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Understanding Nuclear Weapon Risks

John Borrie, Tim Caughley and Wilfred Wan
Editors

UNIDIR RESOURCES

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John Borrie, Tim Caughley, and Wilfred Wan
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Foreword

Over the last several years, international attention on the impacts of the detonation of nuclear weapons in populated areas has arguably been at its most intense since the depths of the Cold War. It has prompted renewed investigation into the consequences of use—such as the likely inability of the United Nations-led humanitarian response system and the Red Cross and Red Crescent Movement to adequately assist victims of nuclear detonations. In the process, the world has been reminded of the continued presence of large nuclear arsenals, including a proportion still on 'hair-trigger' alert.

Irrespective of differences in how States perceive nuclear weapons, it is apparent that a closer understanding of the components of risk surrounding the safety and security of nuclear weapons is warranted—with a view to reducing the probability of nuclear detonation events. Given the enormous lethality of nuclear arms and their potential for global disruption, all States share an interest in prevention, something the President of the International Committee of the Red Cross noted in late 2015.[1]

In 2017, a facts-based discourse that engages the broader international community on reducing nuclear risks has never been more important. This publication and a symposium presenting its findings to multilateral policy practitioners on 10 April 2017 are intended to contribute to such dialogue.

This work is in keeping with UNIDIR's Mandate from the United Nations General Assembly to promote informed participation by all States in disarmament efforts. It will provide the international community with more diversified and complete data on problems relating to international security, the armaments race, and disarmament in the nuclear field. Without the generous support of the Governments of Norway, Sweden, and Switzerland, this work would not have been possible.

Jarmo Sareva
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[1] P. Maurer, at "The humanitarian impact of nuclear weapons: key findings on the consequences and risks of, and the response capabilities regarding, nuclear weapon explosions", 32nd International Conference, 8 December 2015.

Executive Summary

Policy discussion of nuclear weapon risks has until now centred on the disastrous consequences of a detonation. Yet risk exists as a function both of probability *and* consequence. As such, efforts to prevent a nuclear catastrophe demand a more thorough understanding of the factors that can enhance the possibility of such an event. The lack of nuclear weapons use since Hiroshima and Nagasaki cannot on its own be interpreted as evidence that the likelihood of a detonation event is minimal.

The complexity of interactions in the tightly coupled systems linked to the management and operation of nuclear stockpiles make accidents inevitable. While detonations have not occurred in such circumstances, the Cold War was replete with incidences of near-misses, false alarms, and accidents in and around nuclear weapons, even when we draw only from the limited information made available by nuclear-armed States. Indeed, the general secrecy surrounding weapons programmes presents a significant obstacle from a risk assessment perspective.

The lack of in-depth information concerning the precise nature of nuclear risk is especially problematic in the contemporary global environment. Rising tensions involving nuclear-armed and other States, lower thresholds in nuclear use driven by technological developments, growing automation in command and control and weapons systems, and new threats in terms of both actors and crises are prominent features of the current international security situation. Detailing the overall risk "picture" is a critical first step to any mitigation effort.

This study:

- identifies and categorizes some of the sources of risk relating to nuclear weapons, and considers how more precise risk perceptions can drive focused actions towards nuclear disarmament;
- offers varying perspectives on overlapping questions related to nuclear weapon risks. This publication does not catalogue all relevant risks, but provides a cross-section of causes encompassing some of the most pertinent in the contemporary landscape; and
- suggests risk mitigation steps that the international community could take to address these different risk causes, and underscores the need to prevent the devastating consequences that would follow from a detonation event of any kind.

The main findings are as follows:

1. Uncertainty continues to plague existing understanding of nuclear weapon risks. Variables include its critical role in deterrence doctrine as well as unknowns linked to the interaction of complex systems, the possibility of "beyond design-basis" events, and the impact of stockpile aging.
2. The substantial levels of investment in nuclear weapons and nuclear weapons systems and their modernization have enhanced rather than decreased the likelihood of an intentional or inadvertent detonation event.

3. The secrecy associated with nuclear weapons programmes is an obstacle both for assessment and accountability pertaining to risk.
4. Human judgment has been key in identifying and resolving past instances of false alarms. Greater reliance on automated systems can lead to misplaced confidence while introducing new points of vulnerability ("hidden interactions").
5. Technological advance suggests a declining need for terrorists or other groups to directly access an actual weapon in order to effect a nuclear detonation event.
6. Risk is an inherent characteristic of nuclear weapons. The only way to eliminate risk completely is to eliminate nuclear weapons completely.

The authors suggest nuclear-armed States consider the following:

1. Refocus their efforts to exchange information on existing stockpiles and delivery systems, especially those deployed in foreign countries, to prevent misidentification that could prompt retaliatory attack.
2. Take action to extend decision timelines for policymakers in crisis situations, including reducing the alert status of nuclear-tipped missiles and migrating away from "launch on warning" postures.
3. Refrain from developing new nuclear delivery systems, such as air-launched cruise missiles, which would exacerbate ambiguity.
4. Eschew the use of rhetoric that normalizes the nuclear option or suggests the viability of limited nuclear war.
5. Undertake a graded approach to cyber security that assesses the vulnerabilities in every layer of the nuclear weapons system complex.
6. Ensure a level of independent oversight and control within their domestic nuclear weapons complex in order to prioritize safety considerations and thoroughly investigate operational uncertainties.
7. Expand the nuclear security agenda to include the 83 per cent of fissile materials in non-civilian programmes.

In addition, all States should consider the following:

1. Intensify their efforts to implement the existing global nuclear non-proliferation and disarmament regime.
2. Strengthen national safety, security, and safeguards culture, including through outreach with pertinent members of civil society such as academia and the private sector.
3. Address tensions in the international security landscape through greater transparency, communication, and other confidence-building measures.

A risk focus on nuclear weapons has begun to resonate among policymakers. The development of a common understanding of risk causes can serve as a foundation for further dialogue and engagement by a wide range of state actors. This study offers a possible basis on which such a discourse could be built.

Chapter 1
Understanding Nuclear Weapon Risks

Tim Caughley and Wilfred Wan

Introduction

The threat of a nuclear weapon detonation event in 2017 is arguably at its highest in the 26 years since the collapse of the Soviet Union. While the size of the global stockpile has decreased significantly from the peaks of the Cold War, the pace of reductions has slowed, and nine States together still possess over 15,000 nuclear weapons. Global investment on nuclear forces continues to rise, and extended deterrence remains the centrepiece of many states' strategic doctrines. Meanwhile, terrorist groups such as Al-Qaida and Islamic State in Iraq and the Levant have expressed their desire to acquire nuclear weapons and materials. The world appears "full of potential for catastrophe".[1]

Brinksmanship between the Russian Federation and the West over disputes in Ukraine and Syria underline the heightened possibility of a nuclear detonation in the current landscape. The return of Cold War-like confrontational postures has hindered international cooperation and confidence-building, with Russia side-lined from the Global Partnership following its expulsion from the Group of Eight in March 2014, withdrawing from the United States-led Nuclear Security Summit series in November 2014, and suspending or terminating bilateral cooperation with the United States on several nuclear energy agreements in October 2016.

A study of risk

These circumstances provide an immense challenge to the global disarmament machinery, which is already under strain, and the subject of criticism in particular from non-nuclear-armed States frustrated with its slow rate of progress. The fragility of the overall environment has lent greater urgency to concerns raised about the disastrous consequences of a nuclear weapon detonation event since United States President Barack Obama's 2009 "Prague speech".[2] The so-called humanitarian initiative in the half-decade since the 2010 Review Conference of the Parties to the Treaty on the Non-Proliferation of Nuclear Weapons (NPT) has led to increased

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1 Science and Security Board, *Bulletin of the Atomic Scientists*, "It is still 3 minutes to midnight", 2016, p. 1, http://thebulletin.org/it-still-three-minutes-midnight9107.

2 *Remarks of President Barack Obama*, Prague, 5 April 2009, https://obamawhitehouse.archives.gov/video/The-President-in-Prague#transcript.

recognition of the need for a better understanding of the nature and causes of nuclear weapon risk.[3]

This study seeks to add to the facts-based discourse about nuclear weapons in the contemporary era. Authors of the various contributions that follow consider some of the risks associated with nuclear weapons. The remainder of this introduction provides context for that discussion. It outlines the concept of nuclear risk, details how the focus on the topic crystallized, identifies and categorizes sources of risk, and explains why risk and risk perception matter. The chapter concludes with further questions for policy practitioners to consider as they seek to move forward.

The concept of risk

The literature on risk presents risk primarily as a function of probability multiplied by consequences.[4] There is modest variation across works, for instance with some definitions setting forth as a third component the nature of the hazardous event itself, and others outlining the particular social and economic vulnerabilities associated with consequence.[5] In the context of nuclear weapons, discussion of the hazardous event centres on their usage, under any circumstance. Risk therefore concerns both the probability that an accidental, mistaken, unauthorized or intentional nuclear weapon detonation event may occur, and the subsequent impact of that event.

As detailed in the next section, the consequences of detonation lie at the heart of the facts-based discourse that has emerged around nuclear weapons since 2010.[6] The

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3 T. Caughley, "Tracing notions about humanitarian consequences", in *Viewing Nuclear Weapons through a Humanitarian Lens*, UNIDIR, 2013, http://www.unidir.org/files/publications/pdfs/viewing-nuclear-weapons-through-a-humanitarian-lens-en-601.pdf.

4 See J. Borrie and T. Caughley, *An Illusion of Safety: Challenges of Nuclear Weapon Detonations for United Nations Humanitarian Coordination and Response*, UNIDIR, 2014, http://www.unidir.org/files/publications/pdfs/an-illusion-of-safety-en-611.pdf; and European Commission, *Risk Assessment and Mapping Guidelines for Disaster Management*, 2010, https://ec.europa.eu/echo/files/about/COMM_PDF_SEC_2010_1626_F_staff_working_document_en.pdf.

5 The hazardous event links to the concept of threat, which is sometimes used interchangeably with risk. However, risk extends beyond specific hazards. In considering probability then, the term incorporates both threat and vulnerability. See also N. Brooks, *Vulnerability, Risk and Adaptation: A Conceptual Framework*, Tyndall Centre for Climate Change Research, 2003, http://svr.irantvto.ir/uploads/130_622_conceptual%20framework.pdf; and K. Smith, *Environmental Hazards: Assessing Risk and Reducing Disaster*, 2013.

6 Austria, Federal Ministry for Europe, Integration and Foreign Affairs, *Vienna Conference on the Humanitarian Impact of Nuclear Weapons, 8–9 December 2014*, 2015, https://www.bmeia.gv.at/fileadmin/user_upload/Zentrale/Aussenpolitik/Abruestung/HINW14/ViennaConference_BMEIA_Web_final.pdf.

catastrophic nature of nuclear weapons use has been apparent since their use in Hiroshima and Nagasaki in 1945. Yet, the focus on the subject that followed the 2010 Review Conference of the NPT has crystallized further the severity of the consequences of use. In addition to analyses outlining the fire effects of nuclear explosions, likely damage to the world's climate and ecosystems, and corresponding impact on economic and migration patterns, there exists increasing recognition that "it is unlikely that any State or international body could address the immediate humanitarian emergency caused by a nuclear weapon detonation in an adequate manner".[7] The magnitude of consequences thus elevates the risk factor.

Yet, the probability side of the risk equation remains neglected, as even the range of variables that can enhance the possibility of detonation is not well understood. For instance, few have attempted to unpack the risk impact of deterrence doctrine and launch-on-warning strategies, or more indirect variables such as proliferation potential, from the spread of nuclear power and technologies.[8] The assessment of cyber risks remains in its infancy as well, as outlined by Patricia Lewis and Beyza Unal in their chapter on the subject.

Existential risk assessment

Identifying the causes and level of nuclear weapon risk would help in probability assessment. Global catastrophes can present a blind spot for risk probabilistic models.[9] This is because there is a general lack of an empirical record of such events, with limited information on near-misses, false alarms, and accidents. In addition, especially as it pertains to anthropogenic risks, models struggle to account for the spectrum of smaller events that can escalate to the level of global catastrophe.[10] Indeed, uncertainty and error-proneness in risk assessment "often dominates in [assessments of] low-probability, high-consequence risks".[11] Outside of controlled nuclear weapon tests, there has been no detonation of these arms since 1945. The

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[7] R. Miller, "Presentation on responding to the humanitarian consequences of nuclear weapons use in populated areas", *Vienna Conference on the Humanitarian Impact of Nuclear Weapons*, 8 December 2014, https://www.bmeia.gv.at/fileadmin/user_upload/Zentrale/Aussenpolitik/Abruestung/HINW14/Presentations/Rudolf_Muller_for_Vienna_Meeting.pdf.

[8] One early exception is D. Frei and C. Catrina, *Risks of Unintentional Nuclear War*, UNIDIR, 1982, which considered such factors in the context of a global nuclear war between the Cold War superpowers.

[9] B. Tonn and D. Stiefel, "Evaluating methods for estimating existential risks", *Risk Analysis*, vol. 33, no. 10, 2013; M.E. Hellman, "Risk analysis of nuclear deterrence", *The Bent of Tau Beta Pi*, 2008, http://nuclearrisk.org/paper.pdf.

[10] M.M. Ćirković, "Small theories and large risks—Is risk analysis relevant for epistemology?", *Risk Analysis* vol. 32, no. 11, 2012.

[11] N. Bostrom, "Existential risk prevention as global priority", *Global Policy*, vol. 4, no. 1, 2013, p. 16, http://www.existential-risk.org/concept.pdf.

use of nuclear weapons in populated areas has, thus far, been a rare event, in which the past is not necessarily indicative of future event frequency and in which the limits of common inductive approaches are revealed.[12] Further, the purposeful ambiguity associated with weapons programmes often leads to "approximations to reality" in these models.[13] The full range of possibilities related to a detonation event might be beyond our current understanding as a result.[14]

The challenges inherent in existential risk assessment do not preclude its real-world application. As Reza Lahidji observes in his chapter, probabilistic criteria regulate the safety of nuclear weapons in the United States, with the United States Military Liaison Committee formulating a threshold of risk acceptability in 1968. Meanwhile, the United States' 2002 Terrorism Risk Insurance Act requires property and casualty insurers to offer coverage for terrorist incidents; it is likely their calculus includes the possibility of a nuclear detonation event. Still, the dynamic nature of both probability and consequence has led some to argue that risk cannot be assigned a fixed numerical value, and should be considered in relative terms—for instance through the prism of a risk matrix.[15] The role of perception further complicates any risk assessment; as Mark Fitzpatrick and Marc Barnett discuss, this is at the core of deterrence doctrine.

Some might cite the lack of nuclear weapons use since Hiroshima and Nagasaki as evidence that the likelihood of a detonation event is low. However, this is a problematic conclusion. The complex interactions and tightly coupled systems linked to nuclear arsenals (like those for early warning, and launch command and control) have "made *accidental* war more likely".[16] In his overview of command and control systems, Pavel Podvig argues that "accidents in the system are inevitable". Even if such catastrophic events are deemed to be comparatively rare, the probability is greater than zero—and thus, the immensely destructive nature of their consequences is sufficient to demand corrective action (explored further in the concluding chapter). Incomplete information about likelihood should not hinder a strong response given the costliness of delay and the severity of the worst-case

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12 J. Borrie, *A Limit to Safety: Risk, 'Normal Accidents', and Nuclear Weapons*, ILPI–UNIDIR, December 2014, https://www.files.ethz.ch/isn/186094/a-limit-to-safety-en-618.pdf.

13 A.M. Barrett, S.D. Baum, and K. Hostetler, "Analyzing and reducing the risks of inadvertent nuclear war between the United States and Russia", *Science and Global Security*, vol. 21, no. 2, 2013.

14 M.M. Ćirković, A. Sandberg, and N. Bostrom, "Anthropic shadow: observation selection effects and human extinction risks", *Risk Analysis*, vol. 30, no. 10, 2010, http://www.nickbostrom.com/papers/anthropicshadow.pdf.

15 P.M. Lewis et al., *Too Close for Comfort: Cases of Near Nuclear Use and Options for Policy*, Chatham House, 2014.

16 S.D. Sagan, *The Limits of Safety: Organizations, Accidents, and Nuclear Weapons*, Princeton University Press, 1993.

scenario.[17] There may in fact be "very high value in studying existential risks and in analyzing potential mitigation strategies".[18] At a minimum, the existential magnitude of a detonation event demands a deeper look into the risk "picture" associated with nuclear weapons.

Risk and nuclear weapons

The intrinsic dangers of nuclear weapons have long been recognized. Nuclear disarmament was the subject of the first resolution adopted by the United Nations General Assembly in 1946. In 1978 at a time of high Cold War tension, the first special session of the General Assembly devoted to disarmament (UNSSOD I) made clear in its consensus resolution that the accumulation of weapons, particularly nuclear weapons, constituted much more of a threat than a protection for mankind. While "general and complete disarmament under effective international control" was identified by UNSSOD I as the "ultimate objective", nuclear disarmament and the prevention of nuclear war was described as the "highest priority".[19]

By 2009, as observed by Barack Obama in his Prague speech, the threat of global nuclear war had diminished since the end of the Cold War, "but the risk of a nuclear attack ha[d] gone up". That risk, Mr. Obama explained, had increased because of terrorism and because more States had acquired nuclear weapons: "Our efforts to contain these dangers are centered on a global non-proliferation regime, but as more people and nations break the rules, we could reach the point where the center cannot hold". This matters, Obama said, because there is no end to what the consequences of a nuclear explosion might be for "our global safety, our security, our economy, to our ultimate survival".[20]

Likewise, the 2010 Review Conference of the NPT noted "the catastrophic humanitarian consequences of any use of nuclear weapons" and reaffirmed "the need for all States at all times to comply with applicable international law, including international humanitarian law".[21] This language was significant for two main reasons. First, although humanitarian consequences are referred to in the NPT's

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[17] This is the logic of the Precautionary Principle. See C. Sunstein, "Irreversible and catastrophic", *Cornell Law Review*, vol. 91, no. 4, 2006.

[18] N. Bostrom, "Existential risk prevention as global priority", *Global Policy*, vol. 4, no. 1, 2013, p. 26, http://www.existential-risk.org/concept.pdf.

[19] United Nations, *Final Document of the Tenth Special Session of the General Assembly*, UN document S-10/2, para. 8, 20.

[20] *Remarks of President Barack Obama*, Prague, 5 April 2009, https://obamawhitehouse.archives.gov/video/The-President-in-Prague#transcript.

[21] 2010 Review Conference of the Parties to the Treaty on the Non-Proliferation of Nuclear Weapons, *Final Document*, UN document NPT/CONF.2010/50 (Vol. I), part I, p. 19.

preamble, that consideration had not previously been the subject of an expression of deep concern in an agreed final document of any five-yearly review of the treaty. Second, the 2010 Review Conference reference resulted in several international efforts to draw further attention to the humanitarian consequences of nuclear weapons—actions that are sometimes described collectively as the humanitarian initiative.

The humanitarian initiative

Notable among those endeavours was a conference hosted by Norway in Oslo in March 2013. Although the five NPT nuclear-weapon States decided not to attend, 128 States participated, as did several United Nations organizations and the International Red Cross and Red Crescent Movement. Mexico convened a second conference in Nayarit in February 2014 (attended by 146 States). The Nayarit conference extended the facts-based discourse beyond the "immediate death and destruction caused by a detonation" to look at some longer-term consequences and risks of detonations. In December 2014, the Austrian government hosted a third humanitarian conference in Vienna (attended by 158 States, including on this occasion the United Kingdom of Great Britain and Northern Ireland and the United States).[22] The Vienna conference further advanced the facts-based discourse about humanitarian consequences, and expanded on the nature of nuclear weapon risk.

Although not an official output of the Vienna meeting, the humanitarian "pledge" issued by the Austrian government at the conclusion of the event, and subsequently endorsed by over 120 governments, makes a number of references to nuclear risk. Expressing awareness that the "risk of a nuclear weapon explosion is significantly greater than previously assumed and is indeed increasing with increased proliferation", the pledging States undertook to "follow the imperative of human security for all and to promote the protection of civilians against risks stemming from nuclear weapons". They pledged to "call on all nuclear weapons possessor states to take concrete interim measures to reduce the risk of nuclear weapon detonations, including reducing the operational status of nuclear weapons and moving nuclear weapons away from deployment into storage, diminishing the role of nuclear weapons in military doctrines and rapid reductions of all types of nuclear weapons".[23]

Although not without controversy, the humanitarian initiative has resulted in a greater focus in the nuclear disarmament debate on the evidence of impacts of nuclear weapons and the unacceptable humanitarian consequences of nuclear warfare. The initiative awakened interest in the nature, causes, and level of nuclear

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[22] India and Pakistan, two nuclear-armed States not party to the NPT, attended all three meetings.

[23] The pledge was formally tabled by Austria in the Conference on Disarmament on 28 August 2015 (CD/2039). See http://daccess-ods.un.org/access.nsf/Get?OpenAgent&DS=CD/2039&Lang=E.

weapon risk, highlighting issues of lack of transparency about nuclear arsenals and their security, as well as the risk implications—whether positive or negative—of the development of new technologies.

Continuing the conversation

In 2013, a high-level meeting of the General Assembly on nuclear disarmament noted the grave concern expressed by many States at the threat posed to humanity by the continued existence of nuclear weapons and their potential use. As these weapons continued to number in the thousands, they were considered by those States to pose a threat to international peace. As long as nuclear weapons existed, there remained the risk of their use, either intentionally or accidentally, or of their further proliferation. The high-level meeting reaffirmed that the only guarantee against the threat of nuclear weapons was their total elimination.[24]

In the current geopolitical environment, nuclear risk may be greater than it was even in 2010 when the humanitarian initiative first began to emerge. If this is so, the picture of nuclear weapon risks painted by the initiative reinforces the view of an increasing number of States that the status quo is unsustainable. In December 2015, the United Nations General Assembly voted to establish an Open-ended Working Group to meet in Geneva the following year for the purpose of "taking forward multilateral nuclear disarmament negotiations".[25] Among four specific tasks mandated by the General Assembly, the OEWG was required to substantively address recommendations on measures that could contribute to advancing such negotiations, including but not limited to:

(a) transparency measures related to the risks associated with existing nuclear weapons; and

(b) measures to reduce and eliminate the risk of accidental, mistaken, unauthorized or intentional nuclear weapon detonations.[26]

Edging towards the nuclear precipice?

In 2016, reporting back to the General Assembly as required, the OEWG noted that it had discussed a number of factors that could contribute to the current and growing risk of a nuclear weapon detonation. These factors included increasing tensions involving nuclear-armed and other states at the international and regional levels; the vulnerability of nuclear weapon command and control systems and early-warning

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[24] United Nations, *Summary of the High-Level Meeting of the General Assembly on Nuclear Disarmament*, UN document A/68/563, 30 October 2013.

[25] United Nations, *Taking Forward Multilateral Nuclear Disarmament Negotiations*, UN document A/RES/70/33, 7 December 2015. (An earlier OEWG established by A/RES/67/56, also on taking forward nuclear disarmament negotiations, had met in 2013.)

[26] Ibid., operative para. 3.

networks to cyber attacks and attacks by non-state actors; and the growing automation of weapon systems. At the same time, it was acknowledged that the precise nature of the risks was difficult to assess given the lack of transparency in nuclear weapon programmes.[27]

Many States expressed particular concern that the maintenance of nuclear weapons at high alert levels could significantly multiply the risks and the threat posed by nuclear weapons and negatively affect the process of nuclear disarmament. In this regard, they considered that measures to reduce the operational status of nuclear weapons systems would increase human and international security and represent an interim step towards nuclear disarmament as well as an effective measure to mitigate some of the risks associated with nuclear weapons.[28] The OEWG's report also listed seventeen possible measures suggested by States for reducing the risk of accidental, mistaken, unauthorized or intentional nuclear weapon detonations, pending the total elimination of nuclear weapons.[29]

Meanwhile, in January 2017 the Bulletin of the Atomic Scientists Science and Security Board moved the Doomsday Clock forward to two and a half minutes to midnight, its closest since 1953. The Board's cautious optimism since the end of the Cold War about the ability of nuclear-weapon States to keep the nuclear arms race in check and to retreat from the "precipice of nuclear destruction" had proved unfounded.[30] On the contrary, world leaders had "actually increased the risk of nuclear war".[31] The Board thus restated its dire warning that "the probability of global catastrophe is very high, and the actions needed to reduce the risks of disaster must be taken very soon"—in fact, they found "the danger to be even greater, the need for action more urgent".[32]

Elements of nuclear risk

Reducing nuclear risk first requires an understanding of its elements. Indeed, in December 2015 the President of the International Committee of the Red Cross, Peter Maurer, spoke of the great importance of further work on the causes of risk. He said

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[27] United Nations, *Report of the Open Ended Working Group Taking Forward Multilateral Nuclear Disarmament Negotiations*, UN document A/71/371, 1 September 2016, para. 55.

[28] Ibid., para. 56.

[29] Ibid., para. 58

[30] S. Squassoni, in "Press release: It is now 3 minutes to midnight", 22 January 2015, http://thebulletin.org/press-release/press-release-it-now-3-minutes-midnight7950.

[31] Science and Security Board, Bulletin of the Atomic Scientists, "It is two and a half minutes to midnight", 2017, p. 7, http://thebulletin.org/sites/default/files/Final%202017%20Clock%20Statement.pdf.

[32] Ibid., p. 8.

that greater policy exploration of nuclear weapon risks would allow issues around these weapons to be considered in a different way, and so be especially helpful for constructive engagement with nuclear-armed States.[33]

To that end, the chapters that follow look at different causes of nuclear risk. There are many possible origins of that risk, too many to be adequately identified in this study. Several broad categories of risk can, however, be discerned.

Technological aspects

Current efforts by nuclear-armed States to modernize their nuclear arsenals offer opportunities to fine-tune nuclear safety systems and material. This is the purported and contested rationale for some modernization programmes. However, as Hans M. Kristensen argues in his chapter, modernization efforts have also improved the capabilities and effectiveness of nuclear weapons, at times reaffirming their role in limited scenarios. The possibility of human error in design, manufacture, maintenance, and transport of nuclear weapons also cannot be entirely eliminated. And the norm against explosive testing of nuclear arms mostly restricts experimentation to computer-based laboratory models. Technological failures are also possible in ancillary systems such as those designed to provide early warning of a nuclear attack. The risk of a *force majeure* event in relation to nuclear arsenals may, by virtue of their relative physical discreteness, be better guarded against than for civilian nuclear complexes (e.g. Fukushima) but, as already noted, can scarcely be regarded as zero. And to conclude this category of elements, “unknown” risks outside the spectrum of our current understanding (e.g. vulnerability of components to hacking and cyber attack) should be mentioned.

Human and operational factors

Military strategies like those that entail “launch-on-warning” practices (of maintaining warheads on constant high alert) are pregnant with risk. It requires a commander to reach judgment in a matter of minutes on setting in motion nuclear retaliation to a presumed nuclear attack with enormous likely humanitarian and environmental consequences. Such snap judgments under uncertainty clearly present risks. The consequences are clearly so terrifying that human decision makers have erred on the side of caution repeatedly. Yet, judgments remain fallible, and accidents happen, as revealed by independent research, perhaps the best known of which is Eric Schlosser’s study, *Command and Control*.[34] A lack of transparency among the nuclear-armed States about safety and security of their nuclear arsenals and the sometimes insular nature of the military–industrial complex likely masks further incidents of relevance to risk assessment.

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[33] P. Maurer, *The Humanitarian Impact of Nuclear Weapons*, Geneva, 8 December 2015.

[34] E. Schlosser, *Command and Control*, Allen Lane, 2013.

Doctrinal dimensions

Nuclear deterrence doctrine, broadly stated, is rooted in the belief that these weapons serve as a type of assurance against certain forms of aggression and underwrite broader security stability. Developed during the Cold War, the underlying rationale centred on the magnitude of consequences of nuclear weapons use, with "a kind of threat which … should be *absolutely* effective" because just one use would "be fatally too many".[35] Yet, the altered global order has been accompanied by challenges to this conventional wisdom, both in its applicability then and to the contemporary era.[36] After all, divergences abound among nuclear-armed States on their postures surrounding the possible use of nuclear weapons, postures not necessarily entirely clear to anyone but themselves. There is no common commitment to confining use, for example, to extreme circumstances of self-defence in which the very survival of a State would be at stake.[37] There is no uniform commitment to a doctrine of "no first use" of nuclear weapons or of confining retaliation by nuclear forces only to situations of attack by weapons of mass destruction. Given the uncertainty this creates, the continued reliance on nuclear weapons for state security led the former United Nations Secretary-General Ban Ki-moon to say that there are "no 'right hands' that can handle these 'wrong weapons'".[38]

The contributors to this volume examine issues across all of these categories; their chapters encompass the most pertinent concerns in the contemporary nuclear landscape.

Significance of risk today

Thinking in a structured and systematic way about nuclear weapon risks is necessary given the current state of global affairs. Poor relations among the nuclear-armed powers contribute to an atmosphere that lends itself to the onset of crisis. Russia

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[35] B. Brodie, *The Anatomy of Deterrence*, The RAND Corporation, 1958, https://www.rand.org/content/dam/rand/pubs/research_memoranda/2008/RM2218.pdf. See also, T. Schelling, *Arms and Influence*, Yale University Press, 1946.

[36] W. Wilson, "The myth of nuclear deterrence", *Nonproliferation Review*, vol. 15, no. 3, 2008, https://www.nonproliferation.org/wp-content/uploads/npr/153_wilson.pdf.

[37] The International Court of Justice, in its Advisory Opinion of 8 July 1996 on the Legality of the Threat or Use of Nuclear Weapons, decided that while the threat or use of nuclear weapons would generally be contrary to the rules of international law applicable in armed conflict, and in particular the principles and rules of humanitarian law, "in view of the current state of international law, and of the elements of fact at its disposal, the Court [could not] conclude definitively whether the threat or use of nuclear weapons would be lawful or unlawful in an extreme circumstance of self-defence, in which the very survival of a State would be at stake".

[38] Secretary-General, *Press Release*, UN document SG/SM/14968-DC/3432, 22 April 2013.

and the West continue to experience heightened tensions stemming from Russia's 2014 annexation of Crimea. For instance, the United States proposed in February 2016 to quadruple the budget (to $3.4 billion) for its European Reassurance Initiative aimed specifically to deter Russian aggression, while the North Atlantic Treaty Organization (NATO) deployed four battalions to the Baltic States and Poland in June 2016. Russia responded in October 2016 by deploying nuclear-capable *Iskander* missiles into Kaliningrad, its westernmost region.

Other sources of global tension include the growing threat of the Democratic People's Republic of Korea, as Pyongyang successfully tested a submarine missile launch in August 2016, while its nuclear test a month later was its largest to date in terms of explosive yield. Partly as a response, the United States has moved to expand its missile-defence network, though its plan to deploy a Terminal High Altitude Area Defense (THAAD) system to the Republic of Korea has drawn sharp criticism from China and Russia (and intensified bilateral defence cooperation between them). In South Asia, meanwhile, escalating tensions following a series of violent attacks by militants (including on an Indian Army brigade headquarters) in disputed Kashmir reportedly led Pakistani Defence Minister Muhammad Asif to threaten the use of tactical nuclear weapons against India.[39] Pakistan carried out its first-ever test of a nuclear-capable cruise missile from a submarine in January 2017, igniting regional tensions while continuing a worrisome global trend with those weapons—as traced by Christine Parthemore in her chapter.

Compounding the overall issue is the troubled state of the global disarmament machinery. Although disagreement over the Middle East caused the failure of the 2015 Review Conference of the NPT to produce an outcome document, differences of approach to disarmament were also clearly evident.[40] None of the nine nuclear-armed States participated in the 2016 OEWG. The Comprehensive Test Ban Treaty remains yet to be ratified, and both nuclear disarmament and fissile material cut-off treaty talks have been stalled in the Conference on Disarmament for almost two decades. As mentioned, Russia has curtailed cooperation in several bilateral nuclear agreements, including the Cooperative Threat Reduction Program and the Plutonium Disposition and Management Agreement.

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[39] S. Dean and C. Summers, "'We have not made an atomic device to display in a showcase': Pakistan threatens to destroy India with a nuclear bomb as Kashmir crisis edges closer to the brink", *Daily Mail Online*, 30 September 2016, http://www.dailymail.co.uk/news/article-3815272/We-not-atomic-device-display-showcase-Pakistan-threatens-destroy-India-nuclear-bomb-Kashmir-crisis-edges-closer-brink.html.

[40] T. Rauf, "The 2015 NPT Review Conference: setting the record straight", Stockholm International Peace Research Institute, 24 June 2015, https://www.sipri.org/node/384.

A foundation for risk mitigation

With uncertainties marking the geopolitical, security, and institutional landscapes, there is a greater scope for nuclear misperceptions and miscalculation. After all, the current trust deficit among nuclear-armed States contributes to perceptions of crisis, and in some cases, greater preparation for conventional conflict.[41] Combined with shortcomings in institutional safeguards, and broken channels of communication, the threat of escalation into nuclear conflict cannot be taken lightly.[42]

Additional reflection on nuclear weapon risks would enhance the ability of policymakers to address specific vulnerabilities. Since 2001, discussion of detonation risk has been focused mostly on the possibility of deliberate acts by terrorist groups or "rogue states" —though as Elena K. Sokova writes in assessing the international response, "progress remains limited" even in this field. Further disaggregating the nature of technological, human and operational, and doctrinal causes can thus pinpoint spaces for information-sharing and transparency among nuclear-armed States and in ways that do not infringe on their security, which would have benefits for all if it reduces the risk of a nuclear weapon detonation for any reason.

Nuclear weapons have long been linked to the stability of the international order in the eyes of some policymakers and scholars. This linkage remains the rationale behind deterrence doctrine. A better picture of the nuclear risks could contribute to re-evaluation of the costs and benefits of that approach.[43] By assessing policies and policy proposals through the lens of risk mitigation, common ground for disarmament action could even emerge. A factually based reframing of the narrative about nuclear weapon risks would thus contribute toward the kinds of effective measures on nuclear disarmament that the United Nations has sought since its founding.[44]

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[41] A. Barrett, *False Alarms, True Dangers? Current and Future Risks of Inadvertent U.S.–Russian Nuclear War*, The RAND Corporation, 2016, http://www.rand.org/content/dam/rand/pubs/perspectives/PE100/PE191/ RAND_PE191.pdf; V. Shankar, "India-Pakistan: nuclear risk reduction measures", Institute of Peace and Conflict Studies, 10 February 2014, http://www.ipcs.org/article/india/india-pakistan-nuclear-risk-reduction-measures-4301.html; G. Kulacki, *The Risk of Nuclear War with China: A Troubling Lack of Urgency*, Union of Concerned Scientists, 2016, http://www.ucsusa.org/sites/default/files/attach/2016/05/Nuclear-War-with-China.pdf.

[42] R. E. Berls Jr. and L. Ratz, *Rising Nuclear Dangers: Assessing the Risk of Nuclear Use in the Euro-Atlantic Region*, Nuclear Threat Initiative, 2015, http://www.nti.org/media/pdfs/NTI_Rising_Nuclear_Dangers_Paper_FINAL.pdf?=1443443566.

[43] British American Security Information Council, *Reframing the Narrative on Nuclear Weapons: Insights & Findings*, 2016, http://www.basicint.org/sites/default/files/BASIC_NextGen_Jan2016.pdf.

[44] T. Caughley, *Analysing Effective Measures: Options for Multilateral Nuclear Disarmament and Implementation of NPT Article VI*, ILPI–UNIDIR, 2015, http://www.unidir.org/files/publications/pdfs/analysing-effective-measures-en-628.pdf.

Chapter 2

Risk and Nuclear Deterrence

Mark Fitzpatrick and Marc Barnett

Introduction

Nuclear deterrence is inherently risky, both deliberately so and as a function of imperfect systems and human failings. Deterrence theory evolved to prevent North Atlantic Treaty Organization (NATO)–Soviet conflict in a Mutually Assured Destruction (MAD) world. In that bipolar stand-off, success depended on repeated circumstances of good fortune. Today's geopolitical complexities and expanded club of nuclear actors exacerbate the inherent dangers of nuclear deterrence. While mitigation efforts continue rightly to be focused on the superpowers, the policies of newer, smaller nuclear powers may present greater potential for deterrence failure.

This chapter explores the contemporary risks associated with nuclear deterrence, arguing that it is an imperfect model for today's geopolitical environment. The risks of deterrence failing due to accident, misunderstanding, or inadvertent escalation are too high. The chapter briefly summarizes the theory, practice, and pitfalls of nuclear deterrence then examines two regions, South Asia and Northeast Asia, where deterrence is at greatest risk of breaking down.

Nuclear deterrence: theory, practice, and pitfalls

Deterrence theory relies on the credible threat of unacceptable retaliation to forestall attacks from a potential adversary. Nuclear deterrence raises the retaliatory response to an existential level. Deterrence is a function of both capability and credibility, the latter of which is inherently questionable. Political scientist Robert Powell puts it succinctly: "how can a state credibly threaten to impose a sanction (a nuclear attack) that, if imposed, would subsequently result in its own destruction?"[1] In order to overcome this credibility problem, deterrence relies on risk, unpredictability, and extreme consequences. But reinforcing credibility through acts of brinksmanship that threaten nuclear use increases the risk of a conflict spiralling out of control. On one hand, deterrence works to overcome crises when one State backs down in the face of greater resolve by the other, in terms of both firepower and perceived willingness to use it. On the other hand, demonstrations of resolve

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1 R. Powell. "Nuclear deterrence theory, nuclear proliferation, and national missile defense", *International Security*, vol. 27, no. 4, 2003.

that set ambitious red lines, reduce alert times, or send misinterpreted signals increase the potential for nuclear conflict. Risk is thus an inherent part of nuclear deterrence in both theory and practice, meaning the chance of inadvertent nuclear use can never be zero.

Lessons from the Cold War

The lessons of nuclear deterrence come largely from the four decades of the Cold War. The mutual threat of nuclear annihilation helped prevent direct warfare between the Soviet Union and the United States along with their respective allies. In light of the mass casualties that marked the first half of the twentieth century, preventing another world war was no small achievement. Still, political, financial, and military support from the superpowers did fuel a number of proxy wars over the four decades. The period was also marked by a series of near misses and false alarms fuelled by miscalculations, misinformation, and misunderstandings in which luck played a defining role in avoiding nuclear conflict.

The Cuban Missile Crisis, which brought the United States and the Soviet Union to the brink of war, is often seen as a positive example of deterrence theory in practice. But rather than a pure case of backing down in the face of stern American resolve, Moscow's decision to remove nuclear missiles from Cuba was also a quid pro quo for the United States' removal of nuclear systems from Turkey.[2] And respective shows of resolve during the 13-day crisis nearly led to nuclear war. In order to protect Soviet operations on the ground, the Kremlin deployed four nuclear-armed submarines to Cuba and authorized launch of their 15-kiloton nuclear torpedoes if under attack. When the United States ships that were blockading Cuba used "practice depth charges" to force the submarines to surface (a tactical decision that was communicated to Moscow but not forwarded to the four submarines), the captain of one of them, believing to be under attack, prepared to launch a nuclear torpedo. All three senior officers on board had to concur with such a decision, however, and the refusal of one of them to do so prevented a nuclear exchange.[3]

Other examples of near misses during the Cold War include a 1979 incident in which a training tape simulating a Soviet nuclear launch left key principals debating what to do until the North American Aerospace Defense Command (NORAD) confirmed that the attack was a false alarm.[4] On the Soviet side, in 1983, Lieutenant Colonel Stanislav Petrov received incoming data that five United States intercontinental

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2 B. Schwarz, "The real Cuban Missile Crisis", *The Atlantic*, January/February 2013, https://www.theatlantic.com/magazine/archive/2013/01/the-real-cuban-missile-crisis/309190/.

3 P. Roberts, "Arkhipov, Vasili Alexandrovich (1926–1999)", in *Cuban Missile Crisis: The Essential Reference Guide*, ABC-CLIO, 2012, pp. 13–14.

4 United States General Accounting Office, *Report to the Chairman Committee on Government Operations House of Representatives of the United States: NORAD's Missile Warning System: What Went Wrong?*, 15 May 1981, http://www.gao.gov/assets/140/133240.pdf.

ballistic missiles (ICBMs) had been launched towards the Soviet Union. Petrov correctly gambled that the incoming data was a false alarm.[5]

Numerous pitfalls

Such examples point to the many pitfalls that can derail stable deterrence. The command and control systems for nuclear deterrence are exceedingly complex with numerous moving parts and tight coupling, with little time for decision-making, problem-solving, or strategic thinking. As detailed by Pavel Podvig in his chapter, these systems are vulnerable to technical, human, and mechanical failure as well as misinformation in which policymakers must respond under immense pressure. The complex interactions involving considerations of safety, security, maintenance, and command and control make future accidents and errors difficult to predict as prior incidents can rarely be extrapolated beyond the specific case. The issue of human fallibility took on increased visibility during the 2016 United States election campaign with questions raised about the temperament of a president holding the nuclear codes. Deterrence stability is dangerously susceptible to the personality and character traits of individual leaders.

Another pitfall includes nuclear doctrine, designed to send clear signals to adversaries. Doctrine can be ambiguous, abandoned during a crisis, or outdated after leadership changes. As a State deviates from its stated nuclear doctrine in a crisis, mistrust and miscommunication may escalate the situation, increasing the risk of nuclear use. The Russian Federation's leadership today seems particularly prone to nuclear sabre-rattling, such as when President Vladimir Putin said that during Russia's military seizure of Crimea he was ready to put nuclear forces on alert.[6]

Nuclear deterrence also typically leads to a security dilemma and therefore arms racing. There is a logic: stable nuclear deterrence is thought to require secure, reliable second-strike capabilities to effectively deter a pre-emptive first strike. Yet reaching and maintaining stable equations is fraught. As adversaries race to gain a power advantage, one or both may believe it to be in their strategic interest to act before the other moves ahead. Similarly, if one state does gain the technical and strategic advantage, it may perceive it to be in its interest to strike before the other state "catches up" and restores the balance of power. Even with reliable second-strike capabilities on both sides, achieving completely stable nuclear deterrence is

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[5] Y. Vasilyev, "On the brink", *The Moscow News*, 29 May 2004, http://www.brightstarsound.com/world_hero/the_moscow_news.html. For other examples, see E. Schlosser, *Command and Control: Nuclear Weapons, the Damascus Accident, and the Illusion of Safety*, The Penguin Press, 2013, and P.M. Lewis et al., *Too Close for Comfort: Cases of Near Nuclear Use and Options for Policy*, Chatham House, 2014.

[6] L. Smith-Spark, A. Eshchenko, and E. Burrows, "Russia was ready to put nuclear forces on alert over Crimea, Putin says", *CNN*, 16 March 2015, http://edition.cnn.com/2015/03/16/europe/russia-putin-crimea-nuclear/.

impossible due to the inherent need to introduce uncertainty and risk in order to deter adversaries. Imperfect command and control and accidental use may occur, as well as the inherent risk of brinksmanship and escalation leading to nuclear use.

The rise of new, smaller nuclear powers has exacerbated these pitfalls in several ways. Newer powers tend to have less secure control over nuclear weapons, with underdeveloped facilities and procedures that could leave nuclear weapons more vulnerable to non-state actors and more prone to accident (although the nuclear stewardship record of the more established powers is hardly reassuring). They also have less developed civilian control of nuclear weapons, potentially biasing use. New nuclear States often have less transparent governments as well, meaning that nuclear doctrine is frequently obscured and underdeveloped, if articulated at all. Finally, they tend to repeat the arms competition practices of the older nuclear powers.

Nuclear deterrence in South Asia

Although it is an exaggeration to call South Asia a "nuclear tinderbox", if and when nuclear weapons are again used in conflict, the subcontinent is the most likely locale. Since becoming independent states in 1947, India and Pakistan have officially warred three times and engaged in many smaller skirmishes. In the past three decades, cross-border clashes have nearly led to major conflict on at least five other occasions. Meanwhile a central cause of conflict, disputed claims on Kashmir, remains unresolved. If they again go to war it will be as nuclear-armed States. Each has recently expanded nuclear weapons production capabilities and introduced new weapons systems that challenge strategic stability. Although their nuclear arsenals, estimated to be on the order of 120–140 warheads each, are a far cry from those of the superpowers, there is no mistaking the arms race underway between Pakistan and India (which also sees itself in an arms competition with China).[7]

The stability/instability paradox

Strategic thinkers in the two States maintain that just as MAD prevented a third world war, their nuclear stand-off has preserved peace in South Asia by introducing extra caution in the minds of decision makers. Yet possessing nuclear arms has also introduced a greater propensity for adventurism. In 1999, for example, Pakistani Chief of Army Staff Pervez Musharraf was emboldened to move across the Line of Control in northern Kashmir in the expectation that his nation's nuclear weapons would deter a forceful Indian counter-strike against Pakistani territory. This and other cases exemplify the "stability/instability" paradox of international relations

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[7] For stockpile estimates, see H.M. Kristensen and R.S. Norris, "Status of world nuclear forces", *Federation of American Scientists*, 2017, https://fas.org/issues/nuclear-weapons/status-world-nuclear-forces/.

theory, which holds that when adversaries obtain nuclear weapons, the probability of a direct war between them decreases while the probability of minor or indirect conflicts increases.[8]

The theory that nuclear deterrence will keep antagonisms from spilling over is challenged by the geographic proximity of the two states and their asymmetric defence and nuclear postures. At the beginning of the decade, Pakistan lowered the threshold for nuclear use by introducing battlefield-use nuclear systems: the 60-km range ballistic missile *Nasr*, to supplement another solid-fuelled short-range ballistic missile, the 180-km range *Abdali,* both designed for conventional and nuclear use. Pakistan said the purpose was to deter cross-border Indian incursions that would otherwise fall under what had been seen as the tripwire for Pakistani nuclear retaliation.

In 2004, the Indian Army had proposed just such a plan, dubbed "Cold Start", for retaliating against Pakistan-based terrorist attacks by launching rapid-response movements up to 80 km across the border by integrated battle groups. Just as Cold Start was designed to shore up a deterrence vulnerability, it gave Pakistan reason to fear a vulnerability of its own and to take compensatory measures. In the words of Pakistani officials, their shorter-range missile systems would "plug the deterrence gap" and provide "full-spectrum deterrence".[9] Pakistan also expanded its plutonium-production capability in reaction to a sense of strategic handicap caused by the 2005 United States-India nuclear cooperation deal (consummated in 2008) that exacerbated India's industrial and economic advantages. While Pakistan is assessed to be assembling warheads at a faster pace however, India has far greater potential for nuclear weapons production.

Pakistan's lowering of the nuclear threshold to include limited conventional attacks could lead to a failure of deterrence in a crisis and a devastating nuclear exchange. Several experts on South Asian affairs have suggested that an atrocity in India, perhaps akin to the 2008 Mumbai terrorist attack in which 10 jihadists from the Lashkar-e-Taiba group killed more than 170 people, could trigger a nuclear war.[10] Thus, the lingering issue of Kashmir as well as domestic instability in the region remain of concern from this perspective.

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[8] M. Fitzpatrick, *Overcoming Pakistan's Nuclear Dangers*, Routledge, 2014, p. 48.

[9] A. Sultan, *Pakistan's Emerging Nuclear Posture: Impact of Drivers and Technology on Nuclear Doctrine*, Institute of Strategic Studies Islamabad, 17 April 2012, pp. 159, 162; http://www.issi.org.pk/publication-files/1340000409_86108059.pdf.

[10] See, for example, A. Iqbal, "Terrorist attack in India may lead to nuclear war; US experts", *Dawn*, 28 February 2015, http://fpif.org/global-nuclear-winter-avoiding-unthinkable-india-pakistan/; see also E.B. Montgomery and E.S. Edelman, "Rethinking Stability in South Asia: India, Pakistan, and the Competition for Escalation Dominance", *Journal of Strategic Studies*, vol. 38, no. 1–2, 2015.

The question of credibility

In contrast to his predecessor's tepid response to the Mumbai massacre, Indian Prime Minister Narendra Modi, elected in 2014, vowed to respond forcefully the next time. There is a strong sense in India today that deterrence credibility must be restored through use of force. If the response includes a cross-border attack, Pakistan has reserved the right to respond with its battlefield-use nuclear weapons. Officials there contend that *Nasr* would not be pre-deployed, and that firing decisions would remain with the Nuclear Command Authority, an entity legally under the Prime Minister's authority but heavily influenced by the military. Yet Pakistan's need to portray credibility about firing first could sacrifice central control over nuclear weapons in a crisis situation. And due to the "use them or lose them" choice that could face local commanders, deployment of these systems could lead to rapid escalation if deterrence failed. In the miasma of crisis and fog of war, even the most robust of command and control systems cannot preclude human error. [11]

India's own nuclear policy calls for massive retaliation against any nuclear attack against the country, including against Indian forces on Pakistani soil. Massive Indian nuclear strikes would then prompt massive Pakistani strikes on Indian cities. The resulting damage would not be limited to the subcontinent. Researchers with the International Physicians for the Prevention of Nuclear War have assessed that a nuclear exchange between India and Pakistan involving 100 weapons would cause climate disruption putting up to two billion people around the world at risk of starvation.[12]

Nuclear deterrence in Northeast Asia

Vying with the Indian subcontinent for the moniker of nuclear flashpoint is the Korean Peninsula. Highly adversarial relations between the Democratic People's Republic of Korea (DPRK) and the Republic of Korea (ROK), a propensity for provocations on the part of the DPRK, and rapid advances in its nuclear and missile systems make for a combustive mix. The nuclear threat is also stoking motivation for further proliferation in the region, an impulse that is further stimulated when the credibility of the United States' extended deterrence is called into question. This happened during the 2016 election campaign when then-candidate Donald Trump appeared to link security guarantees to the level of host-nation defence spending and support for housing American troops. Some analysts also questioned the

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[11] M. Fitzpatrick, *Overcoming Pakistan's Nuclear Dangers*, Routledge, p. 156.

[12] I. Helfeld, *Nuclear Famine: Two Billion People At Risk? Global Impacts of Limited Nuclear War on Agriculture, Food Supplies, and Human Nutrition*, 2nd ed., International Physicians for the Prevention of Nuclear War, 2013, http://www.ippnw.org/pdf/nuclear-famine-two-billion-at-risk-2013.pdf.

credibility of the United States' extended deterrence when President Barack Obama did not attack the Syrian Arab Republic after it crossed his stated red line on chemical weapons use and when he did not respond militarily to Russia's seizure of Crimea.[13]

DPRK provocations

The armistice that halted fighting in the Korean War in 1953 has never been replaced by a peace treaty, and deadly DPRK provocations have continued every decade since. Already the most militarized nation on Earth, with five per cent of its population under arms, the DPRK has in the past decade added nuclear weapons to its arsenal.[14] It presumably can deliver them in its 1,000-km range *Nodong* missiles, capable of reaching much of Japan and all of the ROK. In 2016 it successfully tested the road-mobile 3,800-km range *Musudan* ballistic missile; leader Kim Jong Un boasted in his 2017 New Year's address that the nation would "reach the final preparation stages for test-firing an ICBM".[15]

Like other nuclear-armed States, the DPRK insists that its nuclear weapons are for deterrence. DPRK officials say they need an ICBM to deter the "hostile" United States. The possibility cannot be excluded that the DPRK might seek to use nuclear weapons in an offensive action aimed at finishing its 1951 effort to reunify the Korean Peninsula by force. In this case, a functioning ICBM would be intended to forestall the United States coming to the aid of the ROK.

The more likely scenario for DPRK nuclear use is as a mistaken effort to forestall a perceived invasion. Every year, the United States and the ROK hold two joint military exercises which DPRK state media claim are a pretext for plans to topple its government. The exercises are defensive in nature, of course; witness the absence of any such attack from the ROK these many decades. Yet ROK officials do speak openly about the potential need for pre-emptive "decapitation" of the DPRK leadership.[16] Pre-emption options are also increasingly talked about in Washington. A former commander of United States Forces–Korea recently commented that the incoming Trump administration must be ready to launch a pre-emptive strike on the DPRK before it tests an ICBM capable of hitting the mainland United States.[17] Trump hinted at the

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13 N. Gaouette and P. Mattingly, "Obama faces Asia allies uncertain of U.S. commitment", *Bloomberg*, 21 April 2014, https://www.bloomberg.com/news/articles/2014-04-21/obama-faces-asia-allies-uncertain-of-u-s-commitment.

14 International Institute for Strategic Studies, *The Military Balance 2017*, Routledge, 2017, p. 303.

15 See https://www.nknews.org/2017/01/expressing-some-regret-kim-jong-un-calls-for-icbm-capabilities-in-2017/.

16 Yonhap News Agency, "S. Korea unveils plan to raze Pyongyang in case of signs of nuclear attack", 11 September 2016, http://english.yonhapnews.co.kr/national/2016/09/11/65/0301000000AEN20160911000500315F.html.

17 R. Sisk, "Former US general calls for pre-emptive strike on North Korea", *Defense Tech*, 1 December 2016, http://www.defensetech.org/2016/12/01/pre-emptive-strike-north-korea/.

same when he tweeted on 2 January 2017 that a DPRK ICBM test launch "won't happen".[18] If the United States were to launch such a pre-emptive strike, the DPRK would likely see it as the first salvo of a larger attack and respond accordingly. Nuclear use could not be ruled out in a fog of misperceptions.

Escalatory scenarios

A nuclear war on the Korean Peninsula could also start from a DPRK provocation such as the 2010 sinking of the ROK *Cheonan* corvette with the loss of 46 crew members (for which Pyongyang never admitted responsibility) and the attack later that year on Yeonpyeong Island, which killed four. After those attacks, the ROK vowed to respond forcefully the next time. New rules of engagement require ROK military officers to respond promptly with proportionate retaliation to any DPRK hostility. How the DPRK would then respond is uncertain, but its militaristic nature make it likely to up the ante, perhaps by shelling ROK residential areas near the border. A resulting escalation in which ROK forces take out DPRK artillery could also be seen by Pyongyang as a prelude for invasion. To preserve the regime, the DPRK might see the need to use its nuclear arsenal. As in the case of South Asia, a self-perceived need to reinforce credibility can make deterrence unstable.

Meanwhile, the DPRK's belligerence could spark a nuclear domino effect. Frustrated by Washington's inability to stop Pyongyang's nuclearization, an increasing number of ROK politicians are calling for their State to fight fire with fire by itself developing nuclear weapons. According to multiple public opinion polls, over 60 per cent of the ROK public back the idea, even though doing so could spark Japan also to acquire nuclear weapons.[19] Nuclear proliferation by United States' allies was encouraged when Donald Trump as a presidential candidate in spring 2015 suggested that they acquire nuclear weapons for self-protection if they did not want to pay more for the United States' security guarantees.[20] After hearing from senior Republican Senators what a bad idea it was to abandon the non-proliferation stance of every one of his predecessors, Trump later denied having said this. Yet the damage was done.

By treating United States defence commitments as a bargaining chip for troop support, Trump undermined the credibility of extended deterrence. The DPRK and China may become marginally more risk-seeking if they think Trump will be less likely to extend the United States' so-called "nuclear umbrella". On the other hand, Trump as a candidate also spoke cavalierly about nuclear weapons, reportedly asking an

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18 See https://twitter.com/realDonaldTrump/status/816057920223846400.

19 M. Fitzpatrick, *Asia's Latent Nuclear Powers: Japan, South Korea and Taiwan*, Routledge, 2016, p. 37.

20 M. Chan, "Here's what Donald Trump has said about nuclear weapons", *Time*, 3 August 2016, http://time.com/4437089/donald-trump-nuclear-weapons-nukes/.

adviser repeatedly, “If we have them, why can’t we use them?”[21] Proud of unpredictable negotiation tactics to put opponents off guard, Trump could very well seek to play the madman role once employed by Richard Nixon, who sought to bring the North Vietnamese government to negotiate an end to the war in Viet Nam by implying he was volatile enough to launch nuclear weapons against Hanoi (a tactic that did not work).[22] To use nuclear rhetoric in such a way undermines the stability and predictability on which sound nuclear deterrence must be based.

Conclusion

Nuclear deterrence works—up until the time it will prove not to work. The risk is inherent and, when luck runs out, the results will be catastrophic. The arms races spawned by putting theory into practice create their own self-perpetuating dynamic. The more arms produced, particularly in countries with unstable societies, the more potential exists for terrorist acquisition and use of nuclear weapons. Nuclear deterrence has also created the paradox of the commitment trap. For example, to deter most of the threats that the United States and its allies may face in Northeast Asia, particularly from the DPRK, nuclear use is neither entirely credible nor necessary.[23] Yet any weakening of the United States’ nuclear umbrella could spur further adventurism by adversaries and proliferation by allies. Breaking out of the conundrum will require steady, collaborative and visionary leadership of a kind that is sadly rare today as major States increasingly turn inward.

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[21] H. Neidi, “Scarborough: Trump asked adviser why US can't use nuclear weapons”, *The Hill*, 3 August 2016, http://thehill.com/blogs/ballot-box/presidential-races/290217-scarborough-trump-asked-about-adviser-about-using-nuclear.

[22] W. Burr and J.P. Kimball, *Nixon’s Nuclear Specter: The Secret Alert of 1969, Madman Diplomacy, and the Vietnam War*, University Press of Kansas, 2015.

[23] M. Fitzpatrick, *Asia’s Latent Nuclear Powers: Japan, South Korea and Taiwan*, Routledge, 2016, p. 167.

Chapter 3

The Quest for More Useable Nuclear Weapons

Hans M. Kristensen

Introduction

One of the greatest achievements of the nuclear age is that nuclear weapons have not been used in anger for 71 years. This may have been because of strategy, sheer luck, or a combination of the two. Fear of the unique destructive power of nuclear weapons and their radiological and climatic effects have served to deter States from using nuclear weapons. But it certainly has not been for a lack of preparing for the use of nuclear weapons: widespread deployments of nuclear weapons on the move around the world in more and more variations, with ever-increasing capabilities, combined with highly offensive and aggressive nuclear strategies primed the nuclear weapon for optimal effectiveness.

All the nuclear-armed States have extensive nuclear modernization programmes underway and appear to plan to retain large nuclear arsenals for the indefinite future. Despite significant differences in the size and composition of the world's nine nuclear weapon arsenals, the modernization programmes have one thing in common: to improve the capabilities and effectiveness of nuclear weapons. In fact, it is fair to say that the primary objective of modernization is to improve the effectiveness of nuclear weapons to destroy targets. As such, the nuclear-armed States are locked in a perpetual technological race.

Modernization and evolution

As the nuclear age progressed and technology matured, modernization programmes extended the range and accuracy of delivery vehicles, which allowed planners to lower the yield needed to destroy a target. As weapons became more effective, strategies changed from a blunt spasm of all-out nuclear attack to more refined strike plans with multiple options directed against different combinations of targets for different objectives at different levels of intensity. Shorter-range weapons were developed for battlefield use below the strategic level to defeat military forces in limited scenarios while strategists toiled with theories about controlling or managing escalation below all-out nuclear war. Usability of nuclear weapons was a key factor in this chapter of the nuclear age.

As the Cold War ended and the superpower competition for world domination subsided, tactical nuclear weapons and nuclear battlefields fell out of favour in several nuclear-armed States. Yet, while overall nuclear arsenals have been reduced, the continued emphasis on maintaining a credible and effective nuclear deterrent against more nuclear-armed States has spawned a requirement to make the remaining nuclear weapons more flexible. Planners have been busy improving the targeting effectiveness of nuclear weapons and are working to combine increased accuracy with lower-yield options to reduce collateral damage from nuclear attacks. These capabilities, some argue, are needed to provide more "tailored" strike options for limited use in regional scenarios. This, in turn, has created concern among some that nuclear arsenals again are being groomed to be more useable and that strategies increasingly prepare for limited but more likely options.

United States of America

Although the United States is not alone in increasing its nuclear capabilities, it is by far the most transparent of the nine nuclear-armed States; this is reflected in the length of this section. The Obama administration's 2010 Nuclear Posture Review pledged that the United States "will not develop new nuclear warheads" and that "Life Extension Programs (LEPs) … will not support new military missions or provide for new military capabilities".[1] The administration never specified what would constitute "new military capabilities" but some officials have privately explained that military capabilities would not be added to a warhead being life-extended that the original versions did not already have. Others have described it more broadly, that "new" referred to capabilities that did not already exist somewhere in the arsenal. Others still have explained that the pledge was intended to support an overall effort to reduce the role of nuclear weapons in United States military strategy.

The W76-1/Mk4A life-extended sea-launched ballistic missile warhead

When President Obama took office in January 2009, the production of the Navy's W76-1/Mk4A life-extended sea-launched ballistic missile warhead was already in full-scale production. The life-extended warhead includes a new fuze that provided enhanced military capabilities compared with the W76-0/Mk4 warhead it replaces. The old Mk4 re-entry body had three fixed height-of-burst settings (ground, optimal, and high) which meant that some warheads would fail to detonate inside the optimal volume above the target to produce the peak pressure needed to destroy the target.[2]

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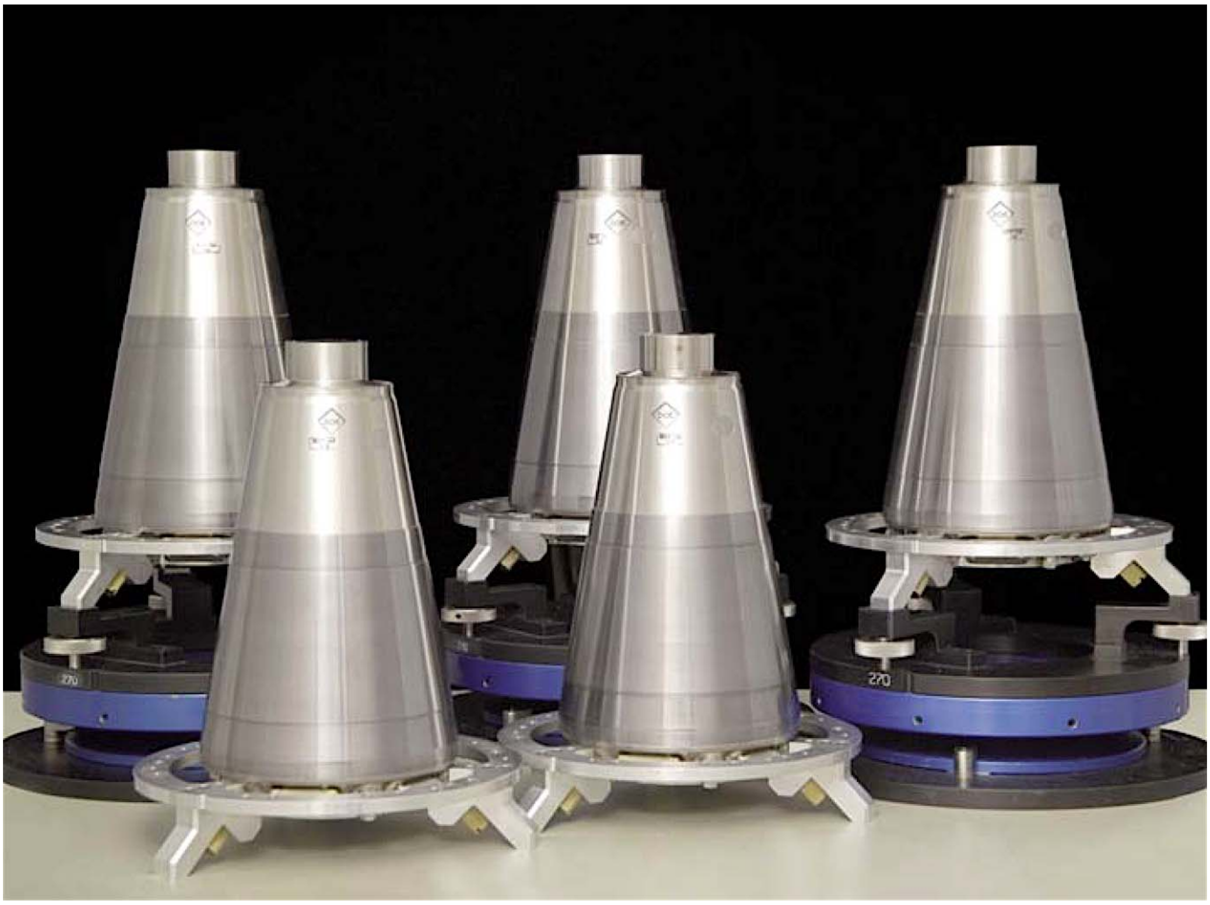
1 United States Department of Defense, *Nuclear Posture Review Report*, April 2010, p. 39, http://www.defense.gov/Portals/1/features/defenseReviews/NPR/2010_Nuclear_Posture_Review_Report.pdf.

2 H.M. Kristensen, M. McKinzie, and T.A. Postol, "How US nuclear force modernization is undermining strategic stability: The burst-height compensating super-fuze", *Bulletin of the*

The new Mk4A re-entry body has an enhanced Arming, Fuzing & Firing (AF&F) unit (see Figure 1) that is intended to “enable W76 to take advantage of higher accuracy of the D5 missile”.[3] The effect of this flexible new fuze increases the warhead’s kill-probability and gives the life-extended warhead “increased targeting flexibility and effectiveness”.[4]

Figure 1. A new fuze on the life-extended W76-1 warhead gives the weapon increased targeting flexibility and effectiveness. Courtesy of Hans M. Kristensen.



Atomic Scientists, 1 March 2017, http://thebulletin.org/how-us-nuclear-force-modernization-undermining-strategic-stability-burst-height-compensating-super10578.

3 United States Department of Energy, *Stockpile Stewardship and Management Plan: First Annual Update*, October 1997. Partially declassified and released under the Freedom of Information Act; available via: H.M. Kristensen, “Administration increase submarine nuclear warhead production plan”, *Federation of American Scientists*, 30 August 2007, https://fas.org/blogs/security/2007/08/us_tripples_submarine_warhead/.

4 “W76-1/Mk4A stockpile life-extension project”, *Los Alamos National Laboratory*, 2005, http://web.archive.org/web/20050101154749/http://www.lanl.gov/orgs/d/d5/projects/W76/W76-1-LEP-Overview.htm.

The United States military is also adding a more capable fuze to its current intercontinental ballistic missile (ICBM) force and its next-generation ICBM, meaning every warhead in the entire United States ballistic missile arsenal will eventually have enhanced target flexibility and an effectiveness. Potential adversaries will likely see this enhancement as further evidence that the United States is increasing its capability to conduct a successful first strike, especially when combined with the modernization of advanced conventional strike capabilities, cyber attack capabilities, and ballistic missile defences.

The B61-12 guided gravity bomb

A later example of an opaque enhancement of military capabilities is the B61-12 guided gravity bomb, which was authorized by the Obama administration in 2010. Officials have described the B61-12 as nothing more than a life-extension of an existing bomb that will provide no enhanced military capabilities, when in fact it appears to significantly increase the capability of the weapon. For example, when international visitors to Sandia National Laboratories in 2015 expressed concern that the United States was using life-extension programmes to increase military capabilities of nuclear weapons, National Nuclear Security Administration (NNSA) Principal Deputy Administrator Madelyn Creedon denied this, claiming that LEPs were only "replacing all the other parts and pieces of the warhead that just simply don't last".[5] Government officials in Europe, including in Belgium, Germany and the Netherlands, have made similar denials.[6]

This characterization is wrong. As a B61-12 programme official recently acknowledged, "it's not as much a refreshment of an old weapon as it is a complete modernization".[7] The United States military does not have a guided nuclear gravity bomb in its arsenal, so the B61-12 represents a "new" weapon. Initially, the B61-12 was said to "consolidate" only the B61-3, -4, -7, and -10 versions. But in 2013, the United States Department of Defense and the Department of Energy informed Congress that the B61-12's unique combination of increased accuracy and lower-yield options also "would allow us to pursue retirement of the B61-11, and the B83 gravity bomb".[8] The B61-12 is equipped with a new guided tail kit that is intended to increase its accuracy (see figure 2)—a deliberate strategy to reduce radioactive

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5 H. Clark, "International visitors learn about Sandia's nuclear weapons, nonproliferation work", *Sandia Lab News*, 13 November 2015, p. 9, http://www.sandia.gov/news/publications/labnews/_assets/documents/issues/labnews11-13-15.pdf.

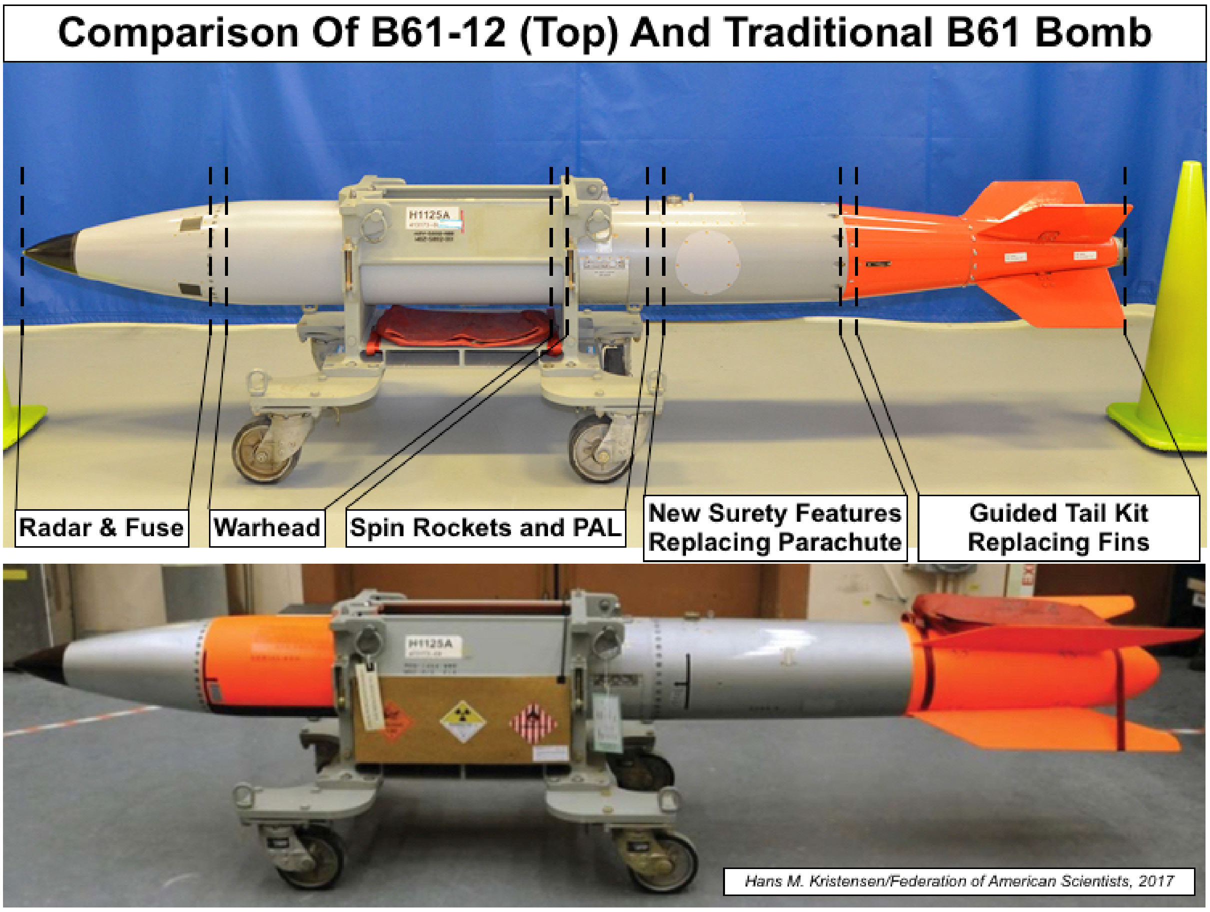
6 Personal conversations with the author, 2015.

7 J. Drew, "Flight testing of B61-12 nuke enters new phase", *Aerospace Daily & Defense Report*, 3 January 2017.

8 C. Hagel and E. Moniz, Letter to the Honorable Dianne Feinstein, Chairwoman of the Senate Appropriations Committee Subcommittee on Energy and Water Development, 6 November 2013.

fallout from an attack. As former Strategic Command (STRATCOM) Commander General Robert Kehler explained to Congress, “we are trying to pursue weapons that actually are reducing in yield, because we are concerned about maintaining weapons that …would have less collateral effect if the President ever had to use them …”. Kehler explained that the B61-12 was more flexible than the high-yield B83 both in terms of lower-yield options and delivery platforms.[9]

Figure 2. The B61-12 is equipped with a new guided tail kit to increase its accuracy. Courtesy of Hans M. Kristensen.



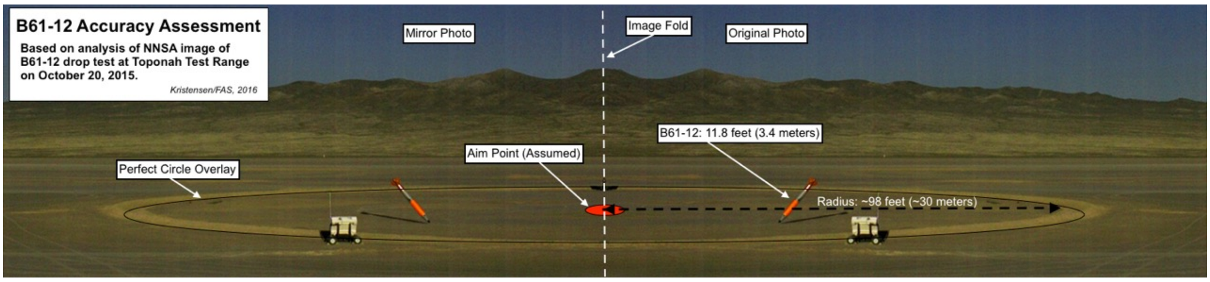
The United States government has been surprisingly clear that the increased accuracy gives the B61-12 the same military capabilities as much more powerful

9 R. Kehler, testimony, Nuclear Weapons Modernization Programs: Military, Technical, and Political Requirements for the B61 Life Extension Program and Future Stockpile Strategy: Hearing before the Subcommittee on Strategic Forces of the Committee on Armed Services, House of Representatives, One Hundred Thirteenth Congress, First Session, Hearing Held 29 October 2013, United States Government Printing Office, 2014, pp. 12–14, https://www.gpo.gov/fdsys/pkg/CHRG-113hhrg86075/html/CHRG-113hhrg86075.htm.

bombs in the arsenal. According to NNSA, "with the accuracy provided by a tail kit, the yield provided by today's lowest yield B61 variant [B61-4; up to 50 kilotons] would be sufficient to meet all of the strategic and nonstrategic requirements for gravity systems".[10] Or as another official said: The B61-12 will have *"the same military capability as the higher-yield bombs it replaces"* (emphasis added).[11] It is this "balancing reduced yield with improved accuracy" that enables the Air Force to pack the military capabilities of all existing gravity bombs into one bomb: the B61-12.

The United States has never deployed its full spectrum of strategic gravity bombs in Europe. The B61-12 will add those military capabilities to the posture once it arrives in Europe in the early-2020s. Just how accurate the B61-12 will be remains a secret. The guidance system does not use the Global Positioning System because it can be jammed and because pinpoint accuracy is not necessary for a nuclear explosion. Instead the B61-12 uses an internal guidance unit that is hardened against radiation effects and can steer the weapon closer to its target than current nuclear gravity bombs. A video of a fully guided test drop in October 2015 suggests an accuracy roughly three times better than current B61 versions (see figure 3).[12] That, in tandem with its apparent earth-penetrating capability in soil, could significantly enhance the

Figure 3. Analysis of a video of a B61-12 drop test in October 2015 indicates significantly increased accuracy. Courtesy of Hans M. Kristensen.



[10] Statement of Dr. Donald L. Cook Deputy Administrator for Defense Programs, National Nuclear Security Administration, U.S. Department of Energy, On the B61 Life Extension Program and Future Stockpile Strategy Before the House Armed Services Subcommittee on Strategic Forces, 30 October 2013, https://nnsa.energy.gov/sites/default/files/nnsa/2013-10-30%20HASC-SF%20Cook%20testimony_0.pdf.

[11] Statement of Robert Scher, Assistant Secretary of Defense for Strategy, Plans, and Capabilities Before the Senate Armed Services Subcommittee on Strategic Forces, 2 March 2016, p. 4, http://docs.house.gov/meetings/AS/AS29/20160302/104619/HHRG-114-AS29-Wstate-ScherR-20160302.pdf.

[12] H.M. Kristensen and M. McKinzie, "Video shows earth-penetration capability of B61-12 nuclear bomb", *Federation of American Scientists*, 14 January 2016, https://fas.org/blogs/security/2016/01/b61-12_earth-penetration/.

targeting capability of the B61-12 against underground facilities because of the special coupling effect created when a nuclear detonation occurs just a few meters below the surface.[13]

The increased capability and the options the B61-12 creates for strike planners to reduce the collateral damage from a nuclear strike have important implications for how military officials would advise the United States President about potentially using nuclear weapons, lowering the nuclear threshold.[14] General James Cartwright, the former STRATCOM Commander and Vice Chairman of the Joint Chiefs of Staff, told *PBS Newshour* in 2015: "If I can drive down the yield, drive down, therefore, the likelihood of fallout, et cetera… it likely could be more usable".[15] General Norton Schwartz, who was the Air Force Chief of Staff when the B61-12 military characteristics were developed, said in 2014 that "improved accuracy and lower yield is a desired military capability", and would result in both a different target set and make the existing weapon better.[16] At the same time, he said the increase in accuracy "has benefits from an employment standpoint that many consider stabilizing", arguing that the enhanced capabilities would enhance deterrence and make use less likely because adversaries would be more convinced that the United States is willing to use nuclear weapons if necessary.

Additional capabilities

The widespread integration of the same weapon on all delivery platforms creates another additional capability. Currently, different aircraft have to be armed with different weapons for different scenarios and missions. Some missions are not available in Europe because the very high-yield versions are only deployed in the United States. But by consolidating all gravity bomb capabilities into one weapon on all platforms (B-2, B-21, F-15E, F-16, F-35A, PA-200), the full spectrum of capabilities will be available everywhere: in the United States, in Europe, on strategic bombers, and on tactical aircraft. That adds significant flexibility to the air-based posture. This is further complemented by the new F-35A, a stealthy fifth-generation aircraft that will have a significantly enhanced capability to penetrate advanced air defences and possibly even deliver the B61-12 on target without ever being detected.

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[13] Ibid.

[14] H.M. Kristensen, "B61 LEP: increasing NATO nuclear capability and precision low-yield strikes", *Federation of American Scientists*, 15 June 2011, https://www.fas.org.blogs/security/2011/06/b61-12/.

[15] J. Cartwright, interview with *PBS Newshour*, 5 November 2015, https://www.youtube.com/watch?v=4wLe1eiPhi4.

[16] H.M. Kristensen, "General confirms enhanced targeting capabilities of the B61-12 nuclear bomb", *Federation of American Scientists*, 23 January 2014, https://www.fas.org/blogs/security/2014/01/b61capability/.

Finally, the United States is also planning a new nuclear air-launched cruise missile, known as the Long-Range Standoff (LRSO) missile. The current air-launched cruise missile (ALCM) has yields ranging from 5 to 150 kilotons, and is only delivered by the non-stealthy B-52. In contrast, a member of Congress who has been briefed on the programme says the LRSO "is low-yield"; it will also be delivered by both the B-2 and B-21 stealth bombers.[17] Defense officials have described the mission of the LRSO in terms that resemble a tactical nuclear weapon, as it provides "credible response options applicable to a broad spectrum of nuclear crises" by allowing the military to "respond proportionately to a limited nuclear attack" and "deter deliberate nuclear escalation like that envisioned in Russia's current strategy".[18] The discussion has caused concern among some that the LRSO is being planned for tactical nuclear missions and could be one of the first nuclear weapons to be used in a conflict.[19]

Russian Federation

Other nuclear-armed States are also modernizing their nuclear postures to improve capabilities and effectiveness. For its part, the Russian Federation is in the second phase of a generational upgrade of its entire nuclear posture that includes replacing Soviet-era weapons with newer ones that appear to have improved military capabilities.

Multiple independently targetable re-entry vehicles

For example, the single-warhead road-mobile SS-25 ICBM is being replaced with the SS-27 with multiple warheads—a multiple independently targetable re-entry vehicle (MIRV). Further upgrades with MIRV include a lighter road-mobile missile known as the SS-26 that will be easier to move around and hide in Russia's vast forests and a rail-based SS-27. Notably, as the MIRVed SS-27 Mod 2 replaces the remaining single-warhead road-mobile SS-25 ICBMS, Russia will likely violate a promise made by

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[17] J. Gueld, "Interview: HASC ranking member Adam Smith", *Defense News*, 30 June 2016.

[18] B. McKeon, letter to Senator Bernie Sanders, 5 February 2016, p. 2. For more examples of official descriptions of the LRSO mission, see: H.M. Kristensen, "LRSO: The nuclear cruise missile mission", *Federation of American Scientists*, 20 October 2015, https://fas.org/blogs/security/2015/10/lrso-mission/.

[19] See for example: D. Feinstein and E. Tauscher, "A nuclear weapons that America doesn't need", *New York Times*, 17 June 2016, http://www.nytimes.com/2016/06/18/opinion/a-nuclear-weapon-that-america-doesnt-need.html; W.J. Perry and A. Weber, "Mr. President, kill the new cruise missile", *Washington Post*, 15 October 2015, https://www.washingtonpost.com/opinions/mr-president-kill-the-new-cruise-missile/2015/10/15/e3e2807c-6ecd-11e5-9bfe-e59f5e244f92_story.html.

Soviet President Mikhail Gorbachev in October 1991 that "the number of our mobile MIRVed ICBMs will not be increased".[20]

Russia is also developing a new "heavy" ICBM known as *Sarmat* (SS-30) that will carry up to 10 warheads each. Moreover, it appears to be advancing a new special payload that may be a manoeuvrable re-entry vehicle designed to evade missile defence systems. The heavy emphasis on MIRV is partially a result of Russia trying to keep parity with the United States, which has significantly more strategic launchers (ballistic missiles and heavy bombers) as well as a large inventory of strategic warheads in reserve. Yet a heavily MIRVed ICBM force is bad for strategic stability because an advanced adversary such as the United States could destroy a large portion of Russia's strategic warheads with much fewer warheads.

There are other potential significant challenges to strategic stability. For instance, Russia is modernizing its ballistic missile submarines with a new missile having a greater warhead-carrying capacity. Thus in the future submarines will carry a greater share of Russia's strategic nuclear warheads. The potential vulnerability of the ballistic missile submarine force to anti-submarine warfare is a major concern. In addition, Russia is upgrading its bombers with new long-range conventional cruise missiles; these have already been used in Syria. As Christine Parthemore's chapter in this study discusses, the mixing of long-range conventional and nuclear cruise missiles on bombers creates risks of misinterpretation and overreaction in a crisis because an adversary cannot tell whether a deployment or an attack involves conventional or nuclear weapons.

Tactical nuclear weapons

The Russian military still relies on tactical nuclear weapons for its non-strategic forces. The Navy is thought to have a significant inventory of nuclear warheads for use by cruise missiles, anti-submarine rockets, torpedoes and depth bombs. The Air Force also has nuclear bombs for some of its tactical fighter-bombers, and the air defence and ballistic missile defence forces also appear to rely on nuclear weapons to a limited extent. Overall, the Russian reliance on tactical nuclear weapons is thought to be intended to compensate for its less capable conventional forces in limited regional scenarios.

In the unilateral presidential initiative of October 1991, Soviet President Mikhail Gorbachev promised that all nuclear warheads for "tactical rockets" would be eliminated.[21] Yet a limited number of warheads for short-range ballistic missiles

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[20] At that time the Soviet Union deployed about 92 SS-24 rail-mobile launchers for MIRVed ICBMs, compared with about 70 road-mobile MIRVed SS-27 Mod 2 (RS-24) ICBMs today. See S.J. Koch, *The Presidential Nuclear Initiatives of 1991-1992*, National Defense University Press, September 2012, p. 30, http://ndupress.ndu.edu/Portals/68/Documents/casestudies/CSWMD_CaseStudy-5.pdf.

[21] Ibid., p. 29.

(SRBMs) appears to have been retained and modernized. In 8 of its 10 SRBM regiments, the nuclear-capable SS-21 (*Tochka*) SRBM has been replaced or is in the process of being replaced with the nuclear-capable SS-26 (*Iskander-M*) SRBM. The SS-26 has more than twice the range of the SS-21, is thought to have greater accuracy, and each SS-26 launcher carries two missiles compared with a single missile carried on the SS-21 launcher. One of the last SRBM regiments to be upgraded is in the westernmost district of Kaliningrad. SS-26 launchers from the Luga regiment near Saint Petersburg have been deployed to Kaliningrad on temporary exercises for the past several years. Permanent deployment is expected in a couple of years, which has caused concern in neighbouring countries, which are also enhancing their military forces.

In other developments, Russia has begun deployment of the *Kalibr* sea-launched cruise missile (SLCM), which exists in both a conventional version for surface ships and a nuclear land-attack version for select front-line nuclear-powered attack submarines. The nuclear version violates a 1992 pledge from President Boris Yeltsin.[22] In addition, Russia allegedly has deployed a state-of-the-art ground-launched cruise missile known as the SSC-8 in violation of the 1987 Intermediate-Range Nuclear Forces (INF) treaty. The SSC-8 is thought to be dual-capable with a focus on conventional operations but with a nuclear warhead option. The redeployment of INF weapons has caused fear of a return to the nuclear stand-off in Europe in the 1980s, but so far there is no indication that the United States intends to develop and deploy an INF weapon in Europe.

Conclusion

Although there is not space in this chapter to be more comprehensive, all of the nuclear-armed States are busy modernizing and improving their nuclear weapons. The People's Republic of China is also significantly improving the military capabilities of its nuclear weapons. During the past decade, China has deployed several new solid-fuel ballistic missiles that are more capable. This includes the road-mobile DF-31 and DF-31A ICBMs as well as the JL-2 SLBM on the new Jin-class submarines. China has also equipped some of its older silo-based ICBMs with multiple warheads, and is developing a road-mobile ICBM with similar capability.[23] These enhancements will enable China to target adversarial facilities with greater accuracy and effectiveness.

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[22] Ibid., p. 35.

[23] For an insightful overview of Chinese nuclear capabilities, see: E. Heginbotham et al., *China's Evolving Nuclear Deterrent: Major Drivers and Issues for the United States*, The RAND Corporation, 2017, http://www.rand.org/content/dam/rand/pubs/research_reports/RR1600/RR1628/RAND_RR1628.pdf.

Improving military capabilities appears to be an inherent characteristic of nuclear weapons modernization. But within the past decade or so, the effort appears to have taken an upswing with additional improvements and a reaffirmation of the role of nuclear weapons, including in limited scenarios. Pakistan for instance has embraced what it calls a full-spectrum deterrent that includes a growing inventory of non-strategic nuclear weapons, raising concerns that they might be distributed sooner to the armed forces in a crisis and are intended for use earlier in a conflict than its longer-range weapons. Potential use of tactical nuclear weapons does not necessarily require Indian use of nuclear weapons against Pakistan first, but could happen in response to an overwhelming Indian conventional invasion.

Equally concerning is that Russian officials have made various explicit nuclear threats and allegedly carried out simulated nuclear strike exercises against several countries in Europe. Combined with yet-to-be-substantiated claims by Western officials that Russia has lowered the threshold for when it would consider using nuclear weapons in a conflict, this has triggered a return to Cold War-like discussions about the utility of nuclear weapons and the need to respond with updated capabilities and strategies. One former United States senior defence official suggested that "Moscow is using *an entirely different definition* of 'escalating to deescalate'" by "employing the threat of selective and limited use of nuclear weapons *to forestall* opposition to *potential* aggression".[24] The implication would be that Russia would not hesitate to launch a few nuclear weapons even before significant fighting had broken out. However, other officials say privately that the fear of Russia's so-called "escalate-to-deescalate" strategy is overblown and being exaggerated by defence hawks.

The United States does not issue explicit nuclear threats lightly but talks about deterrence and reassurance. Still, the message to potential adversaries is the same. While United States officials criticize Russia for its escalate-to-deescalate strategy, they appear to employ a similar strategy. As STRATCOM Admiral Cecil Haney said in 2016, "At the end of the day… our adversaries and potential adversaries must understand that they cannot escalate their way out of a failed conventional conflict, that they will not reap the benefits they seek and that restraint is always the better option. Our nation is prepared to manage escalation using all its instruments of national power".[25] Later, Haney added: "If deterrence fails, you take the lead to bring America's nuclear force to bear, providing "deterrence through strength and global strike on demand".[26] Further, some nuclear modernization programmes—the LRSO

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24 F. Miller, *Keynote, 2015 USSTRATCOM Deterrence Symposium*, 29 July 2015, http://www.stratcom.mil/Media/Speeches/Article/986412/keynote-2015-usstratcom-deterrence-symposium/.

25 C.D. Haney, *Remarks at the 2016 Deterrence Symposium*, 27 July 2016, http://www.stratcom.mil/Media/Speeches/Article/986498/remarks-by-adm-cecil-d-haney-at-the-2016-deterrence-symposium/.

26 C.D. Haney, 8th Air Force/Joint Functional Component Command for Global Strike/Task Force 204 Change of Command, 4 October 2016, statement on file with author.

and B61-12—are now explicitly and prominently being justified with reference to their role in limited regional scenarios. And nuclear and conventional forces are increasingly being integrated into regional deterrence strategies with some officials describing a fluid demarcation between conventional and nuclear operations.

In conclusion, there is evidence that nuclear weapons modernization programmes and evolving military strategies are increasingly based on assumptions about a growing reliance on nuclear weapons in limited scenarios below the strategic level. This trend brings with it increased risks that nuclear weapons could become involved in a regional conflict and potentially be used for the first time since 1945.

Chapter 4
The Unique Risks of Nuclear-Armed Cruise Missiles

Christine Parthemore

Introduction

One nuclear risk reduction concept gaining attention is a universal end to all nuclear sea-, air-, and ground-launched cruise missiles. This chapter explores the current state of debate regarding these weapons, and explains in brief why nuclear-armed cruise missiles are viewed by many as carrying greater risks of misperception, miscalculation, and escalation than other nuclear weapons. It concludes by identifying the risk reduction benefits of stopping further spread of nuclear-armed cruise missiles, ending further investment in them, and eliminating current stockpiles.

The state of affairs

As of February 2017, three States have reported stocks of nuclear-armed cruise missiles. France upgraded its nuclear air-launched cruise missiles in 2011 with the *Air-Sol Moyenne Portée-Amélioré*. The United States maintains 575 air-launched cruise missiles with a service life to 2030, with plans to begin developing around 1,000 Long-Range Standoff (LRSO) air-launched cruise missiles to replace the existing 575. Along with the Soviet Union (later Russia), it had cut its ground-launched nuclear-armed cruise missiles with the 1987 Intermediate-Range Nuclear Forces (INF) Treaty, and later unilaterally retired its nuclear sea-launched cruise missiles in 2011. While details are less clear, Russia has nuclear sea- and air-launched cruise missiles and is believed to have improved both capabilities with its modernization efforts. All three States have also been modernizing their ballistic missile forces.

The United Kingdom has actively decided not to build nuclear-armed cruise missiles, including for many of the reasons outlined in this chapter. A global approach to ending nuclear-armed cruise missiles would therefore entail just a few States disarming their existing weapons. For other States with nuclear weapons, they would need only to pledge not to develop them. This includes China, India, and Pakistan, all of which have the technical capability of building arsenals of nuclear-armed cruise missiles but have restrained so far.

An expanded awareness

Awareness of the risks of nuclear-armed cruise missiles in the changing world security environment expanded significantly in 2015–2016. Many experts and national leaders became vocal for the United States to reconsider its plans to replace its final remaining nuclear cruise missile programme, the LRSO. Several Congressional leaders and numerous retired defence and diplomatic officials were increasingly vocal throughout 2016 on the need to rethink or simply end the programme. Members of the House of Representatives and the Senate raised serious questions about the LRSO in hearings and op-eds throughout 2016, exposing the worrisome trend that many Pentagon officials view it as a potentially destabilizing nuclear weapon intended for operational more than strategic use.

In parallel, officials and experts from around the world have stepped up to begin conceptualizing a global end to nuclear-armed cruise missiles. Participants in the United States–Russian Deep Cuts dialogue recommended in June 2016 that "the United States and Russia should address the destabilizing effects of nuclear armed cruise missiles".[1] The Swedish and Swiss governments proposed in a formal paper to the May 2016 Open-ended Working Group (OEWG) "that States initiate or engage in a process to reduce risks associated with nuclear armed cruise missiles".[2] They followed by co-hosting a side event at the United Nations First Committee session in October 2016 dedicated to the subject. In August 2016, the Hiroshima Roundtable of high-level experts from Japan, the Republic of Korea, China, and the United States formally proposed "that there be international negotiations on the prohibition of the development and acquisition of long-range cruise missiles with nuclear warheads to bridge the gap between nuclear states and non-nuclear states and open a new round of negotiations to reduce the risk of nuclear war".[3]

These are just a few public examples of how the subject has rapidly gained traction. The specific risks of nuclear-armed cruise missiles, and concerns that the world may be on the cusp of a major expansion of these weapons, have driven this urgency.

Risks of nuclear-armed cruise missiles

A number of experts consider the risks of miscalculation, misperception, rapid escalation, and arms racing to be greater for nuclear-armed cruise missiles than for many other types of nuclear weapons. Some of these risks are inherent to the characteristics of current and planned nuclear-armed cruise missiles, while others stem from perceptions of rhetoric regarding their use and other factors.

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1 The Deep Cuts Commission, *Back from the Brink: Toward Restraint and Dialogue between Russia and the West*, Institute for Peace Research and Security Policy at the University of Hamburg, 2016, p. 26, https://www.armscontrol.org/files/Third_Report_of_the_Deep_Cuts_Commission_English.pdf.

2 United Nations, *Nuclear Armed Cruise Missiles: Submitted by Sweden and Switzerland*, UN document A/AC.286/WP.39, 10 May 2016, para. 13.

3 *Hiroshima Round Table 2016: Chairman's Summary*, 27–29 August 2016, para. 2, https://www.pref.hiroshima.lg.jp/uploaded/attachment/219123.pdf.

First, nuclear and non-nuclear States have long held concerns regarding the ambiguity introduced by cruise missiles capable of carrying both conventional and nuclear warheads, as this may increase the risk of miscalculation and overreaction. In 2013, then-Secretary of State for Defence of the United Kingdom Philip Hammond described this succinctly: "A cruise-based deterrent would carry significant risk of miscalculation and unintended escalation. At the point of firing, other states could have no way of knowing whether we had launched a conventional cruise missile or one with a nuclear warhead. Such uncertainty could risk triggering a nuclear war at a time of tension".[4]

In addition to this inherent issue, rhetoric regarding the potential employment of this type of nuclear weapon can add to the ambiguity challenge in peacetime and wartime, in particular when it blurs the lines between conventional and nuclear conflict. Nuclear cruise missiles are often discussed by United States and Russian officials and experts in terms of their utility for "limited" nuclear conflict or for "de-escalatory" nuclear strikes. Whether it is intentional or not, such rhetoric sends a strong signal that these weapons are intended for operational use, not solely for deterrence. These layers of ambiguity can be especially worrisome for countries proximate to possessor States as they may increase the odds of nuclear weapons being used in their territory or near their borders. Additionally, the increasingly frequent launching of conventional sea- and air-launched cruise missiles by Russia and North Atlantic Treaty Organization (NATO) States in the Syrian conflict and against Islamic State in Iraq and the Levant certainly put into context the ambiguity concerns regarding the continuing possession of their nuclear variants.

Second, beyond a recipient potentially reacting to a conventional strike as if it were nuclear, some specific, publicly known attributes of nuclear-armed cruise missiles add to the risks they carry for misperception, miscalculation, and rapid conflict escalation. For the air-launched variety, they fly low and are designed to avoid detection, are difficult to defend against, can be launched without warning, and cannot be recalled once launched. Sea-launched nuclear cruise missiles raise their own concerns, though there is little transparency regarding Russian stockpiles of these weapons. Regardless of the intentions of their possessors, other States may view nuclear-armed cruise missiles as decidedly first-strike weapons that could be used to decapitate their command and control systems, which, rather than deterring them, could unnecessarily provoke them.[5]

Third, nuclear-armed cruise missiles may lower the threshold of nuclear weapons use, especially if they are designed to provide decision makers with greater precision or

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[4] P. Hammond, "The alternatives to Trident carry an enormous risk", *The Telegraph*, 3 February 2013, http://www.telegraph.co.uk/news/uknews/defence/9843848/The-alternatives-to-Trident-carry-an-enormous-risk.html.

[5] B. Watson, "Weapons of the Syrian War: cruise missiles", *Defense One*, 19 July 2016, http://www.defenseone.com/ideas/2016/07/weapons-syrian-war-cruise-missiles/129641/.

lower- or variable-yield nuclear options. For Russia, this is most starkly seen in its concept of "de-escalating" a conventional conflict by limited use of a long-range nuclear cruise missile (or other extended-range assets).[6] Similar logic has been adopted by some experts and officials from other countries as well. Concerns regarding the relative utility of nuclear-armed cruise missiles have been amplified by specific statements from United States officials indicating that investments in nuclear cruise missiles are to provide diverse options for scenarios in which deterrence has failed. In an informal note to Congress, Pentagon staff stated, as an example, “the President might require a nuclear response to a nuclear attack in order to restore deterrence and prevent further attacks, even if a conventional weapon could also destroy the target".[7]

These sentiments regarding nuclear-armed cruise missiles and weapons with similar attributes may inadvertently increase nuclear risks. The rationale could decrease deterrence and increase escalation risks overall if it convinces a State whose leader chooses to use nuclear weapons that even a nuclear response will be limited and survivable. Public dialogue focused on limited nuclear responses, via cruise missiles or other devices, may also convince regimes that political will for massive retaliation has diminished, and thereby reduce the prospects of deterring grave acts on their part.

Advocates for stand-off nuclear weapons such as the LRSO argue that a chief benefit is the flexibility to use a nuclear weapon while keeping pilots at a safer distance. While there is no disputing that this would be a warfighting benefit, it may be read as the possessor State maintaining a lower threshold for using stand-off nuclear cruise missiles than for other delivery systems. The concept that a State's pilots could be kept relatively safe in a conflict in which nuclear weapons are in use also signals a belief that nuclear exchanges can be controlled and won (see Box 1 for more).

Finally, the world is at the cusp of a potentially destabilizing increase in nuclear cruise missile capabilities, unless action is taken to alter the trajectory. In January 2017, Pakistan successfully tested a nuclear-capable cruise missile from a submarine for the first time. India has previously tested its nuclear-capable cruise missiles, though

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6 N.N. Sokov, “Why Russia calls a limited nuclear strike ‘de-escalation’”, *Bulletin of the Atomic Scientists*, 13 March 2014.

7 Statement of Robert Scher, Assistant Secretary of Defense for Strategy, Plans, and Capabilities, Before the Senate Armed Services Committee on Strategic Forces, 9 February 2016, http://www.armed-services.senate.gov/imo/media/doc/Scher_02-09-16.pdf. Note: Scher’s remarks included United States nuclear cruise missiles, as well as combinations of other assets; H.M. Kristensen, “Flawed Pentagon nuclear cruise missile advocacy”, *Federation of American Scientists*, 10 June 2016, https://fas.org/blogs/security/2016/06/dod-lrso-letter/. For both sides to this debate regarding nuclear-armed cruise missiles and other relevant weapons, see W.J. Broad and D.E. Sanger, “As U.S. modernizes nuclear weapons, ‘smaller’ leaves some uneasy”, *New York Times*, 11 January 2016, https://www.nytimes.com/2016/01/12/science/as-us-modernizes-nuclear-weapons-smaller-leaves-some-uneasy.html.

some tests have failed. There is some speculation that Russia's purported INF Treaty breach involves a programme to produce a ground-launched cruise missile.[8] Though China has been restrained to date, it is capable of developing and stockpiling nuclear-armed cruise missiles in response to any of these developments, if they continue.

Box 1: The Myth of Stabilization

Since the most recent prospects of the international community targeting nuclear-capable cruise missiles for elimination began in 2015–2016, advocates for maintaining these weapons have argued that they are not inherently destabilizing. The basis of the argument is often that several States have had these weapons over a period during which they claim nuclear powers maintained strategic stability.

For the United States, advocates extend this argument to the nuclear cruise missile element of its modernization plans: the LRSO will not be destabilizing because it will replace the nuclear air-launched cruise missile (ALCM). At times, they have extended the argument further, claiming that actions by the United States to stop development of its LRSO and/or getting rid of the current ALCM would themselves be destabilizing moves.

There are several flaws to this logic. Based on existing public knowledge, the LRSO will be a more capable weapon than the predecessor ALCM. The LRSO is likely to have stealth capabilities, a longer range, and greater accuracy, among other properties that raise new concerns by potential adversaries and alter strategic calculations. Delivery system upgrades also play into this equation: the ALCM is deployed with the B-52 bomber, neither of which is stealthy (thus the original need for a stand-off capability).[9] If the LRSO is developed as a stealth nuclear cruise missile and deployed on a stealth bomber, this will certainly introduce new dynamics, and illustrates why the argument that the LRSO will not be destabilizing because it replaces the ALCM may lack credibility to some audiences.

Additionally, it is ahistorical to claim that reductions of nuclear-armed cruise missiles by possessor States will be destabilizing, as the primary two possessor States have taken several steps in this direction already. In a bilateral move, the Soviet Union and United States agreed to the INF Treaty in 1987, by which the States agreed to eliminate ground-launched cruise missiles in the treaty's stated range. President

[8] J. Berlinger, "South Asia's nuclear one-upmanship ramps up with Pakistan missile test", *CNN*, 10 January 2017, http://edition.cnn.com/2017/01/10/asia/pakistan-submarine-missile/; R. Bedi, "India's fourth Nirbhay cruise missile test flight fails", *IHS Jane's Defence Weekly*, 22 December 2016, http://www.janes.com/article/66501/india-s-fourth-nirbhay-cruise-missile-test-flight-fails; H.M. Kristensen, "Kalibr: savior of INF Treaty?", *Federation of American Scientists*, 14 December 2015, https://fas.org/blogs/security/2015/12/kalibr/.

[9] S. Young, "Just how new is the new, nuclear-armed cruise missile?", *All Things Nuclear*, 13 January 2016, http://allthingsnuclear.org/syoung/the-new-cruise-missile.

George H.W. Bush ordered nuclear sea-launched cruise missiles taken off American submarines in a unilateral 1991 decision. President Obama then retired these missiles in 2011. The primary negative reactions to these moves were not by nuclear powers, but by allies of the United States (in the case of the sea-launched nuclear cruise missiles) that were concerned that it signalled a weakening of resolve regarding security commitments. However, based on research and extensive personal discussions with representatives of these States, it is clear that better consultation and communication could have potentially alleviated these concerns and may mitigate similar concerns regarding future reductions.

Combined, all of these attributes show why dual-capable cruise missiles contribute an outsized risk of arms racing, both for offensive capabilities and offense–defence contests.

Risks to nuclear state credibility

In addition to the risks outlined above, further investment in nuclear-armed cruise missiles may reduce the credibility of States in possession of nuclear weapons. First, these weapons are part of the larger challenge that nuclear weapons possessors have faltered in concrete steps to continue reducing nuclear stockpiles and risks. Several years of relative stasis and continued investment in extensive modernization plans are sapping the credibility of the major nuclear powers, contributing to the momentum of the humanitarian initiative and ban treaty movements and are placing the global non-proliferation regime under tremendous strain. The fact is that today's nuclear-armed cruise missiles are viewed by many as non-strategic and redundant to other conventional and nuclear capabilities. They, more than some other types of nuclear weapons, call into question the credibility of possessor States that argue for their necessity.

Further, for some States, there is a risk that continued or future investments in nuclear-armed cruise missiles will be seen as contradictory to their own policies. The United States' investment in the LRSO may do this in multiple ways. There is concern that this investment presents a gap between modernization plans and declaratory policies to reduce the role of nuclear weapons, which could reduce trust and alter strategic calculations by other nuclear-weapon States. As there is a robust conventional cruise missile in the extended range Joint Air-to-Surface Standoff Missile (JASSM), the LRSO appears to contradict the United States' policy of favouring conventional alternatives to nuclear weapons. Additionally, many international audiences view the LRSO as a new nuclear weapon rather than a replacement programme, and therefore believe it contradicts declared United States policy.[10] If

[10] H.M. Kristensen, "Forget LRSO; JASSM-ER can do the job", *Federation of American Scientists*, 16 December 2015, https://fas.org/blogs/security/2015/12/lrso-jassm/; C. Parthemore, "What would our friends think? Views from allies on the future of U.S. nuclear armed cruise missiles",

India, Pakistan, or China choose to develop stockpiles of nuclear-armed cruise missiles, any inconsistencies with their own declared policies will likewise raise concerns that extend beyond the weapons themselves. If allies or adversaries of any State with dual-capable cruise missiles cease to believe that stated policies are not credible, it may contribute to a greater risk of miscalculation.

Finally, the world is now seeing doubts regarding the credibility of many States' commitments against nuclear testing. If States wish to newly develop nuclear-armed cruise missiles, tests of the delivery systems may presage a willingness to conduct relevant nuclear tests despite past commitments. If modernization programmes in States such as the United States and Russia continue to bleed into development of new nuclear capabilities as they have and may in the future regarding cruise missiles, they may face internal pressures or leadership decisions to return to testing.

A risk-reduction path

The strongest approach to reducing these risks would be a broad, international agreement to pivot away from nuclear-armed cruise missiles. Switzerland and Sweden introduced this concept to the OEWG in May 2016, recommending that a process of reducing risks of these specific weapons "could include actions to limit, prevent deployment of and lead to a ban on all nuclear-armed cruise missiles, regardless if they are launched from the sea, air or ground. These actions could be taken by States on a unilateral, bilateral, plurilateral or multilateral basis".[11]

This would be a pragmatic move, and holds the possibility of engaging nuclear weapons States and non-nuclear weapons States in productive dialogue together. A broad movement away from nuclear-armed cruise missiles contains the potential to bring China and the United States together in conversations on reducing nuclear risks, which would mark a significant advancement from today's worrisome dearth of nuclear dialogue between the two States. Of course, such an approach could also serve as a narrow, straightforward means of bringing Russia and the United States back into dialogue. For China as well as non-nuclear weapon States in the region, it would promote stability to actively prevent the spread of nuclear-armed cruise missiles across East and South Asia. As Russia and India plan further collaboration regarding cruise missiles, these States discussing a global end to nuclear-capable cruise missiles could be an important step in signalling that this cooperation involves only conventional weapons.

Medium.com, 6 May 2016, https://medium.com/@clparthemore/what-would-our-friends-think-1e106adbc6a9#.1wy97l1ec.

[11] United Nations, *Nuclear Armed Cruise Missiles: Submitted by Sweden and Switzerland*, UN document A/AC.286/WP.39, 10 May 2016, para. 13.

Verification would be a significant topic to work through as States discuss a future of conventional-only cruise missiles. This is a political issue more than a technical one, and is well worth pursuing without haste. In past cases, verification discussions and the conduct of their agreed regimes contributed to trust and understanding among States—a powerful force in reducing risk. As United States President Ronald Reagan said of the INF Treaty:

> The verification measures in this treaty are also something new with far-reaching implications. On-site inspections and short-notice inspections will be permitted within the Soviet Union. Again, this is a first-time event, a breakthrough, and that's why I believe this treaty will not only lessen the threat of war, it can also speed along a process that may someday remove that threat entirely.[12]

As for the INF Treaty and other agreements, a verification system for nuclear-armed cruise missiles would likely require a combination of site visits and technical exchanges by participating States, national technical means, agreement to short-notice inspections, and a mechanism for adjudicating concerns.

Conclusion

Some experts find the concept of focusing on nuclear cruise missiles more feasible in the near-term than on other nuclear risk reduction steps. To some European States, it could be a means of refocusing attention from questions about the B61 guided gravity bomb and dual-capable aircraft to nuclear weapons capabilities that they find less important for their own and alliance security. Negotiating an end to these weapons may also take a step-wise approach that does not require immediate changes to existing arsenals, but instead could start with interim steps such as agreements by States to forego investments in future stocks or a regional agreement to keep this type of nuclear weapon out of Asia. Beginning discussions to flesh out these and other options could show commitment to finding achievable next steps in nuclear arms control and disarmament.

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[12] See "The Summit: Excerpts From Reagan Address on the Talks: 'Toward Building a More Durable Peace'" *New York Times*, 11 December 1987, http://www.nytimes.com/1987/12/11/world/summit-excerpts-reagan-address-talks-toward-building-more-durable-peace.html.

Chapter 5
Risks of Nuclear Command and Control Accidents

Pavel Podvig

Introduction

The nuclear command and control systems that exist today were developed and evolved during the Cold War. As a result, their design and function reflect the often complex nature of nuclear confrontation between the two nuclear superpowers as well as the evolution of the capabilities of their offensive forces. Nuclear deterrence, which emerged as the central organizing principle of the Cold War relationship, required a significant degree of survivability of strategic delivery systems and of the military command structure in order to maintain a credible threat of retaliation. Advances in the capabilities of offensive weapons, including the emergence of intercontinental ballistic missiles (ICBMs) and improvements in missile accuracy, led to the development of increasingly sophisticated means of detecting an incoming attack and ensuring that the command and control system was robust enough to guarantee retaliation.

Each nuclear-armed State has its own way of dealing with the issue of credibility of its deterrence. However, the nuclear postures of the two States with the largest nuclear arsenals, Russia and the United States, include an option known as "launch-on-warning" that provides them with the capability to launch their missiles at the sign of an incoming attack, before the attacking missiles reach their targets. To maintain the launch-on-warning capability, the United States and Russia have deployed early-warning systems to detect an attack; they also developed command and control procedures that allow prompt execution of an order to launch a retaliatory strike. This, in turn, requires constantly keeping a significant number of ballistic missiles in very high readiness, or on a "hair trigger", so they can be launched minutes after receiving an order.

The risks of launch-on-warning

The launch-on-warning option appears to remain an essential element of the nuclear postures of the United States and Russia. Other States may also maintain the capability to launch their nuclear forces on short notice, especially during a crisis. It can be argued that this option strengthens deterrence, since a demonstrated capability to launch on warning removes incentives for the other side to strike first. It also appears to provide the only way to ensure the survivability of vulnerable targets, such as ballistic missile silos or the command and control system itself. Additionally, there is a legacy factor: since the United States and the Soviet Union (later Russia) invested in the development of the infrastructure that supports launch-on-warning, such as early-warning satellites and radars, they built their strategic forces with that option in mind. As a result, they now find it difficult to eliminate hair-trigger alert from their nuclear postures, even in the face of consistent concerns about associated risks.

There are several sources of risk that are associated with the operation of a command and control system designed to support launch-on-warning. The main concern is the highly compressed timeline that leaves very little time for a thorough assessment of information and makes the system vulnerable to a false alarm. It has been estimated that even though it takes an ICBM about 30 minutes to reach its target, the United States President would have no more than eight minutes to make a decision to launch a retaliatory strike.[1] In Russia, that time could be considerably shorter, mostly because of the different geographic position of the country and a different configuration of its early-warning system. In some scenarios the Russian President would not be able to start deliberations before the attacking missiles arrive at their targets.[2] Given the limited time available for evaluating the situation, it is possible that a false alarm would not be properly recognized in time to avert a decision to launch a response strike.

A history of false alarms

The history of United States and Soviet and Russian command and control systems shows that false alarms do occur with some regularity. Indeed, early-warning and command and control systems are designed to deal with these occurrences by implementing procedures that are supposed to recognize false alarms. Most signals of ambiguous nature are filtered out by operators of the early-warning radars and satellites and never reach higher levels of the command and control system. However, this mechanism may not work in those cases when the system has to deal with unexpected and unforeseen circumstances.

There are several known cases when a false alarm generated by an early-warning system was not immediately recognized as such. In the 1970s, both the United States and the Soviet Union experienced what can be described as a "training tape" accident, in which the data used to simulate a nuclear attack was fed into the combat system. In other cases, a false alarm was generated by a technical malfunction (a computer chip in an 1980 incident in the United States) or a natural event that the system was not trained to recognize (a reflection off the clouds in a September 1983

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1 Nuclear Threat Initiative, "Is launch under attack feasible?", 4 August 2016, http://nti.org/6687A.

2 P. Podvig, "Reducing the risk of an accidental launch", *Science & Global Security*, vol. 14, no. 2–3, 2006, pp. 75–115.

incident in the Soviet Union).[3] In January 1995, as a result of an apparent miscommunication exacerbated by the unusual nature of the event, operators of the Russian early-warning system were not prepared for a launch of a sounding rocket from a test site in Norway. The 1995 event is often described as one in which the false alarm was elevated to the level of the President, though the evidence is conflicting and it does appear that the incident was in fact resolved before it got to that point.

Limits of prevention

One feature that is common to these cases of serious false alarms is that each involved an event or a combination of events, whether natural or man-made, that the system was not expected to encounter. Accordingly, although the procedures designed to deal with false alarms provided a useful framework for resolving the issue, in most cases the resolution also required an element of human judgment, which suggests a major vulnerability of the system. In that regard it is especially important to note that even though the command and control system includes safeguards against potential errors, the primary mission of the system is ultimately to support guaranteed retaliation, so it can be expected to act accordingly.

An analysis of past false alarms also indicates that there are certain limits to the ability of command and control systems to learn from experience and adjust their practices in order to exclude future incidents.[4] Although some technical and organizational measures can be implemented relatively easily, for example with the strict separation of training and combat systems to prevent "training tape" incidents, it is of course impossible to predict all circumstances the early-warning and command and control systems may encounter in the future.

Contemporary challenges

The problem is exacerbated by the fact that the nuclear command and control system is operating in an increasingly complex environment characterized by numerous interactions between various independent players, which may create situations that are impossible to predict or prepare for. The number of states that have ballistic missiles has increased in the last two decades. At the same time, arrangements that would regulate ballistic missile launches (for example, through

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[3] W. Burr, "The 3 a.m. phone call: false missile attack warning incidents, 1979–1980", *National Security Archive Electronic Briefing Book No. 371,* 1 March 2012, http://nsarchive.gwu.edu/nukevault/ebb371/; P. Podvig, "Reducing the risk of an accidental launch", *Science & Global Security*, vol. 14, no. 2–3, 2006.

[4] For more examples, see E. Schlosser, *Command and Control: Nuclear Weapons, the Damascus Accident, and the Illusion of Safety*, Penguin Press, 2013; and P.M. Lewis et al., *Too Close for Comfort: Cases of Near Nuclear Use and Options for Policy*, Chatham House, 2014.

notifications) have been much slower to emerge. The spread of other systems, such as cruise missiles and drones, and their increasingly frequent use in military conflicts can also add to the complexity of the situation, as can the development of capabilities to detect missiles. The involvement of various states (and potentially non-state actors) and of a range of delivery systems could make interactions among them very unpredictable. Information about relevant military activities is also often not available to the public; close calls are rarely recognized and often ignored. Accordingly, it is extremely difficult to analyse the overall degree of risk associated with command and control systems.

Complex interactions

There is some information, however, that can provide a general understanding of the nature of the interactions that might affect the nuclear command and control systems in the event of a crisis. The events of the Cuban Missile Crisis in 1962 have been studied in considerable detail.[5] In a more recent example, the report on the terrorist attacks on the United States in September 2001 provides a fairly detailed picture of multiple activities that were underway on the day of the attacks. As it turns out, on 11 September 2001, Russian strategic forces were conducting an exercise that involved bomber flights in the direction of the United States. On the same day, United States Strategic Command (STRATCOM) was conducting its own exercise, Global Guardian, in which nuclear bombs were loaded on strategic bombers at three air bases.[6] Meanwhile, the North American Aerospace Defense Command (NORAD) was planning to hold its own exercise, Vigilant Guardian, "which postulated a bomber attack from the former Soviet Union".[7] Although Russia grounded its bombers as soon as it was able to assess the situation, and STRATCOM and NORAD cancelled their exercises to focus on the terrorist attack, the coincidence of timing is alarming. Another event that illustrated the potential danger of unexpected interactions took place in September 2013, when an unannounced test of the missile defence system conducted by Israel over the Mediterranean Sea coincided with a rather tense moment in the Syrian conflict. The ballistic missile used in the test was detected by one of the Russian early-warning radars and prompted Russia to bring the command centre of the General Staff on high alert.[8]

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5 S.D. Sagan, *The Limits of Safety: Organizations, Accidents, and Nuclear Weapons*, Princeton University Press, 1993.

6 W.M. Arkin and R. Windrem, "Secrets of 9/11: new details of chaos, confusion emerge", *NBC News*, 11 September 2016, http://www.nbcnews.com/storyline/9-11-anniversary/secrets-9-11-new-details-chaos-nukes-emerge-n645711.

7 National Commission on Terrorist Attacks Upon the United States, *The 9/11 Commission Report*, 2004, p. 458, http://govinfo.library.unt.edu/911/report/911Report.pdf.

8 P. Podvig, "Unexpected dangers", *Bulletin of the Atomic Scientists*, 7 October 2013, http://thebulletin.org/unexpected-dangers.

New technologies

Advances in military technologies are constantly adding new layers of complexity to the environment that nuclear command and control systems have to deal with. Sea-launched ballistic missiles and long-range cruise missiles are now capable of striking most military targets with the high accuracy that was earlier available only to land-based ballistic missiles. These delivery systems are more difficult to detect than ICBMs, so they put additional strain on the early-warning system and the decision-making mechanism. There are a number of programmes, often referred to as Prompt Global Strike, that would equip traditionally nuclear delivery systems such as ballistic missiles with conventional warheads, or involve the development of new delivery systems, such as hypersonic vehicles.[9] Since these systems are designed to be non-nuclear, it is possible that they would at some point be used in a military conflict. It should be noted, however, that there has been no precedent of the combat use of a long-range sea-launched or land-based ballistic missile, so it is impossible to predict how the existing early-warning and command and control system may respond to such an event.

Increased capability

It is important to understand that the risks associated with the operations of early-warning systems and the nuclear command and control in general are not directly linked to the question of the capability that these systems provide. It would be wrong to assume, for example, that an early-warning system that can detect a wide range of attacks is necessarily safer than a system that provides much more limited capability. That was an implicit assumption of most discussions about the post-Soviet deterioration of the Russian early-warning system, which lost most of its early-warning radars and satellites. Accordingly, an upgrade of the system or reconstitution of its capability to detect ballistic missiles was seen as a reliable risk-reducing strategy. This approach, however, does not take into account the fact that a more capable system, such as the early-warning system operated by the United States, could present a greater risk, since the confidence in the technical capability of the system could prevent operators from questioning the information provided by the system in an event of a false alarm.

It can be argued that the early-warning capability does make the nuclear posture safer in some respects, since a complete absence of warning would also create considerable risk. But that does not change the fact that as a complex element added to an already complex command and control mechanism, the early-warning system is itself a source of errors and unexpected interactions. Indeed, the notion of an added

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[9] J.M. Acton, *Silver Bullet? Asking the Right Questions About Conventional Prompt Global Strike*, Carnegie Endowment for International Peace, 3 September 2013, http://carnegieendowment.org/2013/09/03/silver-bullet-asking-right-questions-about-conventional-prompt-global-strike-pub-52778.

component designed to provide safety becoming a source of an accident is a well-known phenomenon in complex technical systems.[10] Ultimately, the early-warning system was never intended to be a safety mechanism, as its primary mission is to enable launch-on-warning.

Risk mitigation options and their limits

The risks associated with the nuclear command and control raise the question of whether these risks can be eliminated or at least reduced to some acceptable level. Even though it is difficult to come up with a definitive answer, the analysis done in the past strongly suggests that complete elimination of the risks is not possible. Nuclear command and control appears to be what is known as a complex and tightly coupled system, which means that accidents in the system are inevitable.[11] The experience of recent years provides further evidence to support this conclusion. Unexpected interactions continue to occur and there is no indication that the United States or Russia have created mechanisms that would allow them to learn from past incidents outside their own countries. For example, the details of the January 1995 incident with Norwegian rocket have never been made public, which means that the lessons that could have been learned from that event are lost.

The intensity of interactions between the United States and Russian militaries, although lower than during the height of the Cold War, does not show signs of decreasing. In these circumstances, the various arrangements that were created to make these interactions more predictable—from the hot line to the ballistic missile launch notification agreements—are becoming more important. The idea of creating additional lines of communication and adding channels that would facilitate information exchange has always enjoyed almost universal support. It is not clear, however, if these kind of arrangements would help address the systemic risks associated with nuclear command and control. As with any other safety mechanism, they add a level of complexity to the system, create opportunities for unexpected interactions, and introduce new failure modes. In certain scenarios the existence of a direct communication or data exchange channel can aggravate a crisis rather than help resolve it.

Similarly, adding new elements to the existing systems, for example by improving the capability of the early-warning system, could create new failure points. The September 2013 event in Mediterranean provides a good example of that possibility—the Russian radar that detected the ballistic missile was added to the

[10] C. Perrow, *Normal Accidents: Living with High-Risk Technologies*, Princeton University Press, 1999.

[11] S.D. Sagan, *The Limits of Safety: Organizations, Accidents, and Nuclear Weapons*, Princeton University Press, 1993; C. Perrow, *Normal Accidents: Living with High-Risk Technologies*, Princeton University Press, 1999.

system only recently; without that radar, the missile test would have been undetected. Overall, however, there is a balance between the advantages of having increased situational awareness and the possibility of an accident that can be associated with it.

A more reliable way to address the issue of vulnerability of the nuclear command and control system to false alarms and other types of accidents would be to eliminate the launch-on-warning option and take the nuclear forces off hair-trigger alert. It is indeed the case that the very tight timeline that is associated with launch-on-warning puts enormous pressure on all elements of the decision-making chain, increasing the probability of an error. It should be understood, however, that simply removing the time pressure may not completely eliminate the risk of miscalculation. In addition, the launch-on-warning posture has proven to be extremely resistant to change, which shows that it is an essential element of the current strategic posture. Removing nuclear forces from high alert would probably be impossible without a deeper change in nuclear policies.

Conclusion

The risk of accident is an inherent feature of the nuclear postures that formulated and evolved during the Cold War and have been maintained in the decades after it ended. As long as nuclear weapons remain central to the national security policies of Russia and the United States (as they appear to be today), there are few options that would address that risk in total. Improving the capabilities of early-warning systems or creating new channels of communication or data exchange between the militaries may not help to reduce the risk and, indeed, could create new opportunities for accidents or misunderstandings. The removal of nuclear forces from high alert and elimination of the launch-on-warning option from nuclear planning could help improve the situation dramatically, although it probably would not address all aspects of the problem. Such steps could also bring about their own risks, for example, those related to a potential re-alerting race.

In the end, dealing with command and control risks may require a fundamental re-evaluation of the role of nuclear weapons in national security. It is possible and indeed likely that accidents in the nuclear weapons enterprise as it exists today are inevitable and therefore the only way to safely operate nuclear weapons is to eliminate them.

Chapter 6

Cyber Threats and Nuclear Weapons Systems

Patricia Lewis and Beyza Unal

Introduction

Modern nuclear and conventional weapons systems are highly complex and interconnected, and they depend heavily on digital technologies for launching, targeting, command and control, and other functions including safety and security. All digital technologies that receive, transmit, and manage digital data are potentially vulnerable to digital interference, which are called cyber attacks. These attacks range from data theft, to financial fraud, manipulation of data, or manipulation of machine instructions. Recent events and studies demonstrate how digital technologies are vulnerable to cyber attacks in many sectors, including energy production, shipping, space-based satellites, and financial transactions. Such attacks have the potential to wreak havoc either as part of a wider conflict or as one-off terror attacks.

The use of cyber attacks by a range of States aimed at disrupting and undermining institutional confidence, among other ambitions, is disrupting geopolitical stability. These activities have been evident in conflicts and domestic elections and there are deep concerns as to how they might play out in the event of crisis escalation to large-scale conflict or in doctrines regarding nuclear weapons. Many studies on these developments along with traditional thinking on strategic stability focus on the role of political resolve and “red lines”. Less focus has been devoted to the role of technology in strategic stability and its impact on credibility and increasing uncertainty.

In the event of crisis escalation—such as over events in Ukraine, the Middle East, or Asia—the assumption is that weapons systems will perform as planned. But this is not a safe assumption. Any cyber interference with one or more parts of strategic weapons systems would undo the precarious balance of perceived deterrence and stability, and create confusion and uncertainty as to its origin, which could lead to inaccurate, inadequate, and hasty responses and the possibility of conventional and nuclear war. Loss of trust in technology has further implications for attribution and strategic calculus in crisis decision-making and may increase the risk of misperception.[1] This has implications for all States that rely on nuclear weapons in

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[1] R.J. Danzig, *Surviving on a Diet of Poisoned Fruit: Reducing the National Security Risks of America’s Cyber Dependencies*, Centre for a New American Security, July 2014, https://s3.amazonaws.com/files.cnas.org/documents/CNAS_PoisonedFruit_Danzig.pdf; and

their security planning, whether possessing their own nuclear weapons capabilities or through being part of a nuclear military alliance.

The cyber threat is one of the most important and yet under-considered concerns of our time.[2] If left unaddressed, cyber vulnerabilities of the strategic security infrastructure will result in severe consequences for national and international security.

Cyber technology vulnerabilities

The cyber vulnerable technologies in the nuclear weapons systems—both in the countries that possess them and in those where they are stationed—include:

- communications between command and control centres;
- communications from command stations to missile platforms (e.g. submarines) and missiles;
- telemetry data from missiles to ground- and space-based command and control assets;
- analytical centres for gathering and interpreting long-term and real-time intelligence;
- cyber technologies in transport;
- cyber technologies in laboratories and assembly facilities;
- pre-launch targeting information for upload;
- real-time targeting information from space-based systems including positional, navigational, and timing data from global navigational systems;
- real-time weather information from space-, air-, and ground-based sensors;
- positioning data for launch platforms (e.g. submarines);
- real-time targeting information from ground stations;
- communications between allied command centres; and
- robotic autonomous systems within the strategic infrastructure.

Differential impacts

Cyber vulnerability in nuclear weapons systems is all about connectivity and data integrity. Reliable, trustworthy, and accurate data is vital for targeting, command, and control. The security of data and the security of channels that transmit and receive that data are therefore critical for the reliability of all modern nuclear and conventional weapons systems.

P.M. Lewis et al., *Too Close for Comfort: Cases of Near Nuclear Use and Options for Policy*, Chatham House, 2014.

2 See National Threat Initiative, Project: Cyber-Nuclear Weapons Study Group, http://www.nti.org/about/projects/cyber-nuclear-weapons-study-group/.

Not all attacks on data are the same. While all data attacks are serious, some are far more serious than others. For example, information regarding personnel, nuclear facility layout, design and operational information, or specific tasks such as security personnel shifts are stored within computer-based information systems and could be susceptible to cyber attacks that lead to either high or low levels of consequence.[3] Data exfiltration, denial of service attacks, and theft including cyber espionage are serious but, depending on the nature of the act, the information stolen, and when it was detected, need not necessarily lead to danger.[4]

Industrial control systems (ICS) including supervisory control and data acquisition systems (SCADA), on the other hand, are a critical part of a fully functioning command, control, and communications in the nuclear systems design. These systems relay real-time data and messages from sensors to central locations including to and from satellites and ground stations. Advanced targeted threats to ICS could "reprogram an industrial control system … commanding it to operate at unsafe speed or the valves to open when they should remain closed".[5]

The ubiquity of interconnectivity

The myth that nuclear facilities and platforms are air-gapped—meaning they are not connected to the Internet—is gradually decreasing as nuclear establishments are increasingly informed about cyber threats. Yet, academic and policy analysis on nuclear weapons facilities and nuclear command and control systems is still in its infancy, due to the secrecy surrounding nuclear weapons systems and the under-investment in research into potential problems until recently.

Virtual private networks and hidden supply chain connections are entry points for cyber vulnerabilities in any network. Other areas may include "privilege escalation, roaming notebooks, wireless access points, embedded exploits in software and

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3 A United States Department of Defense Task Force report concluded that "the cyber threat is serious and that the United States cannot be confident that [its] critical Information Technology systems will work under attack from a sophisticated and well-resourced opponent." See Defense Science Board, The United States Department of Defense, *Military Cyber Attacks and America's Vulnerable Nuclear Weapons and Defenses: DoD Task Force Report on Resilient Military Systems and the Advanced Cyber Threat*, January 2013.

4 See A. Futter, *Cyber Threats and Nuclear Weapons: New Questions for Command and Control, Security and Strategy*, Royal United Services Institute, July 2016, https://rusi.org/sites/default/files/cyber_threats_and_nuclear_combined.1.pdf.

5 B. Unal and S. Aghlani, *Use of Chemical, Biological, Radiological and Nuclear Weapons Use by Non-State Actors: Emerging Trends and Risk Factors*, Lloyds, 2016, p. 20, https://www.lloyds.com/~/media/files/news%20and%20insight/risk%20insight/2016/cbrn.pdf; see also, XL Group Insurance, *Environmental Risks: Cyber Security and Critical Industries*, 2013, http://xlgroup.com/~/media/fff/pdfs/environmental_cyber%20risks_whitepaper_xl.pdf.

hardware, or maintenance entry points".[6] Cyber theft and espionage would be two common vectors for conducting a cyber attack against, for example, nuclear weapons laboratories or nuclear weapons facilities that would gather and steal information critical to national and international security and stability.

Submarines—once believed to be air-gapped—are connected via a variety of electromagnetic signals, all subject to possible interference.[7] Submarines receive weather updates, as water temperature level and salinity are conditions for successful submarine disguise strategy, potentially linking their systems to an outside network.[8] Other periods of cyber vulnerability include malware introduced to the network at the design phase or during maintenance.[9] A comprehensive risk assessment on submarines would require a vulnerability assessment of each critical component and point of connectivity, including stealth, navigation, reactor, and missiles.

The future of command, control, and communication

New technologies are being used as part of targeting, command, and control or communication. For instance, the United States is modernizing its integrated communications system (Minimum Essential Emergency Communications Network (MEECN)) to be able to have efficient and integrated nuclear systems—including "facilities, equipment, communications, procedures, and personnel"; this includes the crypto-interoperability of its critical management structure.[10] Artificial intelligence, robotics and autonomous systems (AI/RAS), are also revolutionizing the ways in which security is managed in the military nuclear sector. Russia is field-testing robots to guard strategic forces, perform reconnaissance and even launch ballistic missiles. China has made significant advances in quantum communications, which will open up new pathways for AI/RAS.

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6 J. Fritz, *Hacking Nuclear Command and Control*, International Commission on Nuclear Nonproliferation and Disarmament, July 2009, http://icnnd.org/documents/jason_fritz_hacking_nc2.doc.

7 See A. Datoo and P. Ingram, "A primer on Trident's vulnerabilities", *Parliamentary Briefings on Trident Renewal Briefing No. 2*, BASIC, March 2016, http://www.basicint.org/sites/default/files/BASIC_cyber_vuln_mar2016.pdf.

8 P. Tucker, "Navy submarine drones will predict the weather months in advance", *Defence One*, 14 March 2014, http://www.defenseone.com/technology/2014/03/navy-submarine-drones-will-predict-weather-months-advance/80542/.

9 A. Futter, "Is Trident safe from cyber attack?", *European Leadership Network*, 5 February 2016, http://www.europeanleadershipnetwork.org/is-trident-safe-from-cyber-attack_3506.html.

10 *PE 0303131F: Minimum Essential Emergency Communications Network*, US Air Force, February 2012, http://www.dtic.mil/descriptivesum/Y2013/AirForce/stamped/0303131F_7_PB_2013.pdf.

Increased reliance on AI/RAS in warfare and in military applications is already expanding, as China, for instance, is reported to be building cruise missiles with "high levels of artificial intelligence and automation".[11] Yet, a wide range of vulnerabilities within these systems opens up threats to nuclear weapons systems, to storage facilities, and to waste management. AI/RAS systems cannot yet incorporate all the elements pertaining to security that are significant and important to humans and in-built misjudgement in these early systems may result in unforeseen consequences.[12]

In the past, ballistic missile defence systems required a physical presence, a human-in-the-loop, aiming to intercept a target after it had been launched. Today, the systems are semi-autonomous, relying on radar and missile technologies and transmitting data to ground stations. But missile defence is entering a new phase, which is to "disable missiles before launch" including through cyber means—requiring an earlier infiltration of the adversary's network. The United States calls this "left of launch" capability, a non-kinetic and less costly approach to missiles defence.[13] The introduction of cyber capabilities for missile defence is likely eventually to create competition among nuclear weapons States and have a negative impact on strategic stability in what is already a highly divisive debate.[14] For example, the Russian government has an established view against traditional ballistic missile defence in Eastern Europe, calling it a "direct threat" to its national security.[15] A cyber version of this threat would be viewed with equal concern but indeed may be a far more destabilizing development.

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11 A. Roy, "China building modular next-generation cruise missiles using artificial intelligence", *International Business Times*, 19 August 2016, http://www.ibtimes.co.uk/china-building-modular-next-generation-cruise-missiles-using-artificial-intelligence-1576920.

12 S. Russell and P. Norvig, *Artificial Intelligence: A Modern Approach*, Prentice-Hall Inc., 1995.

13 A. Futter, "The dangers of using cyberattacks to counter nuclear threats", *Arms Control Today*, July/August 2016, https://www.armscontrol.org/ACT/2016_07/Features/The-Dangers-of-Using-Cyberattacks-to-Counter-Nuclear-Threats; E. Gartzke and J. Lindsay, "The U.S. wants to stop North Korean missiles before they launch. That may not be a great idea", *Washington Post,* 15 March 2007, https://www.washingtonpost.com/news/monkey-cage/wp/2017/03/15/the-u-s-wants-to-stop-north-korean-missiles-before-they-launch-that-may-not-be-a-great-idea; E. Gartzke and J.R. Lindsay, "Thermonuclear cyberwar", *Journal of Cybersecurity*, 14 February 2017, https://academic.oup.com/cybersecurity/article/doi/10.1093/cybsec/tyw017/2996537/Thermonuclear-cyberwar.

14 S. van der Meer, "Cyber warfare and nuclear weapons: game-changing consequences?", in O. Meier and E. Suh (eds.), *Reviving Nuclear Disarmament: Paths Towards a Joint Enterprise*, German Institute for International and Security Affairs, December 2016.

15 A.E. Kramer, "Russia calls new U.S. missile defense system a 'direct threat'", *New York Times*, 12 May 2016, https://www.nytimes.com/2016/05/13/world/europe/russia-nato-us-romania-missile-defense.html.

Space-based systems and cyber vulnerabilities

The vulnerability of space assets and space-based technologies to cyber attack could undermine the safety, reliability, and credibility of nuclear and conventional weapons systems. These include missile defences, high-precision semi-autonomous weapons such as drones and all manner of strategic communications and space-based command and control systems in all nuclear weapons possessors. As military situational awareness, observation, and connectivity rely heavily on space-based satellites and are wholly dependent on cyber technologies, vulnerabilities in those systems pose enormous risks with regard to misjudged and irreversible missile launch and thus—particularly in times of heightened tensions—regional or even global war.

Cyber attacks range from jamming, spoofing, data interception, corruption and falsification, deliberate orbit decay, deliberate collisions, grilling (frying of solar panels by turning them to the sun), to full-on system hijacking. In the event of the escalation of an international crisis, cyber vulnerabilities could be exploited as part of diplomatic, civil domestic or military campaigns. Recent research has identified critical satellite vulnerabilities to cyber hacking.[16] In 2014, a cyber attack on a United States weather satellite system brought home the very real danger of cyber vulnerabilities in strategic space-based assets for much of the United States and its allies' strategic infrastructure, of which weather monitoring satellites are a vital part.[17] A National Aeronautics and Space Administration (NASA) Landsat-7 Earth observation satellite was subject to cyber interference in October 2007 and July 2008 and other similar cyber attacks on a NASA Terra AM-1 Earth observation satellite occurred in June 2008 and October 2008.[18]

Military strategic and tactical missile systems rely on satellites and the space infrastructure for navigation and targeting, command and control, operational monitoring and other functions. However, insufficient attention has been paid to the increasing vulnerability of space-based assets, ground stations, and associated command and control systems. Cyber attacks on satellites would undermine the

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16 D. Livingstone and P. Lewis, *Space, the Final Frontier for Cybersecurity?*, Chatham House, September 2016, https://www.chathamhouse.org/sites/files/chathamhouse/publications/research/2016-09-22-space-final-frontier-cybersecurity-livingstone-lewis.pdf.

17 D. Livingstone, ”The intersection of space and cybersecurity is a growing concern”, *Chatham House Expert Comment*, 25 November 2014, https://www.chathamhouse.org/expert/comment/16325.

18 J. Wolf, “UPDATE 1-China key suspect in US satellite hacks: commission”, Reuters, 28 October 2011, http://www.reuters.com/article/china-usa-satellite-idUSN1E79R1LK20111028; S.-L. Wee, “China denies it is behind hacking of U.S. satellites”, Reuters, 31 October 2011, http://www.reuters.com/article/us-china-us-hacking-idUSTRE79U1YI20111031.

Box 1: The United States and the cyber threat

In 2014, a report by the United States National Oceanic and Atmospheric Administration (NOAA) identified "significant security deficiencies in the NOAA's information systems" and a Technical White Paper from IOActive Labs provided a "wake-up call for [Satellite Communication] security".[19] As stated in the 2011 United States International Strategy for Cyberspace, international approaches and cooperation are needed in order to address and mitigate the full range of cyber threats to military systems and space assets.[20]

The United States has been taking this issue seriously for over 20 years. As far back as 1997, the President's Commission on Critical Infrastructure Protection stated that "the most significant projected vulnerabilities are those associated with the modernization of the National Airspace System (NAS) and the plan to adopt the Global Positioning System (GPS) as the sole basis for radio-navigation in the US by 2010" and that "exclusive reliance on GPS and its augmentations, combined with other complex interdependencies, raises the potential for 'single point failure' and 'cascading effects'".[21] This analysis led to a thorough investigation of the threats and vulnerabilities associated with GPS deployment, and to Presidential Decision Directive (PDD) 63, Critical Infrastructure Protection, which laid out the roles, responsibilities and objectives associated with protecting utility, transportation, financial and other critical infrastructure.[22] PDD-63 focused on cooperation and intelligence-sharing among government agencies and with the private sector, and protecting individual sectors such as energy, banking and transport.

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19 NOAA, *Significant Security Deficiencies in NOAA's Information Systems Create Risks in Its National Critical Mission,* United States Department of Commerce, 15 July 2014, https://www.oig.doc.gov/OIGPublications/OIG-14-025-A.pdf; R. Santamarta, *A Wake-up Call for SATCOM Security,* IOActive, 2014, http://www.ioactive.com/pdfs/IOActive_SATCOM_Security_WhitePaper.pdf.

20 B. Obama, *International Strategy for Cyberspace: Prosperity, Security, and Openness in a Networked World,* The White House, May 2011, https://obamawhitehouse.archives.gov/sites/default/files/rss_viewer/international_strategy_for_cyberspace.pdf.

21 President's Commission on Critical Infrastructure Protection, *Critical Foundations: Protecting America's Infrastructures*, October 1997, http://permanent.access.gpo.gov/lps15260/PCCIP_Report.pdf.

22 W.J. Clinton, *Presidential Decision Directive/NSC-63: Critical Infrastructure Protection*, The White House, 22 May 1998, http://fas.org/irp/offdocs/pdd/pdd-63.htm; B. Obama, *Presidential Policy Directive/PPD-21: Critical Infrastructure Security and Resilience*, The White House, 12 February 2013, https://www.whitehouse.gov/the-press-office/2013/02/12/presidential-policy-directive-critical-infrastructure-security-and-resil; B. Obama, *Executive Order-Improving Critical Infrastructure Cybersecurity*, The White House, 12 February 2013,

integrity of strategic weapons systems, destabilize deterrence relationships, and obfuscate the originator of the attack without creating the debris problem that a physical attack would cause. Because cyber technologies are within the grasp of most States and non-state actors, they level the strategic field and create hitherto unparalleled opportunities for small belligerent governments or terrorist groups to instigate high-impact attacks.

Many missile systems depend heavily on positional, navigational, and timing (PNT) data from global navigational satellite systems (GNSS) operated by the United States, Russia, and Europe. They depend on these systems for initial position of the launch platform such as a submarine, or for additional information for guidance in-flight.[23] Until recently much of the international system has been highly dependent on the GPS satellite network managed by the United States Air Force.[24] In 2016, as a result of a glitch in ground-system software that occurred when a satellite was being decommissioned, 15 GPS satellites broadcast signals that were inaccurate by 13 microseconds, and telecommunications suffered thousands of system errors over 12 hours.[25] The incident revealed the significant impact of the satellite system's vulnerabilities to software error and thus to a cyber hack. New GNSS satellite constellations—including regional and global systems from Europe and Asia—aim to reduce risks through increased resilience.

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https://www.whitehouse.gov/the-press-office/2013/02/12/executive-order-improving-critical-infrastructure-cybersecurity.

23 The Russian RT-2PM2 *Topol-M* ICBM is equipped with an on-board GNSS receiver and more recent modifications of the Trident D5 ballistic missile include GNSS features as part of the otherwise self-contained on-board guidance system and includes a digital interface with the launch boat. Russia's short-range *Iskander* missile employs an optical guidance warhead, by which the missile can be controlled by encrypted radio transmissions.

24 The GNSS networks currently available are the United States' GPS, Russia's Global Navigation Satellite System (GLONASS) and Europe's satellite-based augmentation system (SBAS), EGNOS and the new Galileo GNSS. China has developed a regional satellite navigation system, the *BeiDou* Navigation Satellite System (BDS), and is now developing a GNSS (*BeiDou*-2) with the aim of global operation by 2020. India has a regional system NAVIC (Navigation Indian Constellation, formerly called IRNSS) and Japan is also developing a regional system, the Quazi-Zenith Satellite System (QZSS).

25 C. Baraniuk, "GPS error caused '12 hours of problems' for companies", *BBC*, 4 February 2016, http://www.bbc.co.uk/news/technology-35491962.

Insider threats

Another understudied issue concerns insider threats in nuclear weapons facilities and platforms, nuclear bases in nuclear weapons States and host countries, and in nuclear weapons laboratories. Insiders possess knowledge of how to access nuclear facilities, penetrate nuclear systems, equipment or tools; they have knowledge of facility layout structures or processes, physical protection, safety systems, personnel, and other sensitive information; they often possess technical experience and expertise; and they have the ability to acquire equipment in order to conduct malicious activities. They may also be highly trusted and in positions of authority.[26] An insider threat does not always have malign intent. Simple human error and poor practice, including poor cyber security practice, may also lead to high consequences. Increasing situational awareness and training is important to limit errors.

The International Atomic Energy Agency (IAEA) offers guidance on the preventive and protective measures against insider threats in the nuclear industry; yet, there is a lack of an international framework for implementing the mitigation of insider threat.[27] Instead, it is the responsibility of countries to provide prevention measures. The aviation sector provides an effective comparison, as airport personnel are not always held to the same stringent security screening standards as the passengers. A similar type of negligence exists in the nuclear industry, and perhaps even to a higher degree. Psychological screening of the personnel in nuclear submarines, for instance, is an area of high concern. In 2011, a United Kingdom sailor "shot a senior officer on board" a nuclear submarine.[28] Personnel reliability programmes may also fall short in cases where personnel chose to cheat on the test or memorize the questions rather than perform.

While examining insider threats, it is important to understand the influence of different security cultures. In organizations with a strong community feeling, threat is generally perceived as an outside phenomenon. Reporting suspicious behaviour of a colleague in these cultures is akin to the betrayal of one another. Similarly, there are organizational differences from country to country. For instance, in Japan—a country under the nuclear weapons protection of the United States—personnel vetting systems for trustworthiness do not exist.[29] Establishing a security culture that builds

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[26] IAEA, *Preventive and Protective Measures against Insider Threats, Implementing Guide*, IAEA Nuclear Security Series No. 8, 2008, http://www-pub.iaea.org/MTCD/Publications/PDF/Pub1359_web.pdf.

[27] Ibid.

[28] BBC News, "Sailor who murdered officer on submarine HMS Astute jailed for life", 19 September 2011, http://www.bbc.com/news/uk-england-14971198.

[29] E. Blandford and S. Sagan (eds.)*, Learning from a Disaster: Improving Nuclear Safety and Security After Fukushima*, Stanford University Press, 2016, p. 65.

on understanding the consequences of such actions is fundamental to mitigating threats.

Insider threat risks increase in significance in countries that are facing crises, including militant and terrorist attacks. Several physical attacks have occurred, for instance, in Pakistan's nuclear weapon bases.[30] In the attempted coup in Turkey, power was cut off for several hours on and off for several days at the Incirlik airbase where the United States nuclear weapons are stationed.[31] Although nuclear weapons bases are heavily guarded and physically protected, security challenges of today exceed the physical dimensions of protection and require cyber diligence. For instance, assessments of insider threat risks to computer systems have been carried out in other areas.[32] By having easy access to computer systems, a person with malicious intent could steal data and information, including critical design information, operating information, and sensitive personnel data, and could sell this information to others—either to hostile governments or to non-state armed groups.

A final "insider" threat scenario involves individuals beyond the facility. Due to lack of technical knowledge, sources and capacity, nuclear weapons States work with outside defence companies—in designing and building industrial control systems, for instance in a nuclear weapons base, or in submarine systems.[33] Many work closely with the weapons complexes for decades and have stringent vetting procedures, but they may subcontract some of the work to other smaller companies that may not have the required procedures in place. This type of outsourcing can increase the likelihood of systems vulnerability. Routine performance and maintenance screening on nuclear weapons command and control systems conducted by outside companies, even in rare cases, are similar pathways for malware penetration in the systems.[34]

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30 D. Nelson and T. Hussain, "Militants attack Pakistan nuclear air base", *The Telegraph*, 16 August 2012, http://www.telegraph.co.uk/news/worldnews/asia/pakistan/9479041/Militants-attack-Pakistan-nuclear-air-base.html.

31 J. Lewis and K. Schake, "Should the US pull its nuclear weapons from Turkey?", *New York Times*, 20 July 2016, http://www.nytimes.com/roomfordebate/2016/07/20/should-the-us-pull-its-nuclear-weapons-from-turkey.

32 IAEA, *Preventive and Protective Measures against Insider Threats, Implementing Guide*, IAEA Nuclear Security Series No. 8, 2008, http://www-pub.iaea.org/MTCD/Publications/PDF/Pub1359_web.pdf.

33 A. Datoo and P. Ingram, "A primer on Trident's vulnerabilities", *Parliamentary Briefings on Trident Renewal Briefing No. 2*, BASIC, March 2016, http://www.basicint.org/sites/default/files/BASIC_cyber_vuln_mar2016.pdf.

34 Outsourcing is common in information technology systems, but rare in information control systems.

Conclusion

Ascertaining the threats and vulnerabilities to the nuclear weapons systems from cyber attacks is vital in understanding the changing risk picture associated with nuclear weapons. The possessors of nuclear weapons, and those alliance countries that host them or otherwise incorporate them into their defence postures, need to be fully aware of the threats and risks posed to their citizens as well as to the populations of countries at which these weapons may be aimed.

The increasing number of cyber attacks in other domains, including on critical national and international infrastructures, suggests that the nuclear weapons establishments may face similar potential attacks. It may be that the technical measures taken to defend against such attacks, along with air gaps and rigorous training for cyber hygiene and protection, will be adequate to prevent those attacks from having any serious impacts. It is likely however that information theft will occur—such as names and addresses of personnel or facility layout and design—and the integrity and security of data could be compromised.

What is needed then is an all-cyber-risks-based approach in nuclear weapons systems to assess threats, vulnerabilities and consequences against all critical assets. Today state capabilities are viewed as the biggest threats to a state's critical infrastructure; yet, the nature of vulnerability and evolution of technology will likely provide more opportunities for terrorist groups to conduct high-consequence incidents in the future. A graded approach to cyber security in nuclear weapons and systems complex calls for vulnerability assessment of each layer, including command and control systems, communication systems including satellites, space infrastructure, and targeting. It calls for the identification of critical components, assesses the likelihood of insider threat, and requires an efficient and timely reporting structure.

Perhaps the single most significant impact of potential cyber attacks on nuclear weapons systems is that the certainty of information will be questioned. When Lieutenant Colonel Stanislav Petrov judged that he "couldn't trust the computers" and decided that the signals of incoming missiles from the United States to the Soviet Union at the height of tensions in 1983 were a false alarm, he was factoring in the uncertainty of the vulnerability of the technology on which he was supposed to rely.[35] He was correct to do so. Former United States Defense Secretary William Perry's account of how a crisis-simulation training tape was left inadvertently in the computer at North American Aerospace Defense Command (NORAD) leading the United States command to believe—for a short while—that 200 Soviet missiles were incoming

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35 P. Anthony (director), *The Man Who Saved the World*, documentary film, 2014, http://themanwhosavedtheworldmovie.com.

illustrates one possible form a cyber attack could take.[36] Possible cyber interference in the data, management, and operations of nuclear weapons systems increases the uncertainties in the decision-making. In a crisis, with little time to spare, how will these additional uncertainties play out? If the fundamental information cannot be trusted, how do the humans in charge make decisions?

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[36] W.J. Perry, *My Journey at the Nuclear Brink*, Stanford University Press, 2015.; J.F. Harris and B. Bender, "Bill Perry is terrified. Why aren't you?", *Politico Magazine*, 6 January 2017, http://www.politico.com/magazine/story/2017/01/william-perry-nuclear-weapons-proliferation-214604.

Chapter 7

The Safety of Nuclear Weapons and Materials: Lessons from the Assessment of Nuclear Power Plant Risks

Reza Lahidji

Introduction

Safety risks associated with nuclear weapons have often been analysed from the standpoint of the reliability of deterrence, pinpointing the tension between, on one hand, the claim of the deterrence doctrine to guarantee the absence of war thanks to the existence of nuclear weapons and, on the other, the possibility of an inadvertent launch.[1] Less attention has been paid to the management of these risks and to the lessons that forty years of operation of nuclear power plants can teach us with respect to the safety of nuclear weapons.[2] This chapter considers this issue by analysing publicly available information regarding the prevailing approaches to the safety of nuclear weapons and nuclear power plants. While little is known to the public regarding the safety and security of nuclear weapons, the chapter scrutinizes available information provided by some countries such as the United States—admittedly partial and of a general nature—and relates it to the experience of major reactor accidents such as Three Mile Island and the Fukushima disaster.

Accident scenarios

To generate electricity, a nuclear power plant uses the heat generated by nuclear fission within the fissile material placed in the core of its reactor(s). The fundamental objective of a plant's safety provisions is to keep the reaction under control, to evacuate the generated heat by circulating a coolant in the core, and to constantly maintain the radioactive particles in confinement. As a nuclear reactor cannot explode, the most serious health effects expected from a severe nuclear power plant accident result from ionizing radiation. Failures in the control of the chain reaction or in the cooling of the core can result in a core meltdown—an over-heating that leads

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[1] See for instance G.P. Schultz and J.E. Goodby (eds.), *The War That Must Never Be Fought: Dilemmas of Nuclear Deterrence*, Hoover Institution Press, 2015.

[2] A notable exception is G.P. Schultz and S.D. Drell (eds.), *The Nuclear Enterprise: High-Consequence Accidents: How to Enhance Safety and Minimize Risks in Nuclear Weapons and Reactors*, Hoover Institution Press, 2012.

to the emission of particles within the secondary containment building of the plant, typically a reinforced steel or land structure, and in the worst cases, breach of that secondary containment and to large early releases of radioactive material into the environment.[3] Meltdown scenarios have materialized on five occasions in the operation of a pressurized water reactor (PWR): in Three Mile Island (United States) in 1979, in Chernobyl (Ukraine) in 1986, and in three reactors of Fukushima Daiichi (Japan) in 2011. The root causes of any such accident can be the failure of some components or systems inside the plant, human error, the loss of all external sources of power, and various hazards, whether internal (e.g. fires) or external (e.g. earthquakes, plane crashes).

In a nuclear weapon, by contrast, the fissile material is divided into parts that do not have a critical mass individually. This helps to avoid the start of a chain reaction, keeping radioactivity at a low level and making containment a much simpler task. To activate the bomb, a high explosive surrounding the fissile material is detonated; this compresses the fissile material and starts the chain reaction. In the case of a thermonuclear bomb, the fission reaction triggers a fusion reaction in the secondary section of the bomb. Although a nuclear weapon is a less complex technological system than a nuclear power plant, numerous installations, weapon systems, and procedures are involved in its storage and operation. As a consequence, accident risk assessment does not appear as a less daunting task for nuclear weapons than for nuclear power plants. Furthermore, the numerous operations of manipulation and transportation have a multiplying effect on accident risks, in particular due to the possibility of human error. The most severe nuclear weapon accident scenarios involve inadvertent detonations due to the failure of a weapon component (e.g. in the fusing and firing systems) or an external hazard; missile launches based on false premises (due to human or technical error); and malevolent actions by individuals. The immediate casualties caused by an inadvertent nuclear weapon explosion would mostly be due to the immense blast and heat wave, while the harmful effects of ionizing radiation would in large part materialize in the longer term.

The engineering of safety

What makes the case for comparisons and sharing of lessons between the risks associated with nuclear power and those generated by nuclear weapons is the fact that they have been approached in similar ways by national authorities. In the United States in particular, the risks of nuclear weapons and those of nuclear power plants are managed in accordance with the same principles, namely: *deterministic* approaches to safety design that are entirely geared towards providing the assurance that the device or installation is safe and reliable, joined with a set of *probabilistic*

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[3] In Chernobyl, the reactor was not enclosed in a secondary containment building, so that the radioactive material was directly released into the environment.

objectives aiming to assure that the overall level of risk is acceptable.[4] This dual approach is deemed to provide the level of safety that is required for technologies with devastating potential consequences; experience, however, has shown that both approaches can fall short.

Weapons systems and positive measures

Four criteria enacted by the United States Department of Defense in 1984 define the framework for the safety of that country's nuclear weapon systems, each involving positive measures such as "a design feature, safety device, or procedure that exists solely or principally to provide nuclear safety" (see box 1).[5] An additional criterion, designated as "one-point safety", requires that the design of a nuclear weapon inherently prevents a detonation at any one point in the high-explosive system to produce a nuclear yield. The United States Department of Energy has adopted an equivalent set of criteria for the areas under its responsibility, which cover the assembly and disassembly of nuclear weapons, as well as the processing and storage of nuclear waste. Each of these criteria assumes detrimental conditions, such as the intent to launch a weapon outside of the normal command chain, to derive safety requirements. Together, they have led to the adoption of features such as enhanced nuclear detonation safety, insensitive high explosives, and fire-resistant pits, which are deemed to assure a high level of safety to the United States nuclear stockpile.[6]

Box 1: Safety Criteria from the United States Department of Defense

- There shall be positive measures to prevent nuclear weapons involved in accidents or incidents, or jettisoned weapons, from producing a nuclear yield.
- There shall be positive measures to prevent *deliberate* pre-arming, arming, launching, firing or releasing of nuclear weapons, except upon execution of emergency war orders or when directed by competent authority.
- There shall be positive measures to prevent *inadvertent* pre-arming, arming, launching, firing or releasing of nuclear weapons in all normal and credible abnormal environments.
- There shall be positive measures to ensure adequate security of nuclear weapons, pursuant to [Department of Defense] Directive 5210.4.

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4 Safety approaches are called deterministic insofar as they aim to identify all credible hazards, dysfunctions and failures, imagine that they have occurred (individually or, in some cases, jointly) and simulate their consequences to elaborate appropriate responses (safety features).

5 United States Department of Defense Directive 3150.2, *Safety Studies and Review of Nuclear Weapon Systems*, 8 February 1984.

6 S.D. Drell, "Designing and building nuclear weapons to meet high safety standards", in G.P. Schultz and S.D. Drell (eds.), *The Nuclear Enterprise: High-Consequence Accidents: How to Enhance Safety and Minimize Risks in Nuclear Weapons and Reactors,* Hoover Institution Press, 2012.

Power plants and “defence in depth”

The standard approach to power plant safety rests on the concept of “defence in depth”, which organizes safety systems and procedures as successive defence lines, each line being designed to address incidents and accidents that have passed the previous ones. The list of internal and external events that the plant design should be able to handle without experiencing core damage defines the design basis.[7] The approach implies that the design basis defines the level of safety that is deemed necessary and adequate; the handling of beyond design-basis events (items not on the list, whether from a type of hazard or dysfunction that has not been considered, or because they have a stronger magnitude than the design-basis event) constitutes a safety enhancement beyond the adequate level, even when it is required by specific regulations. Implicitly, therefore, the design basis is assumed to correspond with the acceptable level of risk from nuclear power plants.

One of the critical assumptions for the effectiveness of defence in depth is that a single event does not affect safety systems involved in more than one defence line—in other words that the lines are independent. This assumption was violated in Fukushima Daiichi, as the earthquake and tsunami brought down all the defence lines of the reactors, generating the largest common-cause failure in the history of the industry. The event highlighted the vulnerability of defence in depth to beyond design-basis events, and the existence of so-called cliff edge effects; that is, situations in which overall defences shift abruptly from operational to failure mode as the magnitude of events passes a certain threshold. Still, while the industry responded by searching for ways to increase the robustness of defence in depth, a general evaluation of the vulnerability of the approach has not followed.[8] For instance, while the Council of Europe requested all member States to conduct a series of “stress tests” linked to various beyond design-basis events, the process largely focused on enhancing safety requirements for the same hazards and accidents sequences that were involved in the Fukushima accident.[9]

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7 The internal events considered in the design basis include operational occurrences such as valve failure or a fire. External events include the loss of power sources and natural hazards such as floods and earthquakes.

8 In its peer review report on the stress tests, the European Nuclear Safety Regulators Group (ENSREG) notes that “very few [countries] assess cliff-edge situations in the manner requested […]”. See ENSREG, *Peer Review Report: Stress Tests Performed on European Nuclear Power Plants*, 2012, https://www.government.nl/binaries/government/documents/reports/2012/06/20/peer-review-report-on-stress-tests-performed-on-european-nuclear-power-plants/peer-review-report-stress-tests-performed-on-european-nuclear-power-plants.pdf.

9 European Council, *Conclusions – 24/25 March 2011*, European Council document EUCO 10/1/11 REV 1, 20 April 2011, https://www.consilium.europa.eu/uedocs/cms_data/docs/pressdata/en/ec/120296.pdf.

Probabilistic criteria as a measure of risk acceptability

Two probabilistic criteria regulate the safety of United States nuclear weapons and define the level of risk from these weapons that is deemed acceptable:

The probability of a premature nuclear detonation (i.e. prior to receipt of pre-arming or launch signal) due to component malfunctions shall not exceed:

- 1 in 10^9 over the lifetime of a warhead in normal storage and operational environments;
- 1 in 10^6 per warhead exposure or accident in abnormal environments (as described in the weapon stockpile-to-target sequence). [10]

Origins in the United States

The requirement that the chance for a warhead to be accidentally detonated over its entire lifetime should be less than one in a billion was formulated by the United States Military Liaison Committee in 1968, building on more than a decade of reflections. In a 1955 report, the Office of Special Weapons Developments suggested taking natural disasters of the previous 50 years as a benchmark for the acceptability of the risk of an accidental nuclear detonation.[11] On this basis, the report calculated that the acceptable number of accidents in peacetime ranged from 5.10^{-2} per year (i.e. five per century) for a bomb yielding between 0.1 and 1 kiloton to 1.10^{-5} per year (i.e. 1 per 100,000 years) for a bomb yielding more than 10 megatons. A 1957 report by the Armed Forces Special Weapons Projects estimated that these targets were compatible with a probability of "premature" detonation of 1.10^{-7} for weapons yielding more than 1 kiloton (1.10^{-5} for those below) over their entire life, assuming an average life span of 10 years.[12]

This type of probabilistic reasoning was rejected in the early years of the civilian nuclear industry, since it implied that the probability of a major accident was not zero. In the late 1950s, one of the crucial conditions for the involvement of private utilities in the development of nuclear power plants was that regulatory criteria would not

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[10] *The Report of the Nuclear Weapons Safety Panel*, Hearing before the Committee on Armed Services, House of Representatives, One Hundred First Congress, Second Session, 18 December 1990.

[11] Cited in E. Schlosser, *Command and Control: Nuclear Weapons, the Damascus Accident, and the Illusion of Safety*, The Penguin Press, 2013, p. 171.

[12] Armed Forces Special Weapons Project, *Acceptable Premature Probabilities for Nuclear Weapons*, Headquarters Field Command, Document FC/10570136 (declassified), 1 October 1957, http://www-ee.stanford.edu/~hellman/resources/schlosser.pdf.

preclude the siting of plants in urban areas.[13] The secondary containment of PWRs was designed to this aim, under the conviction that even in a worst case scenario (then conceptualized as the "Maximum Credible Accident"), it would ensure that there would not be any significant release of radioactive material into the environment.[14] It took the work of the Rasmussen Commission on the quantification of accident risks and—especially—the Three Mile Island accident to change this official line.[15] The Commission investigating the causes of that accident concluded that "nuclear power is by its very nature potentially dangerous", and supported the use of probabilistic risk assessment methods as an instrument to investigate the uncertainties of nuclear energy generation.[16] By 1986, the United States Nuclear Regulatory Commission (NRC) had adopted safety goals stating that power plant risks should not exceed 0.1 per cent of the overall risk of sudden death due to all other causes for an individual living in the vicinity, or 0.1 per cent of the overall risk of fatal cancers due to all other causes among the population living in the vicinity.[17] From 1990 onwards, the NRC considered that these objectives were compatible with a probability of 10^{-4} for all accidents in which the reactor core experiences damage, and 10^{-5} for the subgroup leading to large early releases.[18]

Uncertainties in assessment

In Japan, where nuclear power plants have a particularly robust design because of their exposure to severe natural hazards, the probability of a severe accident with large early releases was estimated at 10^{-6} in 2011. At the Fukushima Daiichi power plant, this integrated the assumption of an earthquake of 7.1 moment magnitude, producing ground acceleration of 0.45 to 0.5 *g* (acceleration due to the force of gravity) and a tsunami of 5.7 metres at the location of the plant buildings. Instead, the Tohoku earthquake of 11 March 2011 had a 9.0 moment magnitude, and was associated with

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13 B. Balogh, *Chain Reaction: Expert Debate and Public Participation in American Commercial Nuclear Power*, 1945–1975, Cambridge University Press, 1991.

14 J.S. Walker and T.R. Wellock, *A Short History of Nuclear Regulation, 1946–1999*, United States Nuclear Regulatory Commission, October 2010, https://www.nrc.gov/docs/ML1029/ML102980443.pdf.

15 United States Nuclear Regulatory Commission, *Reactor Safety Study: An Assessment of Accident Risks in Commercial Nuclear Power Plants*, WASH-1400 (NUREG-75/014), 1975.

16 J.G. Kemeny et al., *Report of the President's Commission on the Accident at Three Mile Island*, U.S. Government Printing Office, 1979.

17 United States National Regulatory Commission, *Safety Goals for the Operations of Nuclear Power Plants; Policy Statement*, 51 Federal Register 30028, 21 August 1986, https://www.nrc.gov/reading-rm/doc-collections/commission/policy/51fr30028.pdf.

18 United States National Regulatory Commission, *SEC-89-102 - Implementation of the Safety Goals*, Agencywide Documents Access and Management System (ADAMS) Accession No. ML003707881, 15 June 1990, https://www.nrc.gov/docs/ML0037/ML003707881.pdf.

a maximum ground acceleration of 0.56 *g* and a tsunami height probably exceeding 10 metres at the plant location, causing a severe accident in three of the plant's six reactors.[19]

From the standpoint of seismological science, the strength of the Tohoku earthquake was *not* a surprise—indeed, a study published in 2001 indicated that a major earthquake causing a mega-tsunami happened every thousand years in the region, and its last occurrence was in 869.[20] This had led the Japanese nuclear safety authority and the Fukushima plant operator to consider integrating more severe seismic assumptions in the safety provisions of the plant. At the time of the accident however, analysis shows that conditional on the occurrence of a mega-tsunami, the likelihood of severe accident in several of the plant's reactors was exceedingly high.[21] In other words, an event that was considered virtually impossible according to official estimates, would in fact have been deemed likely under different (and more plausible) scientific assumptions.

Notwithstanding the sophistication of quantification methods and the wealth of data on which they build their estimates, probabilistic risk assessments are surrounded with considerable uncertainties. This applies in particular to the assessment of the likelihood of beyond design-basis events, and therefore to the level of safety provided by defence in depth. The magnitude of uncertainties is one of the key reasons why the NRC cautiously presents its goals as objectives, and not as criteria. In the case of nuclear weapons, one of the most critical sources of uncertainty is the aging of stockpiles. Yet, in the safety doctrine of the United States Department of Defense, probabilistic risk acceptability criteria are considered as actual measures of the safety of nuclear weapons, without any mention of the associated uncertainties.

Governance structures and transparency

A final point of comparison between the two sectors concerns institutional set-up. For reasons of secrecy and security, only a limited number of persons and institutions are informed about the precise conditions of the nuclear weapons stockpile and existing safety procedures. Consequently, it is difficult to ensure that the authority in charge of controlling and regulating safety enjoys the necessary independence and power to identify and effectively rectify any shortcomings. For instance, at the end of

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19 Japanese Government, *Report to the IAEA Ministerial Conference on Nuclear Safety - The Accident at TEPCO's Fukushima Nuclear Power Stations*, Secretariat of the Prime Minister's Cabinet Office, 2011.

20 R.J. Geller, "Shake-up time for Japanese seismology", *Nature*, vol. 472, no. 7344, 2011; K. Minoura et al., "The 869 Jōgan tsunami deposit and recurrence interval of large-scale tsunami on the Pacific coat of northeast Japan", *Journal of Natural Disaster Science*, vol. 23, no. 2, 2001.

21 R. Lahidji, *Uncertainty, Causality and Decision: The Case of Social Risks and Nuclear Risk in Particular*, PhD dissertation (in French), Ecole des Hautes Etudes Commerciales, 2012.

the 1960s, a series of near-misses in the United States clearly demonstrated that the inadvertent explosion of an atomic bomb was a concrete possibility, and that serious safety enhancements were necessary.[22] Technological developments such as the Enhanced Nuclear Detonation Safety and the use of Insensitive High Explosives were tested in the National Laboratories of Los Alamos and Sandia, and shown to dramatically reduce accidental detonation risks. Yet, because of institutional inertia and the lack of a truly independent oversight body, it took nearly three decades and the courage and perseverance of a small group of individuals to undertake these changes.[23] A host of systemic issues revealed with respect to the management of the United States arsenal (from the lack of maintenance equipment to discipline problems among missile launch crews and security forces) further demonstrates the difficulty of maintaining an adequate level of safety through exclusive reliance on internal command and control.[24]

The experience of the management of safety in nuclear power plants testifies to the crucial importance of independent oversight and control. Many States have created independent agencies in charge of nuclear safety regulation, like the NRC in the United States. The investigation about the root causes of the Fukushima disaster, which pointed to problematic aspects of the close relationship between the utility Tokyo Electric Power Company and the regulatory Nuclear and Industrial Safety Agency, provided further warning about the risks of "regulatory capture". [25]

An additional handicap for national authorities in charge of nuclear weapon safety is their very limited capacity to exchange information with counterparts from other countries. In nuclear power plant safety, bilateral and regional cooperation and especially knowledge-sharing and standard setting under the aegis of international institutions (primarily the International Atomic Energy Agency and the Organization for Economic Cooperation and Development Nuclear Energy Agency) have been a considerable factor of safety enhancement across the world. In the case of nuclear weapons, there are no comparable information-sharing mechanisms, even among allies.

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22 In particular, the accidents of Palomares (Spain, January 1966) and Thule (Greenland, January 1968) in which the high explosives of six bombs detonated without triggering a chain reaction in the primary (plutonium), but dispersing it in the environment.

23 For a testimony of one of the key actors of this transformation, see R.L. Peurifoy, "A personal account of steps toward achieving safer nuclear weapons in the US arsenal", in G.P. Schultz and S.D. Drell (eds.), *The Nuclear Enterprise: High-Consequence Accidents: How to Enhance Safety and Minimize Risks in Nuclear Weapons and Reactors,* Hoover Institution Press, 2012.

24 See CBS/AP, "Pentagon revamps nuclear arsenal after review finds systemic problems", *CBS News*, 14 November 2014, http://www.cbsnews.com/news/pentagon-revamps-nuclear-arsenal-after-review-finds-systemic-problems/.

25 See for instance The National Diet of Japan, *The Official Report of the Fukushima Nuclear Accident Independent Investigation Commission*: *Executive Summary*, 2012, p. 20, https://www.nirs.org/wp-content/uploads/fukushima/naiic_report.pdf.

Conclusion

Many of the lessons that bitter experience of accidents and disasters taught the civilian nuclear industry seem to be relevant for the safety of nuclear weapon systems. The engineering approaches to safety can be highly vulnerable to beyond design-basis events and need to be continually examined from the standpoint of their robustness. Probabilistic risk assessments should not be taken as absolute measures of safety, but rather as instruments to investigate uncertainties about safety. Finally, the lack of independence, transparency and openness of regulators should be considered as a factor of risk *per se*. The extent to which these lessons can be put into practice by the defence establishments of nuclear-armed States remains an open question.

Chapter 8

Non-state Actors and Nuclear Weapons

Elena K. Sokova

Introduction

The majority of nuclear security experts identify two primary scenarios involving nuclear weapons and non-state actors. The first scenario involves the acquisition of a nuclear device from the existing arsenals of nuclear-armed States by terrorists or other non-state actors. The second scenario envisions the construction of a crude nuclear bomb by non-state actors using special nuclear materials—highly enriched uranium (HEU) or plutonium (Pu). The actualization of each of these scenarios would be very difficult, and the probability of a successful theft and detonation of an actual nuclear weapon or manufacturing of an improvised device by non-state actors is considered to be low.[1] Yet, this probability is not zero.

Nuclear terrorism as a threat entered the international discourse in the mid-1970s. It spurred the negotiation of the Convention on the Physical Protection of Nuclear Materials (CPPNM, which opened for signature in 1980) and the development of the first set of international recommendations for the physical protection of different categories of nuclear materials (now known as the International Atomic Energy Agency's INFCIRC/225). The Japanese doomsday cult Aum Shinrikyo tried to procure nuclear weapons and materials in the early 1990s. But it was the terrorist attacks on the United States in 2001 and the 2003 exposure of the clandestine network headed by Abdul Qadeer Khan, which supplied Libya, the Democratic People's Republic of Korea (DPRK), and Iran with the designs and know-how for the manufacturing of critical nuclear equipment, that added an urgency to closing serious gaps and shortcomings in national and international nuclear security regimes and approaches, particularly with regard to terrorist groups and non-state actors. Al-Qaida, as revealed by documents seized in Afghanistan, actively sought nuclear weapons and clearly expressed desire to use them were it able to acquire them.[2]

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1 For a detailed discussion of various nuclear terrorism scenarios see C.D. Ferguson et al, *The Four Faces of Nuclear Terrorism*, The Center for Nonproliferation Studies, 2005, and M. Bunn and A. Wier, "Terrorist nuclear weapon construction: how difficult?", *The Annals of the American Academy*, vol. 6, no. 1, 2006.

2 R. Mowatt-Larssen, "Al Qaeda's pursuit of weapons of mass destruction: the authoritative timeline", *Foreign Policy*, 25 January 2010, http://foreignpolicy.com/2010/01/25/al-qaedas-pursuit-of-weapons-of-mass-destruction/.

These revelations along with multiple past cases of security breaches at nuclear sites, including thefts of HEU and Pu from both civilian and military facilities, prompted numerous legal, institutional, and political responses to strengthen the control and security of nuclear arsenals and stocks and pursue the reduction and elimination of some of these stocks.

The international response

At the international level, several critical conventions and United Nations Security Council resolutions were adopted and a number of action-oriented initiatives and programmes to strengthen nuclear security worldwide were put in place. Among them is United Nations Security Council resolution 1540 adopted in 2004. It required all Member States to enact and enforce effective measures to prevent non-state actors from acquiring nuclear and other weapons of mass destruction (WMD), relevant materials and delivery systems. The International Convention on the Suppression of Acts of Nuclear Terrorism (2005) and over a dozen other new or amended conventions addressing terrorism and WMD followed suit. Many international initiatives, including the 2006 Initiative to Combat Nuclear Terrorism and a series of four Nuclear Security Summits (2010–2016), provided a necessary boost to practical measures to match the legal requirements. The Nuclear Security Summits, the highest-level initiative to date, brought together leaders from as many as 53 States and four international organizations and provided much needed motivation and peer pressure for individual States to sign and ratify relevant conventions and treaties, strengthen national security systems, and reduce HEU and Pu stocks.

The most challenging part in assessing the progress made in the past 15–20 years is to measure the threat posed by terrorists and other non-state actors vis-à-vis nuclear weapons. On the one hand, we face new terrorist actors such as Islamic State in Iraq and the Levant (ISIL) and the spread of Al-Qaida-type organizations to new regions in Africa, Asia, and the Middle East, yet it is difficult to assess their capabilities, motivations, and intentions. There are some indications of their interest in nuclear sites. For example, in 2015 two ISIL operatives conducted video surveillance of a senior official at the Belgian nuclear research facility.[3] This information, however, is not sufficient to reach broader conclusions. Even less is known about other non-state actors. These uncertainties, at least until either terrorism is eradicated or nuclear weapons are eliminated, leave us with two primary routes to lowering the risk of theft or seizure of nuclear weapons or materials by terrorists or non-state actors: 1)

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[3] M. Schreuer and A.J. Rubin, "Video found in Belgium of nuclear official may point to bigger plot", *New York Times*, 18 February 2016, https://www.nytimes.com/2016/02/19/world/europe/belgium-nuclear-official-video-paris-attacks.html.

the reduction of the nuclear arsenals and stocks, and 2) the reduction and elimination of vulnerabilities in protecting and controlling these assets.

Security and control of nuclear weapons

The existing arsenals of the nuclear-armed States represent the most obvious means by which terrorists or other non-state actors could acquire a nuclear weapon, although these are supposed to be very tightly guarded, without exception. Over the course of the last three decades, the number of nuclear weapons has been significantly reduced through a series of bilateral United States and Russian arms control agreements as well as unilateral reductions implemented by them and other nuclear states (the United Kingdom and France). These reductions were not necessarily motivated by nuclear terrorism considerations, but they nonetheless resulted in the elimination of tens of thousands of nuclear weapons and thus contributed to lowering the risk. The United States and the Soviet Union (now Russia) dramatically reduced their arsenals from about 70,000 warheads combined at the height of the Cold War to 6,800 and 7,000 warheads respectively by January 2017.[4] Yet, the global stock of nuclear weapons is still estimated at 14,900 warheads.[5] Moreover, in contrast to the overall reduction of the number of nuclear weapons, the arsenals of India and Pakistan have nearly quadrupled in size since the early 2000s. The DPRK, a newcomer to the nuclear club, conducted five nuclear tests between 2006 and 2016 and is estimated to have enough nuclear material for up to 15 devices.

State vulnerabilities

The developments involving the "new" nuclear-armed States perhaps represent the most alarming possibilities for nuclear diversion, particularly in light of the regional instability and terrorist activities in South Asia and the potential for the collapse of the DPRK. Indeed, prior nuclear history demonstrates that political turmoil, government instability, and crisis situations put the security and control of nuclear weapons at risk of falling into the wrong hands. These include the 1961 coup in Algeria when a French nuclear site and a nuclear device were at the centre of a battle for competing loyalties; the internal power struggle within the Chinese nuclear research and development programme and within the Chinese strategic missile forces during the Cultural Revolution in 1966; the storming by anti-Moscow rebels of

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4 H.M. Kristensen and R.S. Norris, "Status of world nuclear forces", *Federation of American Scientists*, 2017, https://fas.org/issues/nuclear-weapons/status-world-nuclear-forces/.

5 Ibid.

an army base with nuclear weapons in Azerbaijan in 1990; and many other incidents.[6]

Security lapses and incidents unfortunately continue nowadays in both "old" and "new" nuclear-armed States despite new treaties, resolutions, and reports on security improvements. In 2007, for example, six nuclear-armed cruise missiles were mistakenly flown across the United States and left unguarded for 36 hours.[7] In Pakistan between 2007 and 2012, several armed attacks occurred on air force bases thought to station nuclear-capable missiles. In July 2016, during a coup attempt in Turkey, the Turkish commander of the Incirlik Air Base, at which an estimated 50 B61 nuclear bombs are stationed by the North Atlantic Treaty Organization, gave orders to allow the anti-government forces to use the base for refuelling F-16s that bombed the Turkish parliament.[8] As the last two examples illustrate, insiders with legitimate access to weapons or materials can pose a threat if they are sympathetic to the goals of non-state actors or decide to assist them for any reason, including coercion.[9]

The limits of assessment

In most instances, military and security officials downplay the seriousness of these incidents. Unfortunately, in response to legitimate concerns about the vulnerabilities and breaches at nuclear bases and facilities, they offer only their "solemn word" that "nuclear weapons are safe, secure and under complete institutional and professional control", for example, as Lieutenant-General (Retired) Khalid Kidwali, former head of the Pakistan National Command Authority, stated in 2015.[10]

The majority of nuclear-armed States view nuclear security information as highly sensitive and rarely report breaches and vulnerabilities. Even in the United States,

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6 For details of these and additional cases, see H.D. Sokolski and B. Tertrais (eds.), *Nuclear Weapons Security Crises: What Does History Teach?*, U.S. Army War College Strategic Studies Institute, 2013, http://www.strategicstudiesinstitute.army.mil/pubs/display.cfm?pubID=1156.

7 J. Warrick and W. Pincus, "Missteps in the bunker", *Washington Post*, 23 September 2007, http://www.washingtonpost.com/wp-dyn/content/article/2007/09/22/AR2007092201447.html.

8 For additional cases and details, see chp. 3 in M. Fitzpatrick et al., *Improving the Security of All Nuclear Materials: Legal, Political, and Institutional Options to Advance International Oversight*, International Institute for Strategic Studies, James Martin Center for Nonproliferation Studies, and the Vienna Center for Disarmament and Non-Proliferation, September 2016.

9 For the discussion of insider threats and specific cases, refer to M. Bunn and S.D. Sagan, *A Worst Practices Guide to Insider Threats: Lessons from Past Mistakes*, American Academy of Arts and Sciences, 2014, https://www.amacad.org/multimedia/pdfs/publications/researchpapersmonographs/insiderThreats.pdf.

10 "Transcript: a conversation with Gen. Khalid Kidwali", Carnegie International Nuclear Policy Conference, 23 March 2015, http://carnegieendowment.org/files/03-230315carnegieKIDWAI.pdf.

which has been much more open about security lapses, many historical cases became known only recently. Other States are much less forthcoming with such information. In the absence of this information, it is impossible to provide an assessment that goes beyond the commonly agreed postulates that the security of nuclear weapons and military materials is generally much more rigorous as compared to civilian nuclear sites, and that terrorism threats of the twenty-first century have prompted further improvements in the security of nuclear arsenals.

Security of nuclear materials

The second risk scenario involves the theft or acquisition of nuclear materials and their fashioning into an improvised nuclear device by non-state actors. The two primary materials that could serve as fuel for a bomb are HEU and Pu. Although it is by no means a trivial task to construct a working device from these materials, numerous assessments by governmental and non-governmental experts confirm that it is not an insurmountable one either. With technical assistance and sufficient finances, it is within reach of non-state groups to construct a primitive device, particularly a gun-type device that uses HEU. The Hiroshima bomb, codenamed Little Boy, utilized a gun-type design. The designers were so confident that it would detonate that they did not even test the bomb. The know-how and other technical information, unfortunately, is much more accessible today, and as long as the perpetrators can acquire enough HEU (approximately 25–50 kg of uranium-235), they have the necessary fuel for a gun-type device.

An implosion-type device is a much more challenging technical task. Nevertheless, experts warn that there is “a very real possibility that a technically sophisticated terrorist group, given sufficient effort, could make a crude implosion-type bomb—particularly if they got knowledgeable help”.[11] Moreover, the implosion-type bomb requires much less nuclear material, particularly if Pu metal is used as fuel. These are the reasons why so much emphasis is put on the security of HEU and Pu and the minimization of their use and stocks. One of the challenges to achieving the latter objectives is that HEU and Pu are used in both military and civilian applications. While the majority of civilian uses of HEU can be replaced either by low enriched uranium (LEU) that is not suitable for the construction of nuclear weapons or by other alternative technologies, there are both technical and political challenges to implementing this switch.

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[11] M. Bunn, A. Wier, and J. Friedman, “The demand for black market fissile material”, *Nuclear Threat Initiative Research Library: Securing the Bomb*, Project on Managing the Atom, 2005.

Building political momentum

The risk centred on nuclear materials has inspired efforts both to reduce and eliminate HEU and Pu stockpiles and to strengthen the security of remaining stocks and sites. Facilities with these materials in the civilian sector, including research and test reactors, have long been a target. The first efforts to replace HEU in research reactors with LEU and eliminate HEU use in civilian applications date back to the late 1970s. The 2001 terrorist attacks against the United States brought new urgency to these efforts, yet progress was slow. Some countries were not prepared to part with HEU for economic, technical, or political reasons. In 2009, United States President Barack Obama promised in his famous Prague speech to convene a Nuclear Security Summit in order "to secure all vulnerable nuclear material around the world within four years", particularly HEU and Pu.[12] The first Summit held in 2010 injected a renewed sense of urgency into these efforts.

Six years and four Summits later, while President Obama's timeline has not been met, nevertheless 16 States have removed HEU from their territories; several tons of HEU were repatriated back to the United States and Russia for downblending, rendering this material unusable for weapons.[13] The majority of the States which participated in the Summit process took steps to demonstrate progress in strengthening their nuclear security by ratifying international nuclear security and terrorism conventions, enacting relevant domestic legislation, subscribing to the nuclear security standards and recommendations developed by the International Atomic Energy Agency (IAEA), and putting in place capacity-building and training programmes for nuclear security specialists.[14] These achievements are laudable and may not have been enacted without this top-level attention.

Remaining gaps

Nonetheless, progress remains limited and varies from country to country. Not all States with HEU and Pu holdings participated in the Summits. Even among the participating States not all were keen to reduce their HEU and Pu stocks or agree on security measures. Another disconcerting shortcoming is that, while the political declarations of the Summits referenced the security of all nuclear materials, actual

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12 *Remarks of President Barack Obama*, Prague, 5 April 2009, https://obamawhitehouse.archives.gov/video/The-President-in-Prague#transcript.

13 For a summary of the Summit's achievement, see "FACT SHEET: The Prague nuclear agenda", The White House, 11 January 2017, https://obamawhitehouse.archives.gov/the-press-office/2017/01/11/fact-sheet-prague-nuclear-agenda.

14 For a detailed account of the achievements of the Nuclear Security Summits, see W. Tobey, "Descending from the summit: the path toward nuclear security 2010–2016 and beyond", *Policy Analysis Brief*, September 2016, http://www.stanleyfoundation.org/publications/pab/DescendingFromtheSummit-Tobey916.pdf.

implementation efforts and commitments have concentrated on the civilian nuclear material, which constitutes only 17 per cent of global stocks of HEU and separated Pu.[15] The remaining 83 per cent of HEU and Pu is in weapons or other non-civilian applications and was effectively outside the discussions and concrete measures at the Summit and in other forums. This is not to say that these materials did not receive security upgrades or attention. However, as in the case with nuclear weapons, information about the security of nuclear materials, particularly in the non-civilian applications, is limited.[16] The international community relies on indirect indicators, including the size of stocks, treaty ratification, political stability, and corruption to assess the state of nuclear security. For instance, the Nuclear Threat Initiative (NTI) Nuclear Security Index, while limited in scope and precision, provides several useful reference points particularly for tracking progress.[17]

Spoofing, cyber, and other threats

The theft of a nuclear weapon or the manufacturing of an improvised nuclear device are unfortunately not the only scenarios involving nuclear weapons and non-state actors. Terrorist or other groups may not need to lay hands on an actual weapon itself in order to cause nuclear harm. One of the potential scenarios involves the deliberate manipulation of early-warning systems. Several historic incidents demonstrate that these systems have vulnerabilities and are prone to false alarms. Such past "close calls" are discussed alongside a variety of risks associated with the early-warning and control and command systems in Pavel Podvig's chapter in this study. It is also notable that a 2009 study commissioned by the International Commission on Nuclear Non-proliferation and Disarmament warned that, under the right circumstances, terrorists could break into these systems and launch an attack. "This may be an easier alternative for terrorist groups than building or acquiring a nuclear weapon or dirty bomb themselves".[18] Moreover, these systems are complicated, and they often incorporate commercial off-the-shelf technologies that

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15 NTI Military Materials Security Study Group, *Bridging the Military Nuclear Materials Gap*, Nuclear Threat Initiative, 2015, p. 3, http://www.nti.org/media/pdfs/NTI_report_2015_e_version.pdf?_=1447091315.

16 For a detailed discussion of the security and transparency of the security of materials in military programmes and other non-civilian applications, see M. Fitzpatrick et al., *Improving the Security of All Nuclear Materials: Legal, Political, and Institutional Options to Advance International Oversight*, International Institute for Strategic Studies, James Martin Center for Nonproliferation Studies, and the Vienna Center for Disarmament and Non-Proliferation, September 2016.

17 See http://www.ntiindex.org/behind-the-index/about-the-nti-index/.

18 J. Fritz, *Hacking Nuclear Command and Control*, International Commission on Nuclear Nonproliferation and Disarmament, July 2009, http://icnnd.org/documents/jason_fritz_hacking_nc2.doc.

may introduce unexpected vulnerabilities to cyber attack, despite the fact that they are allegedly not connected to the Internet and operate as "closed" systems.

Digital-age developments exacerbate these vulnerabilities and introduce multiple additional cyber technology risks and insider threats that go beyond the penetration and manipulation of the control and command system. Patricia Lewis and Beyza Unal's chapter in this study examines a wide array of cyber vulnerabilities, including possibilities for their abuse by insiders. Other scenarios that non-state actors could exploit include a staging of escalatory attacks that draw States into a nuclear crisis or the false blame of one State for the actions of a non-state actor. The manipulation of social media and the spreading of false news could be exploited as well. A false news story on the AWD News site in late December 2016 claimed that Israel had threatened to attack Pakistan with nuclear weapons if Islamabad interfered in Syria. The report triggered a Twitter response by Pakistani defense minister Khawaja Muhammad Asif, who indicated that Israel should remember that Pakistan is a nuclear-armed State, as well.[19] Fortunately, the Israeli Defense Ministry quickly responded that the story was "totally fictitious". This episode, however, highlights the potentially serious consequences of deliberate misinformation or manipulation of information, particularly in a crisis and in instances where the sides do not have reliable communication channels, have a very short time to act on such information, or where local commanders have been delegated the authority to launch theatre nuclear weapons or submarine-based systems. Such scenarios are particularly relevant in conflict-prone South Asia.[20]

Conclusion

International and national efforts of the past 15–20 years to reduce vulnerabilities and lower the risk related to non-state actors acquiring and using nuclear weapons have yielded some tangible progress. This work, however, is far from being finished. The security upgrades and the reductions in nuclear arsenals and stocks have been limited, uneven, and in many instances difficult to measure due to the lack of transparency on the part of States. At the same time, the digital age and other new and emerging technologies have opened up new vulnerabilities and threats that can be exploited by non-state actors. Unfortunately, both the understanding of these new risks and strategies to address them are lagging behind, adding to the uncertainties in assessing the risk of non-state actors vis-à-vis nuclear weapons.

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19 R. Goldman, "Reading fake news, Pakistani minister directs nuclear threat at Israel", *New York Times*, 24 December 2016, https://www.nytimes.com/2016/12/24/world/asia/pakistan-israel-khawaja-asif-fake-news-nuclear.html.

20 H.E. Haegel and R. Verma, "The terrifying geography of nuclear and radiological insecurity in South Asia", *Bulletin of Atomic Scientists*, 27 January 2017, http://thebulletin.org/terrifying-geography-nuclear-and-radiological-insecurity-south-asia10416.

Chapter 9

Reducing Nuclear Weapon Risks

John Borrie, Tim Caughley, and Wilfred Wan

The state of play

Today, in 2017, there are mounting challenges to the prevailing nuclear order. At the same time, some nuclear non-proliferation and disarmament diplomats and commentators talk of increasing political polarization in approaches to curbing nuclear weapons that they worry will further undermine it. Different causes are ascribed to this situation. At times the finger of blame is pointed at rogue "outliers" (for subverting or defying the rules against possessing nuclear weapons), and at other times toward the nuclear-armed States (for failing to give effect to disarmament and their other undertakings). Lately, even "radicals" among the non-nuclear-armed States have been blamed for daring to undertake negotiations on a treaty to prohibit nuclear weapons, which opponents fear will undermine nuclear deterrence and so—their logic goes—compel additional States to seek their own nuclear arsenals, or encourage "forum" shopping in terms of compliance obligations.[1] These arguments are ongoing, and are described elsewhere.[2]

Instead, the contributions in this volume have focused on aspects of something that should be of common interest to both opponents of nuclear weapons and supporters of nuclear deterrence—that is, the need to understand and address the full range of dangers that could lead to the use of nuclear weapons. Reasonable people might disagree as to exactly how to quantify the danger, and as contributors to this study have shown, there are real obstacles to precise, objective quantification. But no sane person would say nuclear risk reduction efforts are unnecessary or even unimportant, however sceptical they might be, say, about the prospects of nuclear terrorism or an inadvertent nuclear war.[3] This is because even very low probability events still

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1 R. Einhorn, *Non-Proliferation Challenges Facing the Trump Administration*, The Brookings Institution, March 2017, https://www.brookings.edu/research/non-proliferation-challenges-facing-the-trump-administration; A. Mount and R. Nephew, "A nuclear weapons ban should first do no harm to the NPT", *The Bulletin of the Atomic Scientists*, 7 March 2017, http://thebulletin.org/nuclear-weapons-ban-should-first-do-no-harm-npt10599.

2 For an introduction see UNIDIR, *The Treatment of the Issue of Nuclear Disarmament since the Open-Ended Working Group in 2013*, UNIDIR OEWG Briefs No. 2, 15 February 2016, http://www.unidir.org/files/publications/pdfs/oewg-briefing-paper-no-2-en-646.pdf.

3 For one prominent—and thoughtful—sceptical view, see J. Mueller, *Atomic Obsession: Nuclear Alarmism from Hiroshima to Al-Qaeda*, Oxford University Press, 2010.

happen, and the humanitarian consequences of even a single low-yield nuclear weapon detonation in a populated area like a city would be massive.[4]

As prosaic as it sounds, a common and continuing interest in nuclear weapon risk reduction is an important point of policy convergence for the international community, and it must remain so. This imperative manifested itself even during the deepest chill of the Cold War, when nuclear near-misses in the 1962 Cuban Missile Crisis engendered the idea of a Moscow–Washington hotline, agreed the following year between the two nuclear superpowers.[5] Since the 1960s, a central plank of multilateral non-proliferation efforts—ranging from the Nuclear Non-proliferation Treaty to strategic export control regimes to United Nations Security Council resolution 1540—has been that nuclear weapons in more hands means greater nuclear danger. Expressed in an even stronger form, the 2016 Open-ended Working Group's final report warned that "the risk of accidental, mistaken, unauthorized or intentional nuclear weapon detonations" persists "for as long as nuclear weapons exist"—making it clear that this concern is an important animating concept for non-nuclear-armed States to try to constructively alter a nuclear situation they view as risky.[6]

The revitalization of multilateral nuclear disarmament efforts would be a boon to reducing the risks associated with nuclear weapons. Yet currently there are few signs that any of the nine States possessing these weapons is about to discard strategies that envisage use, let alone relinquish their nuclear arsenal. Their postures commit them to continuing nuclear weapon-related preparations and investments in complex and tightly coupled detection, command and control systems, as well as doctrines and practices that are a long way from foolproof, as the contributions in this study show. Moreover, despite the dangers, a number of other states allied to some of the nuclear-armed powers also continue to rely on nuclear weapons for their security, and apparently view their continued deployment as barometers of alliance resolve and strategic assurance at a tense time.

It means that the nuclear age and its anxieties look set to continue, and the risk of a detonation event remains very much a reality for the foreseeable future. To that end, and although not exhaustive, the contributions in this study have outlined the wide spectrum of risk variables that exists. Together, they constitute a timely reminder to nuclear policymakers not to bury their heads in the sand. It simply is not credible to

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4 For instance, see J. Borrie and T. Caughley, *An Illusion of Safety, Challenges of Nuclear Weapon Detonations for United Nations Humanitarian Coordination and Response*, UNIDIR, 2014.

5 *Memorandum of Understanding Regarding the Establishment of a Direct Communications Line*, 20 June 1963, signed in Geneva, Switzerland, by representatives of the Soviet Union and the United States.

6 United Nations, *Report of the Open Ended Working Group Taking Forward Multilateral Nuclear Disarmament Negotiations*, UN document A/71/371, 1 September 2016, para. 54.

claim that those nuclear risks are wholly manageable with full confidence, or to pretend that they do not exist.

Still, while risk cannot be altogether eliminated so long as nuclear weapons exist, in the meantime there are measures that can be taken to mitigate that risk. This concluding chapter turns to the question of nuclear weapon risk reduction and presents some ideas to frame further exploration by policymakers about what could be done in present circumstances.

Preventive measures

Transparency and information-sharing

As the introductory chapter posited, incomplete understandings of nuclear weapon risk are intimately linked to the lack of information concerning existing nuclear weapons programmes. This lack of information makes it difficult for independent, critical examination of nuclear safety, for instance, because there is a fundamental asymmetry between knowledge held on the inside (national military nuclear programmes) and the outside (everyone else, even other parts of national governments possessing nuclear arsenals). Almost a quarter-century ago the scholar Scott Sagan concluded that the burden of proof for demonstrating that nuclear weapon control systems are acceptably safe needed to shift. He said, "those who predict that nuclear weapons can be managed safely indefinitely into the future should have to prove their case and not simply refer back to a perfect safety record that never really existed".[7] Today, that has yet to occur, even in the United States, which was Sagan's main subject of investigation, and which is often the most transparent of the nuclear-armed States.[8]

There is no simple solution here. After all, secrecy is often a deliberate manoeuvre on the parts of nuclear-armed States. Efforts at greater transparency can come into conflict with their national interests, or be interpreted as an infringement on their sovereignty. And it should be recognized there has been some progress towards greater information sharing on the part of certain nuclear-armed States, in particular regarding weapons and materials stockpile sizes. Nevertheless, existing transparency measures appear insufficient in the eyes of many, and do not offer more than a hazy picture of contemporary nuclear weapons records and practices.

There appears to be scope for progress. Some have identified the New Strategic Arms Reduction Treaty (New START) between the United States and Russia as a

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[7] S.D. Sagan, *The Limits of Safety: Organizations, Accidents, and Nuclear Weapons*, Princeton University Press, 1993, p. 264.

[8] See J. Borrie, *A Limit to Safety*: *Risk: 'Normal Accidents', and Nuclear Weapons*, UNIDIR and the International Law and Policy Institute Paper no. 3, December 2014, p. 6.

model, which features data exchanges and notifications on the number, location, and technical details of strategic offensive arms.[9] Such information exchange on air-launched cruise missiles and delivery systems, or on weapons deployed in foreign countries, for instance, could help address issues of ambiguity—especially as the doctrinal line between nuclear and conventional war-fighting continues to seem to blur.[10] The establishment of dedicated communications channels can further help to prevent misidentification that could prompt retaliatory attack.[11]

Operational procedures

Even if the veil of secrecy can be removed, there is a limit to the impact of such transparency and communications measures. This is especially true during times of crisis, when the warning and decision time available decreases for pertinent individuals to process that data. Indeed, Podvig's chapter on command and control referred to a number of instances during the Cold War in which false alarms linked to malfunctioning sensors or misinformation brought both sides to the brink of nuclear war. Such issues are compounded by the fact that short decision timelines have pushed militaries to develop "rapid-reaction procedures [that] have the effect of biasing the process toward a decision to launch".[12]

In order to lengthen the fuze, various scholars and analysts have suggested a range of actions to the nuclear-armed States. These include different approaches for States to reduce the alert status of their nuclear-tipped missiles, for instance through the activation of safety switches on missile silos, the deactivation of mechanisms that automatically open silo covers, or the removal and separate storage of warheads from their delivery systems.[13] Some have also prescribed the physical separation of

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9 See T. Patton, P. Podvig, and P. Schell, *A New START Model for Transparency in Nuclear Disarmament*, UNIDIR, 2013, http://www.unidir.ch/files/publications/pdfs/a-new-start-model-for-transparency-in-nuclear-disarmament-en-409.pdf.

10 T. Rauf, "Nuclear weapons: transparency and risk reduction", *Taking Forward Multilateral Nuclear Disarmament Negotiations: Open-ended Working Group*, Geneva, 25 February 2016, http://www.atomicreporters.com/wp-content/uploads/2016/02/OEWG_25Feb2016_Final_RAUF2.pdf.

11 P. Podvig, "Blurring the line between nuclear and nonnuclear weapons: Increasing the risk of accidental nuclear war?", *Bulletin of the Atomic Scientists*, vol. 72, no. 3, 2016.

12 Union of Concerned Scientists, "Reducing the risk of nuclear war: taking nuclear weapons off high alert", 2016, p. 6, http://www.ucsusa.org/nuclear-weapons/us-nuclear-weapons-policy/reducing-the-risk.

13 L. Gronlund, "Top scientists call for Obama to take nuclear missiles off hair-trigger alert", *Union of Concerned Scientists*, 22 June 2016, http://blog.ucsusa.org/lisbeth-gronlund/top-scientists-call-for-obama-to-take-nuclear-missiles-off-hair-trigger-alert; Global Zero, *Global Zero Commission on Nuclear Risk Reduction: De-Alerting and Stabilizing the World's Nuclear Force Postures*, 2015, http://www.globalzero.org/files/global_zero_commission_on_nuclear_risk_reduction_report.pdf

the respective stockpiles, or of their command-and-control systems.[14] Such moves are intended to roll back any normalization of the nuclear option, even in crisis situations.

Strategic doctrines

More effective means of risk reduction must move beyond operational measures and tackle the overriding military strategies that can contribute to crisis development and escalation. This entails a reassessment of nuclear doctrines among the nuclear-armed States. For instance, the adoption of no-first-use policies could serve as a key confidence-building measure (currently, of the nine nuclear-armed States, only China and India have taken that stance), as could the elimination of "launch-on-warning" postures that dictate nuclear retaliation following detection but prior to an incoming attack.[15] Some argue that the United States should revisit the logic of its "hedge" force—a stockpile kept in reserve should technical problems arise with deployed weapons.[16] At a more basic level, cavalier threats and rhetoric centred on the use of nuclear weapons against adversaries should be rejected and denounced by the broader international community.

The risks borne by new technologies have also led some to suggest ambitious measures that would apply to entire classes of nuclear weapons. There is historical precedent, as the United States unilaterally eliminated all non-strategic naval nuclear weapons from its arsenal over a 25-year process.[17] A move along those lines in the contemporary era could do much to reduce nuclear ambiguity, and help once again to raise the threshold for nuclear use (especially of lower-yield weapons) in the process. Former United States Secretary of Defense William Perry is one of the more prominent supporters of a ban on nuclear-armed cruise missiles, an approach Parthemore examines in her chapter.[18] Prohibiting short-range nuclear-capable tactical missiles (currently possessed by the Democratic People's Republic of Korea

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[14] P. Hayes, *Nuclear Command-and-Control in the Millenials Era*, NAPSNet Special Reports, 17 February 2015, http://nautilus.org/napsnet/napsnet-special-reports/nuclear-command-and-control-in-the-millenials-era/.

[15] B. Blair, "How Obama could revolutionize nuclear weapons strategy before he goes", *POLITICO Magazine*, 22 June 2016, http://politi.co/28PYwFp.

[16] E. MacDonald, "Cuts to the hedge", *Union of Concerned Scientists*, 8 December 2016, http://allthingsnuclear.org/emacdonald/cutthehedge.

[17] H.M. Kristensen, "Declassified: US nuclear weapons at sea", *Federation Of American Scientists*, 3 February 2016, https://fas.org/blogs/security/2016/02/nuclear-weapons-at-sea.

[18] W.J. Perry and A. Weber, "Mr. President, kill the new cruise missile", *Washington Post*, 15 October 2015, https://www.washingtonpost.com/opinions/mr-president-kill-the-new-cruise-missile/2015/10/15/e3e2807c-6ecd-11e5-9bfe-e59f5e244f92_story.html.

(DPRK) and Pakistan but not other nuclear-armed States) would also help to undermine the notion of a “flexible” response that does not preclude nuclear use.[19]

International cooperation

As suggested above, individual nuclear-armed States could unilaterally alter their strategic doctrines or operational procedures (e.g. de-alerting) in ways that would reduce their resort to nuclear force, and in turn likely contribute to the marginalization of nuclear weapons’ utility more broadly.[20] Nevertheless, differences among the various theatres for potential nuclear escalation means there is unlikely to be an effective “one size fits all” approach in efforts to reduce the likelihood of a detonation event. For instance, because Pakistan’s nuclear doctrine is conditioned by India’s conventional superiority, de-alerting measures appear unlikely there, at least without the presence of stronger security assurances from India. Instead, risk reduction in South Asia probably begins with modest trust-building exercises, for instance the development of a common nuclear lexicon, greater transparency in strategic and doctrinal foundations, and the establishment of more communication channels.[21]

In Northeast Asia, meanwhile, the intensification of the DPRK’s nuclear and missile development places great urgency on the resumption of six-party talks. Some have argued for an altered approach that at least de-emphasizes denuclearization; United States negotiator Sung Kim opened the door for exploratory talks without preconditions in early 2016.[22] Others suggest that the tightening of existing United Nations sanctions is key to slowing the DPRK’s nuclear and missile progress. Yet, an economically battered Pyongyang may also be at greater risk of selling weapons technology.[23]

Further demonstrating the interlinkages and complexities of risk reduction, moves by the United States to expand its missile defence capabilities—partly, it says, in response to the DPRK nuclear missile threat—has in turn ratcheted-up tensions with

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19 W.P.S. Sidhu, “To reduce missile threats, think outside the silo”, *Bulletin of the Atomic Scientists*, 10 August 2016, http://thebulletin.org/too-late-missile-nonproliferation/reduce-missile-threats-think-outside-silo.

20 On de-alerting, see H.M. Kristensen and M. McKinzie, *Reducing Alert Rates of Nuclear Weapons,* UNIDIR, 2012, http://www.unidir.ch/files/publications/pdfs/reducing-alert-rates-of-nuclear-weapons-en-307.pdf.

21 V. Shankar, “India-Pakistan: nuclear risk reduction measures”, *Institute of Peace & Conflict Studies,* 10 February 2014, http://www.ipcs.org/article/india/india-pakistan-nuclear-risk-reduction-measures-4301.htm.

22 L.V. Sigal, “Getting what we need with North Korea”, *Arms Control Today*, 29 March 2016, https://www.armscontrol.org/print/7384.

23 J. Park and J.B. Miller, “Is North Korea’s nuclear tech for sale?”, *East Asia Forum*, 3 November 2016, http://www.eastasiaforum.org/2016/11/03/is-north-koreas-nuclear-tech-for-sale/.

China and Russia. This is significant as relations between those three powers may have the greatest impact on the likelihood of a nuclear weapons detonation event for years to come, given the size of American and Russian stockpiles, and potential strategic flashpoints both in Europe and the Asia–Pacific. Transparency regarding Washington's missile defence programmes (and its future intentions for these programmes) is clearly of key concern to both China and Russia in their relations with the United States—relations that have deteriorated lately.[24]

Securing nuclear materials

The suspension of existing nuclear non-proliferation and security agreements between Russia and the West has hindered efforts to deny non-state actors access to nuclear knowledge, equipment and materials. Renewing bilateral cooperation between Russia and the United States must be a priority, as the two States account for over 82 per cent of the global fissile materials stockpile.[25] In addition, the development of a minimum global standard, or fleshing out of the "appropriate effective" measures specified in United Nations Security Council resolution 1540, would do much to bolster the global nuclear security apparatus.[26] States would also do well to expand the agenda, which remains circumscribed to the 17 per cent of fissile materials currently under civilian control.[27]

In addition, there are measures that can and should be taken outside the realm of nuclear weapons programmes. The strengthening of nuclear safety, security, and safeguards cultures is vital, especially for states beginning to undertake or expand their nuclear energy programmes. Japan's December 2016 offer of $2.2 million to Iran for nuclear safety and safeguards initiatives to help Tehran to implement its Joint Comprehensive Plan of Action with the P5+1 and the European Union reflects the type of outreach that should be encouraged and facilitated.[28] There is a particular need to address nuclear waste management and radioactive source management

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[24] Y. Lu, "Reflections on strategic stability", in B. Li and Z. Tong (eds.), *Understanding Chinese Nuclear Strategy*, Carnegie Endowment for International Peace, http://carnegieendowment.org/files/ChineseNuclearThinking_Final.pdf; T.Z. Collina, "Russia, U.S. trade missile defense offers", *Arms Control Today*, 3 June 2013, https://www.armscontrol.org/print/5795.

[25] International Panel on Fissile Materials, http://fissilematerials.org/.

[26] M.B. Malin and N. Roth, "A new era for nuclear security", *Arms Control Today,* 31 May 2016, https://www.armscontrol.org/ACT/2016_06/Features/A-New-Era-for-Nuclear-Security.

[27] M. Fitzpatrick et al., *Improving the Security of All Nuclear Materials: Legal, Political, and Institutional Options to Advance International Oversight*, International Institute for Strategic Studies, James Martin Center for Nonproliferation Studies, and the Vienna Center for Disarmament and Non-Proliferation, September 2016.

[28] "Japan to offer $2.2 million to Iran for nuclear safety cooperation", *Japan Times Online*, 8 December 2016, http://www.japantimes.co.jp/news/2016/12/08/national/politics-diplomacy/japan-offer-e2-million-iran-nuclear-safety-cooperation/.

issues, which are both pertinent to reducing the risk of nuclear terrorism. The adoption of additional regulatory frameworks and establishment of regional and global nuclear fuel banks can provide other means to this end.

The limits of risk reduction

For all the potential risk reduction measures discussed however, there does appear to exist a minimum threshold or "floor" to that risk. The special characteristics of complex and tightly coupled systems such as early-warning and command and control systems for nuclear weapons make accidents endemic and "inevitable, even normal"; nuclear weapons systems, according to some experts, "are hopeless and should be abandoned".[29] This is for a range of reasons, including the potential for hidden interactions between a system's components in cases of failure, of which the operator may not be aware. Several times during the Cold War, for instance, nuclear decision-makers urgently had to decide whether alarms indicating an imminent nuclear attack were real or false, and which were subsequently found to be due to failures ranging from the wrong tape being used in a machine to failed electronic components.[30] Even the introduction of technical redundancies and other measures intended to reduce risk can introduce new interactions and new uncertainties. Others have made the argument that technology itself is embedded in organization and culture, which itself can exacerbate dangers. The disaster at Fukushima stands as an example of nuclear security as "a complex societal problem", in which individuals—including those working for the plant operator, regulatory bodies, and government ministries—made incorrect assumptions coloured by their knowledge and interests, both individual and organizational.[31]

Ultimately, the interactions between people and hazardous technology produces risk, even in ways that can appear entirely disconnected from that technology. Declassified documents reveal that during the Cold War, a number of United States Navy warships and attack submarines experienced collisions, fires, even sank—with the nuclear weapons they carried threatened, at risk of damage, and in several instances lost at sea as a result.[32] The United Kingdom's experience is allegedly not dissimilar: "16 submarine collisions since 1979, 266 submarine fires in the past 25 years, numerous safety shortfalls with nuclear-armed submarines and at the Atomic

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[29] C. Perrow, *Normal Accidents: Living with High-Risk Technologies*, Princeton University Press, 1999, pp. 4, 304.

[30] On 9 November 1979 and 3 June 1980 respectively. See P.M. Lewis et al., *Too Close for Comfort: Cases of Near Nuclear Use and Options for Policy*, Chatham House, 2014, p. 7.

[31] R. de Man, *Global Nuclear Security: The Role of Uncertainty, Disputed Values and Non-State Actors*, The Hague Institute for Global Justice, 2015, p. 10.

[32] H.M. Kristensen, "Declassified: US nuclear weapons at sea", *Federation Of American Scientists*, 3 February 2016, https://fas.org/blogs/security/2016/02/nuclear-weapons-at-sea.

Weapons Establishment, 158 fires at the Atomic Weapons Establishment between 2000–2011, and serious unresolved safety concerns with the Trident warhead”.[33]

The diversity of risk has been exacerbated by the cyber domain, which presents new challenges in a multitude of ways for command and control safety, information security, strategic deterrence, and the overall “integrity and security of nuclear systems, and their component parts”.[34] Militaries of nuclear-armed nations have thus far publicly insisted that their systems are, in effect, “air-gapped” from the outside. But even if this has been the case (which is contestable), it is unlikely to remain so with continued nuclear modernization. As Lewis and Unal noted in their chapter, there is ample possibility for disruption or subversion of critical electronic systems as these become more complex, and cyber-intrusion methods become more sophisticated in exploiting gaps in defences. Decision-makers’ loss of confidence in the information supplied from their nuclear detection, command and control systems in a crisis situation could also have devastating consequences, for instance.

Finally, there exists a changing geopolitical landscape that also serves to hinder risk reduction efforts as trust declines and suspicion increases among the nuclear-armed powers. A clear example is the suspension of cooperation on nuclear risk reduction measures between Russia and the United States that had helped them understand each other’s perceptions, preoccupations, and intentions since the 1990s. Other geopolitical features are more structural in nature. The disparity in nuclear arsenal sizes has made it difficult to extend arms control and disarmament discussions beyond the United States and Russia to date. Moreover, conventional military imbalances—like that between India and Pakistan—can increase the reliance of the weaker party on a “credible” nuclear deterrent in the absence of trust. In that vein, it has been argued that the United States’ development of missile defense systems and counterforce capabilities could put China or Russia in a position to “either lose the capability to launch a strategic nuclear counterattack or use nuclear weapons first to avoid devastation” and thus in itself be profoundly destabilizing.[35] Renewed nuclear arms races or revisited nuclear postures could ensue.[36] And that is not to dwell on wildcard factors such as nuclear decision-makers with unstable personalities, or events in which central authorities lose physical control of nuclear weapons or their

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[33] N. Ritchie, *Nuclear Risk: The British Case*, Article 36, 2014, p. 1, http://www.article36.org/wp-content/ uploads/2013/06/Nuclear-risk-paper.pdf. On the danger of British nuclear convoys, see also R. Edwards, *Nukes of Hazard: The Nuclear Bomb Convoys on Our Roads*, International Campaign to Abolish Nuclear Weapons UK, 2016, http://nukesofhazard.gn.apc.org/wp-content/uploads/2016/09/NoH_Report_Final.pdf.

[34] A. Futter, *Is Trident Safe from Cyber Attack?*, European Leadership Network, February 2016.

[35] Y. Hu, “US playing strategic arms game”, *China Daily,* 10 January 2013, http://www.chinadaily.com.cn/opinion/2013-01/10/content_16103821.htm.

[36] F.S. Cunningham and M.T. Fravel, “Assuring assured retaliation: China’s nuclear posture and U.S.-China strategic stability”, *International Security,* vol. 40, no. 2, 2015.

fissile components, for instance in a theft or coup, as some experts fear could conceivably occur in Pakistan.[37]

Trends in nuclear risks

The probability and consequences of nuclear weapon detonation events are far from trivial, and underline the need for concerted action to resume disarmament with a view to achieving a nuclear weapon-free world. Here is a list of key facts and trends drawn from the contributions to this study for policymakers as they discuss next possible steps to take in nuclear risk reduction:

- Risk is intrinsic to nuclear deterrence doctrine as instilling uncertainty in potential adversaries is regarded as a beneficial property. Yet in a nuclear crisis situation, mistakes in estimating the inadvertent outcomes of given behaviours and interactions can lead to further escalation or actual nuclear conflict.
- Despite claims to the contrary by possessors, nuclear modernization is making nuclear weapons more usable by improving their operational flexibility and effectiveness in locating and reliably destroying targets.
- Such modernization efforts (e.g. nuclear-armed cruise missile capabilities) threaten strategic stability by creating ambiguity that increases the chance of miscalculation, misperception, escalation, and arms racing.
- Technological and doctrinal modernization efforts aimed at allowing for greater integration of conventional and nuclear warfare threaten long-standing taboos related to nuclear weapons testing and use.
- Technological advances of various kinds add new complexities and potential failure points that will strain early-warning and command and control systems, while compressing human decision-making timelines and exposing those systems to false alarms and accidents.
- New technologies also expand the range of actors, including non-state actors, that might be able to exploit vulnerabilities (e.g. cyber) in nuclear weapons systems, including in indirect ways such as the manipulation of policymakers' and military strategists' perceptions. This could have profound effects in a crisis.
- The idea that nuclear command and control systems can be fully air-gapped from the outside is a myth, and they contain components that are vulnerable in ways not fully understood.
- Given also considerable uncertainties (e.g. about the impacts of natural disasters and other phenomenon), the probabilistic risk acceptability criteria that guide national approaches to both power plants and weapons should not be taken as an actual measure of safety.

[37] M. Krepon, "Can deterrence ever be stable?", *Survival,* vol. 57, no. 3, 2015, p. 127.

- Recent attention on securing highly enriched uranium and plutonium stocks and sites is laudable, but has been inconsistent and, to date, remains concentrated only on civilian nuclear material when the majority of stocks are in military hands.
- Independent safety oversight remains largely lacking in the domain of nuclear weapons, a special concern given its crucial importance in reducing the frequency of serious accidents across a range of hazardous technologies.
- New and smaller nuclear powers can exacerbate risk, as they may have less secure physical and operational control of their nuclear weapons, and less doctrinal transparency; and are particularly susceptible to political turmoil, government instability, and crisis situations.

As already explained, this study does not claim to present an exhaustive list of risk causes. Still, by identifying some of the most pertinent variables linked to a potential nuclear weapons detonation event, this study extends a conversation about the whole of the risk equation. And it points to issues on which nuclear weapons possessors and non-possessors alike should engage with a view to reducing the risk of use of nuclear weapons.

List of Acronyms

AI/RAS	artificial intelligence, robotics and autonomous systems
ALCM	air-launched cruise missile
CPPNM	Convention on the Physical Protection of Nuclear Materials
DPRK	Democratic People’s Republic of Korea
GNSS	global navigational satellite systems
GPS	Global Positioning System
HEU	highly enriched uranium
IAEA	International Atomic Energy Agency
ICBM	intercontinental ballistic missile
ICS	industrial control systems
INF	Intermediate-Range Nuclear Forces
JASSM	Joint Air-to-Surface Standoff Missile
LEP	Life Extension Programs
LEU	low enriched uranium
LRSO	Long-Range Standoff missile
MAD	mutually assured destruction
MEECN	Minimum Essential Emergency Communications Network
MIRV	multiple independently targetable re-entry vehicle
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organization
NNSA	National Nuclear Security Administration
NOAA	National Oceanic and Atmospheric Administration
NORAD	North American Aerospace Defense Command
NPT	Nuclear Non-proliferation Treaty
NRC	Nuclear Regulatory Commission
OEWG	Open-ended Working Group
PNT	positional, navigational, and timing
PWR	pressurized water reactors
ROK	Republic of Korea
SCADA	supervisory control and data acquisition systems
SRBM	short-range ballistic missile
UNSSOD	United Nations Special Session on Disarmament
START	Strategic Arms Reduction Treaty
STRATCOM	United States Strategic Command
THAAD	Terminal High Altitude Area Defense
WMD	weapons of mass destruction

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Understanding Nuclear Weapon Risks

John Borrie, Tim Caughley and Wilfred Wan
Editors

Policy attention to date has focused predominantly on understanding the *consequences* of nuclear weapon detonations. The *probability* side of the risk equation, by contrast, is less well understood. Risk assessment and risk management warrant more attention. In response, this study seeks to contribute to the facts-based discourse about nuclear weapons by drawing on a range of expert perspectives. It explores various sources of nuclear weapon risk, from technological aspects to military strategy to political considerations, among others, and considers recent security developments of relevance. In disaggregating the causes and level of nuclear weapon risk, the study provides a foundation for further dialogue and information-sharing. It seeks to identify common ground for reducing the risk of detonation of nuclear weapons for any reason.

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