and lack adequate verification components for the purposes of a MEWMDFZ.
21. Such as the Intermediate-Range Nuclear Forces Treaty (INF), the Strategic Arms Reduction Treaty (START), and the Strategic Arms Limitation Talks (SALT).
22. Chen Kane, ‘Planning Ahead: A Blueprint to a Middle East WMD-Free Zone’, CNS Occasional Paper No. 22, James Martin Center for Nonproliferation Studies, Middlebury Institute of International Studies at Monterey, April 2015.
23. Under a Comprehensive Safeguards Agreement (CSA), a state accepts IAEA Safeguards on all nuclear material under its control, and gives the IAEA the authority to carry out monitoring and verification activities to ensure that no nuclear material is diverted to produce nuclear weapons.
24. A Model Additional Protocol builds on a CSA to provide greater monitoring and accounting of a state’s nuclear activities, allowing the IAEA to better detect undeclared nuclear activities through inspections and enhanced information-gathering activities.
25. John Carlson, ‘Nuclear Verification in a Middle East WMD Free Zone: Lessons from Past Verification Cases and Other Precedents’, UN Institute for Disarmament Research, 2021.

zone. Similar to verification, it is likely that dual-track regional and international organisations will be required.

Drawing on lessons learned from the Joint Comprehensive Plan of Action (JCPOA),[26] a robust regional dispute mechanism is required for all parties to ensure that legal, technical and political concerns are addressed in an appropriate forum.[27]

Building the Foundations for a Future MEWMDFZ

While the challenges are numerous and require significant further study and dialogue among experts and the states of the region, like any major arms agreement, political conditions and timing are essential to the long-term success of the MEWMDFZ. While the current conditions do not appear to be overly conducive to fruitful negotiations, there is a range of realistic steps that can be taken to lay a strong foundation for future processes. States of the region have the chance to build on regional developments – including the signing of the Abraham Accords, normalisation with Israel and the shifting role of external players – that may lead to greater dialogue on mutual challenges in the region.[28] Increased regional science and technology cooperation is another chance for states to enhance scientific links and development, such as the SESAME Research Centre in Jordan.[29] The establishment of regional risk reduction centres for chemical, biological, radiological and nuclear risks and disaster response would also promote scientific and technical exchanges, through the creation of centres of expertise in different countries.

Regional capacity-building is a promising area for realistic progress. Extra-regional and regional partners should work together to foster civil society dialogue around issues related to the MEWMDFZ, through education and research. Having a strong Track Two dialogue[30] will lay the groundwork for when political conditions are conducive to negotiations. Providing training and expertise across WMD issues for young people and junior diplomats from the region will ensure

26. The Joint Comprehensive Plan of Action (JCPOA) is a 2015 agreement between Iran, China, France, Russia, the UK, the US, Germany and the EU regarding Iran's nuclear activities. The deal included stringent restrictions and monitoring of Iran's nuclear activities, in return for the lifting of economic sanctions against Iran.
27. Chen Zak and Farzan Sabet (eds), 'From the Iran Nuclear Deal to a Middle East Zone? Lessons from the JCPOA for an ME WMDFZ', UN Institute for Disarmament Research, 27 May 2021.
28. This could include issues such as cross-border terrorism, criminal activities such as arms and drug trafficking, and environmental issues. While these are not directly related to the MEWMDFZ, they present an opportunity for dialogue and cooperation which might not have been previously possible.
29. SESAME, 'What is SESAME?', <https://www.sesame.org.jo/about-us/what-is-sesame>, accessed 1 September 2021.
30. Track Two diplomacy is considered to be non-official and informal negotiations, consultations and dialogue among private groups and individuals. Track One diplomacy, in contrast, involves official contact between governments and their representatives.

a level playing field and raise awareness and understanding for the next generation who will be dealing with these challenges. This can be achieved through funding and training, perhaps provided by the P5 (China, France, Russia, the UK and the US) or co-sponsors of the zone issue at the NPT. Without expertise on very complex legal, technical and political components, the zone will be impossible to negotiate.

At a political level, a number of areas need to be re-examined to strengthen efforts to establish a MEWMDFZ. The renewal of the JCPOA would be an essential building block for the zone.[31] Reimplementation of the deal would help to stabilise some regional tensions, and if successful, would allow time for negotiations and dialogue to improve relations.[32] States should also reconsider their positions on treaties such as the Comprehensive Nuclear Test Ban Treaty (CTBT) and the Chemical Weapons Convention (CWC). The regional states have no security or strategic reason to conduct nuclear tests, and if Israel, Iran and Egypt[33] were to ratify the CTBT it would give new impetus to bring the treaty into force.[34] Non-parties to the CWC, Israel and Egypt, again do not have substantial security rationale for not joining the CWC: Israel will not ratify unless Egypt does the same, while Egypt will not ratify unless Israel joins the NPT, tying chemical weapons and nuclear weapons together.[35]

Ultimately, increased dialogue on security issues will be beneficial, and hosting an ACRS 2.0-type meeting would be an excellent opportunity for states to address mutual security challenges and share security perceptions. ACRS 2.0 would help build expertise and contacts among participants and provide an appropriate forum for discussing the regional security architecture, without binding commitments. With a better understanding of the regional security landscape, states may feel better equipped to engage in parallel discussions on the MEWMDFZ. A long-term aspiration may be to consider the creation of an OSCE-type body for the region as an official forum where security issues could be discussed.

As far as the MEWMDFZ conference at the UN is concerned, the US and Israel can explore ways to re-engage with the zone process. Informal dialogue with regional partners on the issue would be a good first step, and perhaps participating as an observer at future zone conferences would be a way to show goodwill and acknowledge the process. The creation of a parallel security track, while challenging, would help to alleviate concerns that the MEWMDFZ is being

31. Tytti Erästö, ‘The Lack of Disarmament in the Middle East: A Thorn in the Side of the NPT’, Stockholm International Peace Research Institute, January 2019.
32. Longer term, it would also leave the door open for a ‘JCPOA-plus’ deal in the future, which could expand on a reimplemented JCPOA to cover other areas of concern such as missiles, which could be adapted as a model for the MEWMDFZ.
33. Israel, Iran and Egypt are Annex II states under the CTBT, meaning that their ratification is required for the treaty to enter into force.
34. Mark Fitzpatrick, ‘Steps en Route to a WMD-Free Zone in the Middle East’, Institute for International and Strategic Studies, 15 May 2019.
35. Mostafa Elwi Saif, Emily B Landau and Radwan Ziadeh, ‘Time to Ban Chemical Weapons from the Middle East?’, *Bulletin of the Atomic Scientists*, 27 February 2014.

addressed in a silo, without regard for the broader regional security landscape.[36] Attention should be paid to reframing the current debate on the zone to acknowledge that there is a joint regional responsibility to address WMDs, and without the equal participation of all states, a MEWMDFZ will be unachievable.

Conclusion

The establishment of a MEWMDFZ is one of the most complicated challenges in the history of non-proliferation, disarmament and arms control, beset by a unique host of technical, legal and political problems which makes the negotiation process particularly daunting. Despite this, a process of dialogue, engagement and mutual understanding among the states of the region could be intrinsically beneficial. Confidence-, security- and capacity-building measures are realistic steps which can create a platform for engagement among the regional states and pave the way for political progress. Even if the final goal of a MEWMDFZ may not be achievable in the near or even medium-term future, the states of the region, in cooperation with the international community, have a responsibility to lay solid foundations for negotiations as a pathway to a more peaceful, prosperous and secure Middle East for future generations.

36. Tomisha Bino, ‘A Middle Eastern WMD-Free Zone: Are We Any Closer Now?’, *Arms Control Today*, September 2020.

Section VI. Future Nuclear Technologies

XIII. Is Thorium-Based Nuclear Fuel Really Proliferation Proof?

Bhaumik Brahmbhatt

THIS PAPER EXPLORES whether thorium-based nuclear fuel is really proliferation proof. Thorium is often described as having better resistance to nuclear weapons proliferation compared to more traditional uranium-based fuel. This is because thorium is not a fissile material and therefore cannot be used directly in a weapon. The thorium fuel cycle creates Uranium-233 (U-233), a fissile isotope that can be used in weapons, but this fuel cycle also creates Uranium-232 (U-232), a highly radioactive isotope. High-energy photons from U-232 can aid in passive detection, adding to the argument that thorium is proliferation resistant. These properties will help an organisation such as the International Atomic Energy Agency (IAEA) to monitor and track nuclear fuel.[1]

However, thorium could be a greater proliferation threat than previously thought, as it is possible to chemically extract the fissile U-233 without creating U-232 in the process, therefore evading monitoring. U-233 is proven to have potential properties for weapons material, and several countries – the US, Russia and India – have all tested U-233-based devices.

This paper explores the reasoning behind thorium's alleged resistance to proliferation and examines whether there are hidden proliferation risks to its use.

Why Is There a Sudden Interest in Nuclear Energy and Thorium?

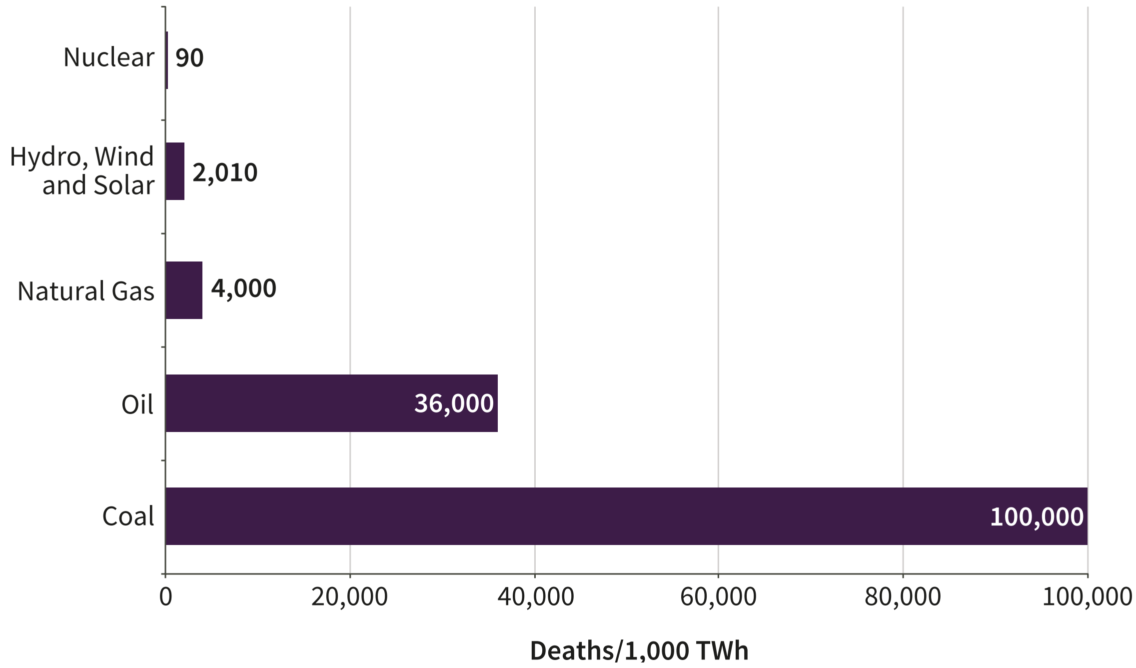
In recent years there has been increased awareness of climate change, leading to renewed attention in nuclear energy.[2] However, incidents such as Chernobyl in 1986 and Fukushima in 2011 have helped perpetuate the myth that nuclear energy is dangerous and paints it in a negative light, despite nuclear energy being one of the safest ways to produce energy.[3] As

1. Matti Tarvainen et al., 'NDA Techniques For Spent Fuel Verification and Radiation Monitoring', Radiation And Nuclear Safety Authority, Helsinki, Finland, August 1997, <https://inis.iaea.org/collection/NCLCollectionStore/_Public/29/000/29000984.pdf>, accessed 29 September 2021.
2. Nikolaus Muellner et al., 'Nuclear Energy: The Solution to Climate Change?, *Energy Policy* (Vol. 155, 2021).
3. Nicole Jawerth, 'Q&A: Public Opinion of Nuclear and Why it Matters to the Clean Energy Transition', International Atomic Energy Agency (IAEA), 15 September 2020, <https://www.iaea.

Figure 1 shows, deaths per 1,000 terawatts/hour of energy produced by nuclear energy are far fewer compared to alternative energy sources: experts therefore claim that nuclear energy is the answer to help combat rapid climate change.[4]

Figure 2 compares the amount of carbon dioxide produced per 1kWh of energy being generated for various energy sources. With regards to carbon dioxide generation, it can be seen that nuclear energy is superior to coal, natural gas and even solar. It is comparable with popular renewable energy sources. Nuclear energy also has the added benefit of being extremely reliable and does not rely on external weather environments.

Figure 1: Deaths per 1,000 TWh by Energy Source

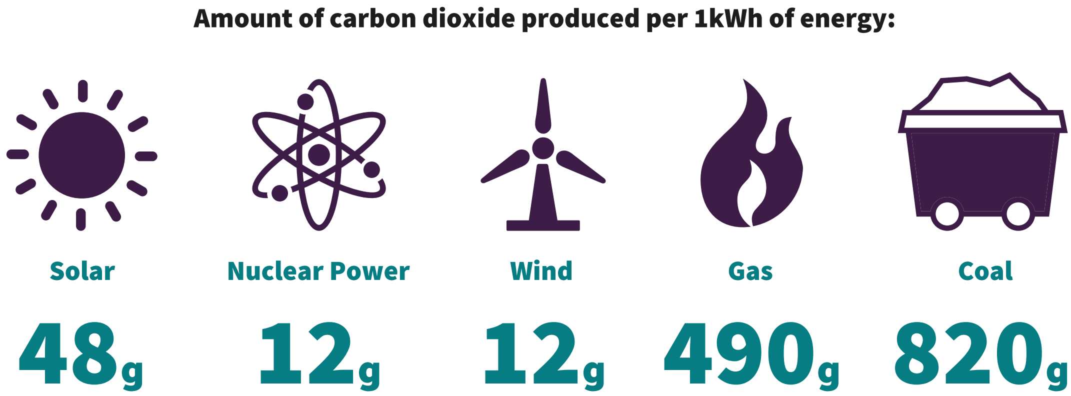


Source: Jeff Desjardins, 'The Safest Source of Energy Will Surprise You', Visual Capitalist, 10 May 2018, <https://www.visualcapitalist.com/worlds-safest-source-energy/>, accessed 14 September 2021.

org/newscenter/news/qa-public-opinion-of-nuclear-and-why-it-matters-to-the-clean-energy-transition>, accessed 14 September 2021.

4. Roger Harrabin, 'Climate Change: Is Nuclear Power the Answer?', *BBC News*, 17 January 2019.

Figure 2: CO^2 Emissions of Different Production Modes During Their Life-Cycle



Source: Teollisuuden Voima Oyj (TVO), 'Nuclear Power and Climate Change', 2019, <https://www.tvo.fi/en/index/responsibility/nuclearpowerandclimatechange.html>, accessed 14 September 2021.

In the media, thorium-based nuclear fuel is touted as 'wonder fuel',[5] 'an answer to our energy crisis'[6] and a source of 'clean energy'.[7] Thorium has recently gained much interest from the nuclear industry due to molten salt reactor (MSR) technology developments that use thorium as fuel.[8] MSRs are nuclear fission reactors and are deemed a safer option compared with light-water reactors (LWR) as they operate at atmospheric pressure. In contrast, LWRs typically operate at around 100 times atmospheric pressure. Additionally, thorium-based nuclear fuel has clear advantages over uranium-based nuclear fuel. One of the most significant advantages of the thorium fuel cycle over uranium is nuclear waste. Thorium fuel cycle waste only needs to be stored for 500 years compared with uranium fuel cycle waste, which must be stored for thousands of years. The amount of waste produced by thorium as nuclear fuel is also drastically less compared to the amount of waste produced by uranium-based nuclear fuel.[9] Thorium-based nuclear fuel also provides economic advantages over uranium-based nuclear fuel. Thorium-232, the isotope required for nuclear fuel, is extracted from mines and therefore does not require extensive extraction and refining processes, unlike uranium-based nuclear fuel. Thorium is three times as abundant as uranium. Although the availability of uranium is

5. Thomas Jam Pendersen, 'Making Safe Nuclear Power from Thorium', TEDx Talk, 15 November 2016, <https://www.youtube.com/watch?v=tHO1ebNxhVI>, accessed 14 September 2021.
6. *The Independent*, 'Is Thorium the Answer to Our Energy Crisis?', 13 December 2006.
7. Kirk Sorensen, 'Thorium Can Give Humanity Clear, Pollution Free Energy', TEDxTalk, 8 January 2015, <https://www.youtube.com/watch?v=kybenSq0KPo>, accessed 14 September 2021.
8. M W Rosenthal, P R Kasten and R B Briggs, 'Molten-Salt Reactors – History, Status, and Potential', Oak Ridge National Laboratory, revised 10 October 1969, <https://www.moltensalt.org/references/static/downloads/pdf/NAT_MSRintro.pdf>, accessed 14 September 2021.
9. Marin Katusa, 'The Thing About Thorium: Why the Better Nuclear Fuel May Not Get a Chance', *Forbes*, 16 February 2012.

not an issue, the world's population and corresponding energy demands are growing rapidly.[10] At present, nuclear energy amounts to 2–3% of the world's annual energy demand. Therefore, alternative fuel sources need to be explored and researched. Thorium is a prime candidate.

Proliferation Resistance

There are three main arguments as to why thorium is often described as having better resistance to nuclear weapons proliferation: 1. thorium itself is not a fissile material; 2. extraction of U-233 from spent fuel is hard; and 3. the existence of U-232 makes it easier to trace the spent fuel.

1. Thorium itself is not a fissile material, so thorium cannot be directly used to produce nuclear weapons. This also means thorium itself does not produce any energy in a nuclear reactor. Thorium-232, a non-fissionable material, needs to be converted into fissionable material to produce energy. Figure 3 shows this fuel cycle. Within the cycle, Thorium-232 absorbs a neutron, n, which creates Thorium-233. Thorium-233 is unstable and decays into Protactinium-233 within 22 minutes via beta decay (when an atom loses an electron). Protactinium-223 has a half-life of roughly 27 days. Therefore, Protactinium-233 decays into U-233 via beta decay. U-233 is fissile material; therefore, it can be used to create energy and nuclear weapons.

Figure 3: Thorium Fuel Cycle

$$ {}^{232}_{90}Th + n \rightarrow {}^{233}_{90}Th \xrightarrow{\beta\ \text{decay}} {}^{233}_{91}Pa \xrightarrow{\beta\ \text{decay}} {}^{233}_{92}U $$

Source: Author generated.

2. Thorium-based nuclear reactors use the thorium fuel cycle to create fissile material, U-233, and this fissile material is used to generate energy. The fissile material, U-233, can still be present in the thorium-based nuclear reactor spent fuel, but it is not easy to reprocess and extract U-233 from these fuels. These processes require significant infrastructure, which can be easily detected. This adds to the argument that thorium-based nuclear fuel has better resistance to nuclear weapons proliferation.

10. Emily Bobruff, 'Population Growth and Sustainability', Mathematics of Sustainability, 23 September 2018, <https://muse.union.edu/mth-063-01-f18/2018/09/23/population-growth-and-sustainability/>, accessed 14 September 2021.

Figure 4: Different Ways Uranium-232 Is Created Within the Thorium Fuel Cycle

$$\text{A: } {}^{232}_{90}Th \xrightarrow{+\,n} {}^{233}_{90}Th \xrightarrow{\beta\text{ decay}} {}^{233}_{91}Pa \xrightarrow{\beta\text{ decay}} {}^{233}_{92}U \xrightarrow{+\,n\,-\,2n} {}^{232}_{92}U$$

$$\text{B: } {}^{232}_{90}Th \xrightarrow{+\,n} {}^{233}_{90}Th \xrightarrow{\beta\text{ decay}} {}^{233}_{91}Pa \xrightarrow{+\,n\,-\,2n} {}^{232}_{91}Pa \xrightarrow{\beta\text{ decay}} {}^{232}_{92}U$$

$$\text{C: } {}^{232}_{90}Th \xrightarrow{+\,n\,-\,2n} {}^{231}_{90}Th \xrightarrow{\beta\text{ decay}} {}^{231}_{91}Pa \xrightarrow{+\,n} {}^{232}_{92}Pa \xrightarrow{\beta\text{ decay}} {}^{232}_{92}U$$

Source: Author generated.

3. The fact that U-232 is created within the thorium fuel cycle adds to the argument as to why thorium-based nuclear fuel has better proliferation resistance compared with uranium-based nuclear fuel. There are three different ways U-232 can be created within the thorium fuel cycle (Figure 4). U-232 is created by an n-2n reaction within the thorium fuel cycle. The n-2n is a nuclear reaction, and this is when an atom absorbs a neutron; however, it loses two neutrons. Figure 4 shows how this n-2n reaction can occur at a different stage of the thorium fuel cycle to create U-233. U-232 is an isotope of uranium with a half-life of 68.9 years and highly radioactive properties, emitting high-energy photons. These high-energy photons can aid in passive detection and require significant shielded facilities, meaning it would be challenging to make improper use of the spent fuel for 68.9 years.

Proliferation Concerns

Regarding proliferation concerns, thorium could be a greater proliferation threat than previously thought. It is possible to chemically extract the fissile U-233 without creating U-232 in the process, therefore evading monitoring and increasing the risk of proliferation of nuclear weapons.[11] This chemical process involves extracting Protactinium-233 from spent fuel rather than extracting U-233 (Figure 3). The U-233 is proven to have potential properties for nuclear weapons. The US tested a U-23-based nuclear device in 1955 as part of Operation *Teapot*, a series of 14 nuclear test explosions at the Nevada Test Site.[12] India also tested a U-233-based

11. Stephen F Ashley et al., ‘Thorium Fuel Has Risks’, *Nature* (Vol. 492, 2012), pp. 31–33.
12. Nuclear Weapons Archive, ‘Operation Teapot: 1955 – Nevada Proving Ground’, last modified 15 October 1997, <http://nuclearweaponarchive.org/Usa/Tests/Teapot.html>, accessed 14 September 2021.

nuclear device in Shakti V, the fifth of five nuclear bomb tests that were part of Operation *Shakti* in 1998.[13]

The half-life of roughly 27 days for Protactinium-233 can complicate the extraction of U-233 as the U-233 would need to be processed quickly. The extraction of Protactinium-233 does not require bespoke facilities, tools or equipment; standard nuclear lab equipment – including a hot cell – is sufficient to successfully extract pure Protactinium-233, which later can be decayed into pure U-233 with minimal impurities. The equipment in these nuclear labs is not necessarily subject to IAEA safeguards; therefore, a civil nuclear energy facility can be used for dual purposes.

There are two tried-and-tested processes: the acid-media technique;[14] and liquid bismuth reductive extraction.[15]

1. The acid-media technique uses manganese dioxide to precipitate the protactinium as protactinium oxide.[16] Any U-232 created during the process (see Figure 4) is dissolved in acid and removed during the precipitation.[17] The extensive quantity of material handling during this technique can be complex as Protactinium-233 produces 50 watts of heat per gram from beta decay.[18] The properties of this material pose a significant challenge to develop the necessary tools, pieces of equipment and processes for handling a large quantity of Protactinium-233. Therefore, it would also be challenging to develop this technique on an industrial scale.
2. Due to developments within molten salt reactors, the liquid bismuth reductive extraction technique has gained renewed interest. This process was first suggested in 1972 by Oak Ridge National Laboratory and involved using high-temperature oxidation-reduction reactions.[19] At the start of the process, fluorination and then extraction is completed using molten bismuth to obtain Protactinium-233. This technique is more complex than the acid-media technique. However, either of these techniques can be used in small batches to accumulate Protactinium-233.[20] Once Protactinium-233 is extracted, it can

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13. *Times of India*, 'Forces Gung-Ho on N-Arsenal', 28 August 2009, <https://web.archive.org/web/20130521000616/http:/epaper.timesofindia.com/Repository/ml.asp?Ref=VE9JTS8yMDA5LzA4LzI4I0FyMDE1MDA>, accessed 14 September 2021.
14. J W Codding et al., 'Separation and Purification of a Gram of Protactinium-233', Commission Report IDO 17007, Atomic Energy Division, Phillips Petroleum Company, 1964.
15. L E McNeese, L M Ferris and E L Nicholson, 'Molten-Salt Breeder Reactor Fuel Processing', Technical Report No. CONF-720522-3, Oak Ridge National Laboratory, 1972, <https://www.osti.gov/servlets/purl/4628558>, accessed 14 September 2021.
16. Leonard I Katzin and Raymond W Stoughton, 'A Manganese-Dioxide Procedure for Isolation and Concentration of Protactinium from Irradiated Thorium Compounds', *Journal of Inorganic and Nuclear Chemistry* (Vol. 3, Nos. 3–4, 1956), pp. 229–32.
17. *Ibid.*
18. Codding et al., 'Separation and Purification of a Gram of Protactinium-233'.
19. McNeese, Ferris and Nicholson, 'Molten-Salt Breeder Reactor Fuel Processing'.
20. Stephen F Ashley et al., 'Thorium Fuel Has Risks', *Nature* (Vol. 492, 2012), pp. 31–33.

be stored separately and will decay into pure U-233, a fissile material that can be used to create nuclear weapons.

Conclusion

In summary, thorium-based nuclear fuel has clear advantages over uranium-based nuclear fuel. Thorium-based nuclear fuel is more economical, produces less toxic nuclear waste with a low half-life while producing the same amount of energy, helps tackle climate change challenges, and is three times more abundant compared to uranium-based nuclear fuel. However, thorium is not the ‘wonder fuel’ as it is touted in some media. The language used during the discussion of thorium needs to be changed, and a more significant debate and research are required to understand the proliferation risk attached to thorium-based technology.

Although thorium-based nuclear technology is deemed to have better resistance to proliferation than uranium-based nuclear technology, thorium-based nuclear technology still poses a proliferation risk as it is possible to extract and produce fissile material for nuclear weapons. Such dual-purpose capability can be used to produce enough material for nuclear weapons within a year by accumulating small batches of fissile material.

All nuclear technology has a proliferation risk. Regardless of the state’s capability and infrastructure, a state may choose to proliferate nuclear technology out of political necessity and imperatives. Proliferation is a political issue, and therefore it needs to have a political solution.

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XIV. Nuclear Propulsion in the UK: Can the UK Accelerate Humans Towards Colonising Mars?

Sam Brass, Rebecca Desmond, Jennifer Edwards, Myles Johnson and Dougal McDonald – Lockheed Martin UK

Shyam Sikotra – Rolls-Royce

NUCLEAR PROPULSION FOR spacecraft technology was first demonstrated in the 1950s,[1] promising fuel efficiencies far greater than the chemical rocket thrusters that have been used for launches.[2] Recent advances in launcher capabilities, particularly in the heavy lift category,[3] have enabled the possibility of initiating the construction of permanent settlements on the Moon and Mars within the next decade.[4] The UK has become a world leader in the development of advanced nuclear power sources in recent years, from Rolls-Royce's

1. W H Esselman, 'The NERVA Nuclear Rocket Reactor Program', *Westinghouse Engineer* (Vol. 25, No. 3, 1965), pp. 66–75, <https://www1.grc.nasa.gov/wp-content/uploads/NERVA-Nuclear-Rocket-Program-1965.pdf>, accessed 2 August 2021.
2. Stanley K Borowski, David R McCurdy and Thomas W Packard, 'Nuclear Thermal Propulsion (NTP): A Proven, Growth Technology for "Fast Transit" Human Mission to Mars', NASA, October 2014, <https://ntrs.nasa.gov/api/citations/20140013259/downloads/20140013259.pdf>, accessed 2 August 2021; International Atomic Energy Agency (IAEA), *The Role of Nuclear Power and Nuclear Propulsion in the Peaceful Exploration of Space* (Vienna: IAEA, 2005); Michael G Houts et al., 'NASA's Nuclear Thermal Propulsion (NTP) Project', American Institute of Aeronautics and Astronautics, July 2015, <https://ntrs.nasa.gov/api/citations/20150016484/downloads/20150016484.pdf>, accessed 2 August 2021.
3. A heavy lift launch vehicle is defined as being capable of lifting over 20 metric tonnes of payload to Low Earth Orbit.
4. SpaceX, 'Starship User's Guide', Revision 1.0, March 2020, <https://www.spacex.com/media/starship_users_guide_v1.pdf>, accessed 2 August 2021; NASA, 'Artemis Plan: NASA's Lunar Exploration Program Overview', September 2020, <https://www.nasa.gov/sites/default/files/atoms/files/artemis_plan-20200921.pdf>, accessed 2 August 2021.

modular reactors[5] to the National Nuclear Laboratory's use of Americium-241.[6] This joint Lockheed Martin UK/Rolls-Royce paper explores the capabilities of a UK-designed[7] nuclear-powered transportation system for colonising Mars faster, more safely and in larger numbers than conventional chemical systems in development.

The use of a nuclear propulsion system for fast transit to Mars has been identified in previous research as a driving mechanism in reducing a human crew's long-term exposure to harmful cosmic radiation and micro-gravity-related physical and psychological strain.[8] Additionally, nuclear solutions may enable a greater payload to be transferred to the Martian surface in a single mission.[9]

The most promising technologies are nuclear thermal propulsion (NTP) and nuclear electric propulsion (NEP), which both harness fission reactor technologies. Thermal engines heat up propellants and expand them through a nozzle to generate thrust and can provide significantly more power over a shorter lifetime. Electrical engines generate electricity from their reactor and typically use ion thrusters to provide more than double the specific impulse than NTP.[10] NEP power sources also provide the versatility to produce energy on the Martian surface, which may be used on a manned base, for example.

This paper compares the performance of an NTP engine with a Rolls-Royce nuclear power source against an existing chemical system, exploring the benefits of a UK sovereign nuclear

5. Power stations using small modular reactors will be 20% of the size of traditional nuclear power stations, as 75% of their design (by cost) is modular and reactors are small enough to be transported by truck, train or barge. See Rolls-Royce, 'Small Modular Reactors – Once in a Lifetime Opportunity for the UK', July 2017, <https://www.rolls-royce.com/~/media/Files/R/Rolls-Royce/documents/customers/nuclear/smr-brochure-july-2017.pdf>, accessed 2 August 2021.
6. Am-241 is a by-product of nuclear energy production which is often disposed of as waste. The National Nuclear Laboratory are using these by-products to develop space-faring radioactive power sources for the European Space Agency. See National Nuclear Laboratory, 'New Contract for NNL to Progress Space Battery Work', October 2020, <https://www.nnl.co.uk/blog/2020/09/28/new-contract-for-nnl-to-progress-space-battery-work/>, accessed 2 August 2021.
7. The study focused on the top-level future uses of nuclear power sources in space, including propulsion and energy generation on spacecraft and lunar or Martian bases. See UK Space Agency, 'Rolls-Royce and UK Space Agency Launch Study into Nuclear-Powered Space Exploration', 12 January 2021, <https://www.gov.uk/government/news/rolls-royce-and-uk-space-agency-launch-first-ever-study-into-nuclear-powered-space-exploration>, accessed 2 August 2021.
8. Nilvarna et al., 'Fast Transit: Mars & Beyond. International Space University Space Studies Program', 2019, <https://isulibrary.isunet.edu/doc_num.php?explnum_id=1658>, accessed 2 August 2021.
9. Borowski, McCurdy and Packard, 'Nuclear Thermal Propulsion (NTP)'.
10. T A Bond and J A Christensen, 'NSTAR Ion Thrusters and Power Processors', NASA, November 1999, <https://ntrs.nasa.gov/api/citations/20000003023/downloads/20000003023.pdf>, accessed 2 August 2021.

solution. This was achieved by identifying optimal Earth–Mars transfer windows for a 2035 cargo mission and 2037 human mission. The research then simulated the corresponding trajectories using commercial mission analysis software. The results for critical mission parameters such as payload capacity, transfer time and crew radiation dose indicate significant improvements over existing chemical propulsion systems. Due to the modelling assumptions made, NEP engines were excluded from this study.

Why Nuclear Propulsion Systems?

Nuclear propulsion systems are beneficial for long-duration space missions due to having reactor lifespans over 10 years[11] and that they can operate far from the Sun, unlike solar electric propulsion systems. Before the Apollo programme achieved its goal of landing humans on the moon in the 1960s, nuclear propulsion was already of interest to NASA as a potentially superior method for deep space transportation systems. During the 1950s and 1960s, the Los Alamos Scientific Laboratory in New Mexico conducted a technology demonstrator programme called the Nuclear Engine for Rocket Vehicle Applications (NERVA). This prototype successfully demonstrated, through over 20 static fires, that NTP could produce twice the thrust per unit mass of propellant than chemical counterparts.[12]

In the last few years, Blue Origin, Lockheed Martin, General Atomic and Ad Astra have signed contracts to develop flight prototypes for both NTP and NEP, each aiming to demonstrate the viability of these technologies before the end of the 2020s.[13]

Given this recent surge in activity, nuclear space power represents a significant opportunity for the UK to grow a strategic national capability in space-based systems, technologies, science and applications. The benefits might include new exports, the creation of skilled jobs across the UK and new value-adding products in the space domain. Rolls-Royce and the UK Space Agency have recently created a development roadmap for a national programme that would allow the UK to become an indispensable player in the space industry.[14]

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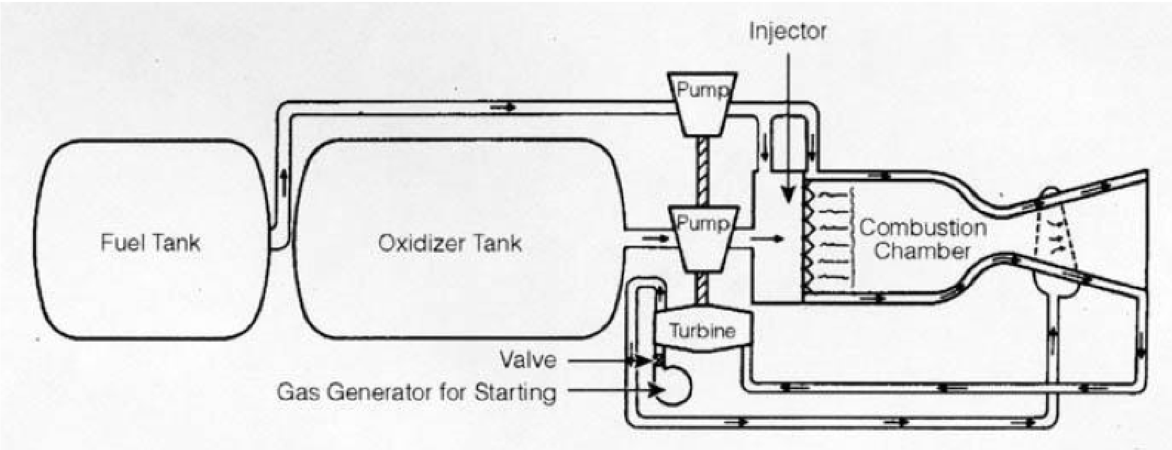
11. IAEA, *The Role of Nuclear Power and Nuclear Propulsion in the Peaceful Exploration of Space*.
12. Esselman, 'The NERVA Nuclear Rocket Reactor Program'.
13. Kate Duffy, 'Jeff Bezos' Blue Origin Lands a Pentagon Contract to Design a Nuclear-Powered Spacecraft', *Insider*, 13 April 2021; Chris Gebhardt, 'NASA Awards Contracts for Deep Space Advanced Propulsion Systems', NASA Spaceflight, 23 November 2015, <https://www.nasaspaceflight.com/2015/11/nasa-awards-contracts-deep-space-advanced-propulsion-systems/>, accessed 2 August 2021.
14. UK Space, 'Rolls-Royce and UK Space Agency Launch First Ever Study into Nuclear-Powered Space Exploration', 12 January 2021, <https://www.ukspace.org/rolls-royce-and-uksa-launch-first-study-into-nuclear-powered-space-exploration/>, accessed 2 August 2021.

Propulsion Systems Overview

Conventional Chemical Propulsion

In a traditional chemical rocket, an engine burns liquid or solid fuel in the presence of an oxidiser to generate thrust. A schematic of a chemical rocket is shown in Figure 1. These rockets produce high thrust but only operate for a short amount of time and, therefore, have a low specific impulse. Specific impulse is the thrust produced per unit rate of consumption of the propellant and is a measure of efficiency of a propulsion system. These specific impulses are lower than that of nuclear thermal or nuclear electric propulsion engines.[15]

Figure 1: Conventional Rocket Engine Schematic



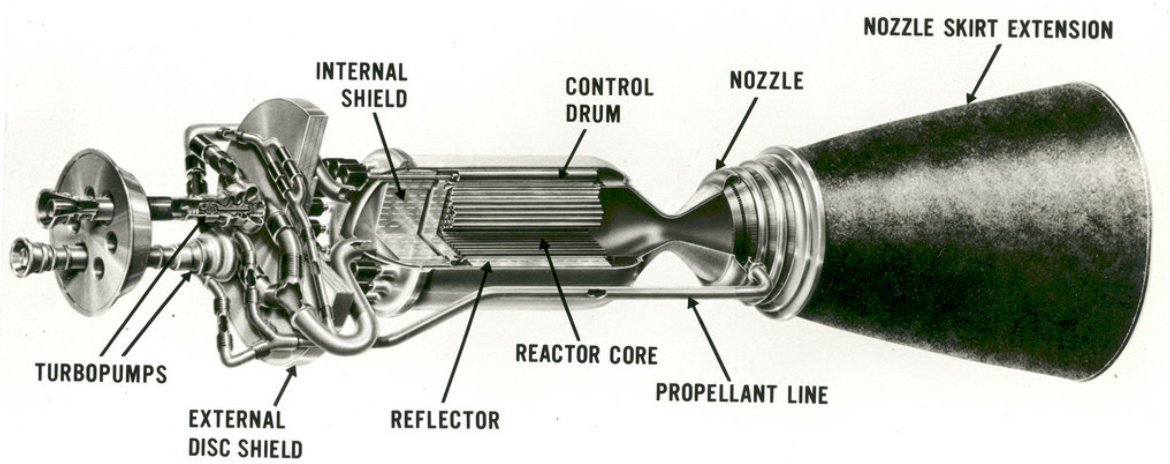
Source: T A Heppenheimer, 'The Space Shuttle Decision: Chapter 1: Space Stations and Winged Rockets', National Space Society, 1999, <https://space.nss.org/the-space-shuttle-decision-chapter-1/>, accessed 2 August 2021.

Nuclear Thermal Propulsion (NTP)

In NTPs, the thermal energy from a nuclear reactor is used directly to heat a propellant into an ionised gas which is then expanded through a nozzle to generate high levels of thrust, a schematic of which is shown in Figure 2. There is no need for the propellant to be combustible, eliminating the need to carry heavy oxidisers. Light propellants offer the greatest efficiency; thus, hydrogen is usually selected, although other gases such as helium, ammonia or CO_2 have also been proposed.

15. IAEA, *The Role of Nuclear Power and Nuclear Propulsion in the Peaceful Exploration of Space*.

Figure 2: Nuclear Thermal Propulsion System Schematic

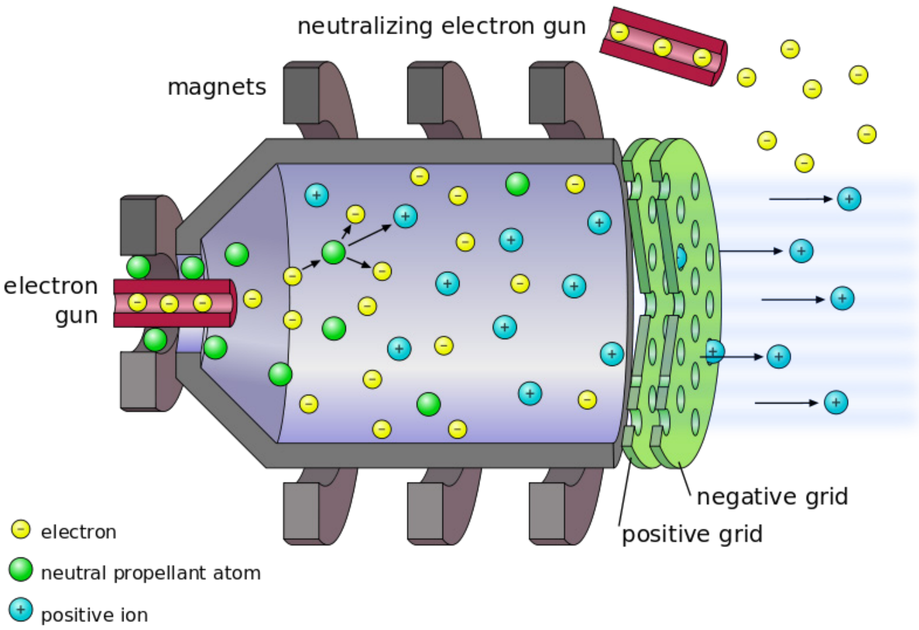


Source: Stanley K Borowski, David R McCurdy and Thomas W Packard, 'Nuclear Thermal Propulsion (NTP): A Proven, Growth Technology for "Fast Transit" Human Mission to Mars', NASA, October 2014, <https://ntrs.nasa.gov/api/citations/20140013259/downloads/20140013259.pdf>, accessed 2 August 2021.

Nuclear Electric Propulsion (NEP)

An NEP system incorporates a reactor plant and power conversion system to ionise and/or accelerate a propellant at high speeds to produce thrust. This is achieved by applying electric fields, currents and/or magnetic fields. Typical propellants used in these systems are inert gases such as xenon or krypton. Figure 3 shows a gridded ion thruster which generates thrust. A positively charged stream of ions is produced in an ionisation chamber and then accelerated through a nozzle. A stream of electrons is added to the propellant as it leaves the spacecraft to prevent the build-up of negative charge on the grid.

Figure 3: Gridded Ion Thruster Schematic



Source: Joel Hruska, 'New Kickstarter Ion Thruster Would Speed Space Exploration Using Nanosatellites', Extreme Tech, 8 July 2013, <https://www.extremetech.com/extreme/160630-new-kickstarter-ion-thruster-would-speed-space-exploration-using-nanosatellites>, accessed 2 August 2021.

There are several benefits of NEP over chemical propulsion, including a significant reduction in mass of propellant required, low system unit cost, and the ability to generate thrust over a long period of time, resulting in higher possible travel speeds.[16] However, the acceleration generated by NEP systems is much less than that through conventional chemical propellant systems, so they are not suitable for high-impulse manoeuvres such as launch or escape from Earth's gravitational field.

Physiological Effects of Spaceflight

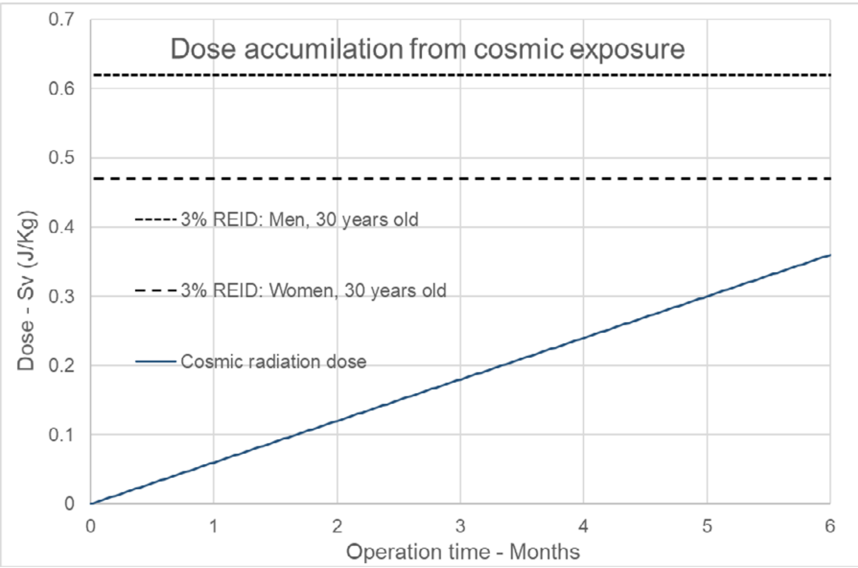
The potential to reduce the inter-planetary transfer time presents a significant benefit from a health perspective via a reduced cosmic radiation dose and a reduced occupation in a microgravity environment. The crew's proximity to a nuclear reactor, however, clearly presents its own challenges, but optimisation of the structure, including fuel tank placement and disk shielding, can significantly reduce the health risk (by 20x or more).[17]

16. R Joseph Cassady et al., 'Recent Advances in Nuclear Powered Electric Propulsion for Space Exploration', *Energy Conversion and Management* (Vol. 49, No. 3, 2007), pp. 412–35.
17. D R Rogers, E A Warman and B A Lindsey, 'Radiation Environment for Rendezvous and Docking with Nuclear Rockets', NASA, January 1972, <https://ntrs.nasa.gov/api/citations/19720009984/downloads/19720009984.pdf>, accessed 2 August 2021.

The contribution of cosmic radiation is greatest outside the protection of the Earth's magnetic field which extends out to altitudes of 25,000 miles.[18] At this altitude, astronauts are exposed to increased high-energy galactic cosmic radiation, as well as an increased risk of solar particle events.[19] Ionising radiation from solar or deep space sources has been described as the most significant barrier to deep space missions.[20]

NASA regulates the levels of radiation exposure their astronauts may receive during operation, and a cumulative career dose is not to exceed a 3% risk of exposure-induced death (REID) (from terminal cancers) predicted to a 95% confidence level.[21] These 3% REID levels vary with age and gender, and for a 30-year-old individual, these are stated as 620 millisievert (mSv) for a male and 470mSv for a female. The estimated average 2mSv cosmic dose per day results in this career-long limit being neared by six months of transit time alone, as illustrated in Figure 4.

Figure 4: Cosmic Radiation Dose Accumulation



Source: Lockheed Martin UK Ampthill.

18. Charles W Lloyd, Scott Townsend and Katherine K Reeves, 'Space Radiation', eBook, NASA, undated, <https://www.nasa.gov/sites/default/files/atoms/files/space_radiation_ebook.pdf>, accessed 2 August 2021.
19. Nilvarna et al., 'Fast Transit'.
20. Kira Bacal and Joseph Romano, 'Radiation Health and Protection', *Space Physiology and Medicine*, 15 December 2016, <https://link.springer.com/chapter/10.1007%2F978-1-4939-6652-3_7>, accessed 2 August 2021.
21. Francis A Cucinotta, 'Radiation Risk Acceptability and Limitations', Space Radiation Program Element, NASA Johnson Space Center, December 2010, <https://three.jsc.nasa.gov/articles/AstronautRadLimitsFC.pdf>, accessed 2 August 2021.

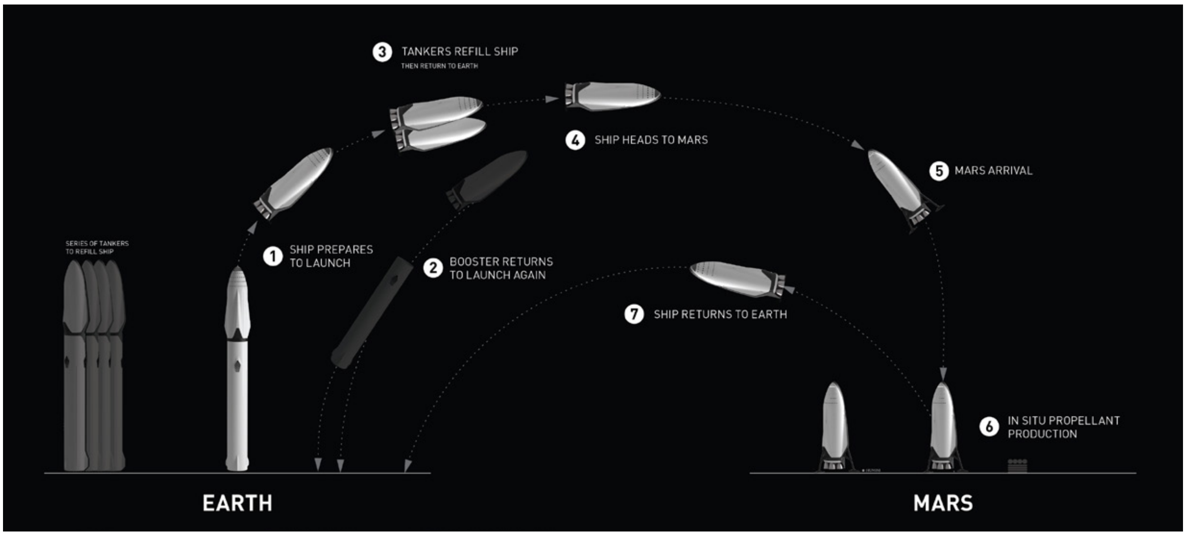
Modelling Methodology

The purpose of the research for this paper is to quantitatively compare the top-level differences between a 2035 cargo mission and a 2037 human mission to Mars using conventional and NTP systems. The following parameters, along with justifications, were selected as the most significant for each mission.

- Payload mass capacity to Martian surface, kg (cargo mission). Maximising the mass of scientific equipment transported per flight.
- Interplanetary transit time, days (crewed mission). Minimising the crew's time spent in close confinement, enabling longer stays on the Martian surface.
- Cosmic radiation dose, mSv (crewed mission). Minimising the health risk on the crew and passengers.

A baseline conventional case was derived using open-source data for the Starship vehicle currently in development by SpaceX. Figure 5 illustrates a typical mission profile.

Figure 5: Typical Starship Mars Mission Profile



Source: SpaceX, 'Making Life Multiplanetary', 2016, <https://www.spacex.com/media/making_life_multiplanetary_2016.pdf>, accessed 2 August 2021.

Given that the interplanetary transfer phase (Step 4) has the longest duration, typically in the order of months, a quantitative comparison between systems was focused on this step. This research, therefore, assumed that both conventional and nuclear-powered missions would use a Starship vehicle structure but differ in engine and propellent type, performing a one-way Earth–Mars journey only.

Table 1 outlines the properties which were kept constant across these missions.

Table 1: Vehicle Parameters Common to Conventional and Nuclear Cases

Property	Value	Units
Vehicle Structural Mass	150,000	kg
Passenger Capacity	100	pax
Total Propellant Volume (Derived)	43,860	m^3
Propellant Tank Pressure	6.0	bar
Fuel Safety Reserve (For Orbital Corrections)	10	%
Passenger Mass*	1,000	kg/pax

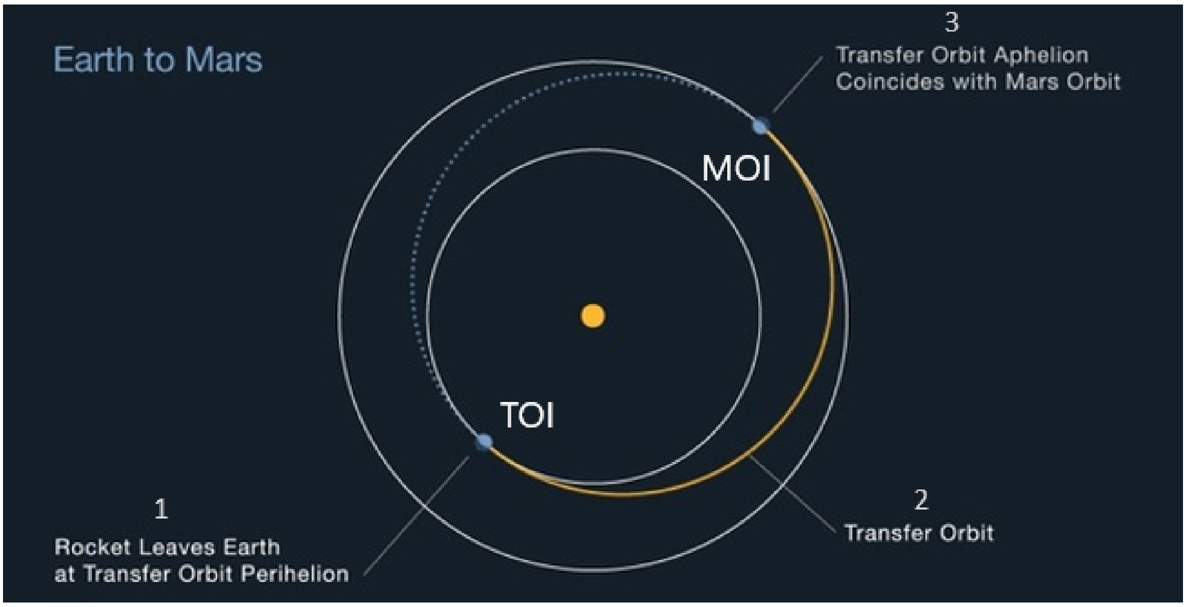
** Includes supplies and luggage.*

Source: Elon Musk, 'Making Humans a Multi-Planetary Species', New Space *(Vol. 5, No. 2, 2017), p. 54.*

Launch windows were examined using NASA's online Trajectory Browser tool,[22] which solves the Lambert Problem to determine the time of flight between two points on an orbit.[23] The spacecraft velocity changes required to perform a transfer orbital insertion (TOI) manoeuvre and a Martian orbit insertion (MOI) manoeuvre were then obtained from the tool. These were performed at the start and end of the transfer, as shown in Figure 6.

22. NASA Ames Research Center, 'Trajectory Browser', July 2019, <https://trajbrowser.arc.nasa.gov/traj_browser.php>, accessed 2 August 2021.
23. The Lambert Problem is concerned with the determination of the properties of an orbit based on two position vectors from the focus and the time of flight between them. See Howard D Curtis, *Orbital Mechanics for Engineering Students*, 3rd Edition (Oxford: Elsevier, 2014), pp. 247–58.

Figure 6: Earth–Mars Interplanetary Manoeuvres



Source: Lockheed Martin UK Ampthill.

The mass of propellant required to perform each manoeuvre was calculated using equations by Howard D Curtis, available in the literature.[24] The trajectories were then simulated using NASA's General Mission Analysis Tool open-source software.

The analysis required an assumption that manoeuvres were impulsive, meaning changes in velocity occurred instantaneously. This was valid for conventional and NTP cases due to high thrust outputs resulting in burn times in the order of minutes. However, it would not hold for NEP, which require months to induce the same velocity changes. This study was therefore limited to conventional and NTP cases, assuming a vacuum SpaceX Raptor engine[25] against an NTP system with fission reactor core parameters provided by Rolls-Royce.

Model inputs for the conventional and NTP propulsion systems are outlined in Table 2.

24. Curtis, *Orbital Mechanics for Engineering Students*, pp. 619–30.
25. This engine was selected as it is used on Starship to perform manoeuvres in a vacuum.

Table 2: Model Inputs

Property	Conventional	NTP
Propellant Type	Methane/Oxygen	Hydrogen
Storage Temperature (°C)	-180/-207	-251
Propellant Capacity (kg)	1,100,000	290,000
Propellant Flow Rate (kg/s)	650	34
Specific Impulse (s)	380	900

Source: Musk, 'Making Humans a Multi-Planetary Species'; Esselman, 'The NERVA Nuclear Rocket Reactor Program'.

Modelling Results

2035 Cargo Mission

This case aimed to maximise the mass of payload delivered to the Martian surface in a single mission. Achieving this would enable the equipment and supplies required to build a colony on the planet to be delivered in as few flights as possible. This was accomplished by minimising propellant consumption, hence minimising the change in velocity required to perform the transfer. The trajectory in Table 3 was calculated as it required the minimum total velocity change.

Table 3: 2035 Cargo Mission Results

Property	Conventional	NTP	Units
Earth Departure Date	26 June 2035		-
TOI Spacecraft Velocity Change	3,650		m/s
Mars Arrival Date	20 January 2036		-
MOI Spacecraft Velocity Change	660		m/s
Total Spacecraft Velocity Change	4,310		m/s
Transfer Duration	208		days
Payload to Surface	**195,000**	**236,000**	**kg**

Source: Lockheed Martin UK Ampthill.

For this trajectory, the NTP engines increased the maximum payload to surface by 21%.

2037 Crewed Mission

The aim of this case was to minimise the transfer time of Starship when at capacity, transporting 100 passengers as fast as possible to mitigate the detrimental health effects caused by microgravity and radiation. Assuming the average mass of each passenger and their supplies was equal to the value in Table 1, the maximum spacecraft change in velocity was calculated for each propulsion type, producing the trajectory results shown in Table 4.

Table 4: 2037 Crewed Mission Results

Property	Conventional	NTP	Units
Earth Departure Date	03 September 2037	19 September 2037	-
TOI Spacecraft Velocity Change	4,030	4,520	m/s
Mars Arrival Date	14 March 2038	26 February 2038	-
MOI Spacecraft Velocity Change	930	1,350	m/s
Total Spacecraft Velocity Change	4,960	5,870	m/s
Transfer Duration	**192**	**160**	**days**
Cosmic Radiation Dose	**384**	**320**	**mSv**

Source: Lockheed Martin UK Ampthill.

The total velocity change offered by the NTP engines was 19% larger than using conventional engines, resulting in a 17% faster transfer time.

The cosmic radiation dose in the conventional case approached the acceptable limit for 30-year-old females (see Figure 4). The dose was reduced slightly in the NTP case, but it would still not be acceptable when factoring in a return journey. If the assumption of equal fuel volume between cases was replaced with equal fuel mass, the NTP transfer time could be reduced to 112 days, reducing the dose to 224mSv. These times are likely to be possible since the spacecraft geometry would be optimised for the NTP system, rather than simply using the Starship structure as assumed here.

Conclusions

The aim of this paper was to compare the performance of conventional and nuclear space propulsion systems for cargo and human missions to Mars. Given the assumptions made and the example trajectories considered, the research identified the following:

1. The 2035 cargo mission showed that NTP increased the maximum payload to the Martian surface by 21%.
2. The 2037 manned mission showed that NTP decreased the Earth–Mars transfer time by 17%.
3. The reduction in transfer time reduced the crew's exposure to cosmic radiation but still resulted in an unacceptable dose for two-way journeys. A real mission would likely reduce the transfer time further, allowing the dose to drop within 3% REID limits.

About the Authors

Jonathan Balakumar has a Master's in Systems Engineering from Loughborough University and joined Lockheed Martin as a Graduate Engineer straight out of university, and now works as a Systems Engineer at Thales. He has gained a wide range of experience and knowledge in various fields of study, including civil and military space, armoured fight vehicles, mission support, and internal research and design. His exposure to the military space has sparked his interest in hypersonic vehicles which inspired him to co-author last year's PONI paper, 'Hypersonic Glide Vehicles: Stopping the Unstoppable'. He is keen to further broaden his knowledge and skills in this area.

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ERC Towards a Third Nuclear Age project and is working on a book critiquing the technological determinism underpinning predictions of a US–China arms race in outer space.

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