

This is a repository copy of *Nuclear risk : the British case*.

White Rose Research Online URL for this paper:

<https://eprints.whiterose.ac.uk/78773/>

Version: Published Version

Other:

Ritchie, Nick orcid.org/0000-0002-6397-7498 (2014) *Nuclear risk : the British case*. Article 36.

Reuse

Items deposited in White Rose Research Online are protected by copyright, with all rights reserved unless indicated otherwise. They may be downloaded and/or printed for private study, or other acts as permitted by national copyright laws. The publisher or other rights holders may allow further reproduction and re-use of the full text version. This is indicated by the licence information on the White Rose Research Online record for the item.

Takedown

If you consider content in White Rose Research Online to be in breach of UK law, please notify us by emailing eprints@whiterose.ac.uk including the URL of the record and the reason for the withdrawal request.

Article36

Nuclear risk: the British case

Dr Nick Ritchie
University of York

Article 36 is a UK-based not-for-profit organisation working to prevent the unintended, unnecessary or unacceptable harm caused by certain weapons.

www.article36.org

Article 36 is a member of the International Steering Group of ICAN - the International Campaign to Abolish Nuclear Weapons.

www.icanw.org

Any use of nuclear weapons would cause unacceptable, immediate and long-term humanitarian and environmental harm and the international community would be unable to respond in any meaningful way.

Advocates of nuclear deterrence argue that this is precisely the point: the unparalleled and incontestable effects of nuclear violence induce sufficient caution into inter-state relations so as to dampen incentives for major power war and deter the use of nuclear weapons. The certainty of the deterrent effect ascribed to nuclear weapons generates stability, predictability, and security for states.¹

In the UK, for example, the defence establishment refers to its nuclear weapons as 'the deterrent'. In doing so it implies that deploying a 'deterrent' automatically and unproblematically ensures that others will be deterred thereby eliminating strategic risk. Prime Minister Tony Blair was quite clear in 2006 when he stated that 'We believe that an independent British nuclear deterrent is an essential part of our insurance against the uncertainties and risks of the future' and that 'An independent deterrent ensures our vital interests will be safeguarded.'²

Unfortunately there are no risk-free nuclear futures. Nuclear weapons generate considerable risk of immediate and long-term and wide-spread humanitarian and environmental harm, at the individual, societal and potentially civilisational level. Risk can be defined as the probability of a harmful event occurring combined with the likely severity of its consequences. If the probability of a 'nuclear event' is greater than zero and the foreseeable consequences are considered very harmful and potentially catastrophic, then the existence of nuclear weapons carries great risk.

Nuclear deterrence is a risky business: it is fallible, its effects are contingent on context, and escalation of a conflict to the actual use of nuclear weapons cannot be ruled out. In fact, the successful practice of nuclear deterrence between states *requires* the perceived probability of the use of nuclear weapons to be high. This form of nuclear risk is compounded by the routine safety problems of running a national nuclear weapons enterprise. The data on such safety risks is striking. In the UK context alone we outline 16 submarine collisions since 1979, 266 submarine fires in the past 25 years, numerous safety shortfalls with nuclear-armed submarines and at the Atomic Weapons Establishment, 158 fires at the Atomic Weapons Establishment between 2000-2011, and serious unresolved safety concerns with the Trident warhead. These two dimensions of nuclear risk – deterrence and safety – are outlined below.

Considering the very harmful and potentially catastrophic consequences of a nuclear weapon explosion, the existence of nuclear weapons generates an *unacceptable risk*. The international community has worked hard over the past century to regulate and constrain the means of violence at the disposal of states, most recently through further regulation of the arms trade. Yet nuclear violence remains unencumbered despite the very severe risks nuclear weapons pose. This risk *can* be eliminated through rapid progress to a world free of nuclear weapons. The early negotiation of an international treaty

prohibiting nuclear weapons, even without the participation of nuclear-armed states, would be an important contribution towards this goal.

The contingency of nuclear deterrence

The successful practice of nuclear deterrence is far from certain. Nuclear weapons don't come with a money-back guarantee that they will always successfully deter strategic threats to a country. Nuclear deterrence is not a rational, objective, or exact science. It is not a 'law of history'.³ It is not an effect automatically generated by the mere presence of nuclear weapons. Instead, it is a process and its effects are contingent upon the context of the threat. Indeed, nuclear deterrence is a theory, an intellectual construct that represents international society, states, and weapons, in a particular way. It is a theory that is contested, and, as discussed in this paper, carries a high risk of unacceptable nuclear violence.

Nevertheless, the Cold War witnessed a 'scientization of nuclear strategy'.⁴ This was based on the idea that the practice of nuclear deterrence automatically stabilises relations between nuclear-armed opponents because the extreme levels of violence embodied by nuclear weapons will always induce caution into hostile relationships. Leaders could use or threaten to use nuclear weapons as rational instruments of the state for achievable political ends.⁵ The awesome destructiveness of nuclear weapons could be effectively tamed for practical purposes. But this was, and remains, an illusion of control. It requires what US political scientist James Lebovic calls 'heroic assumptions about the adversary – its ability to think dispassionately, process information, and make the "right" decision under the most challenging of conditions'.⁶ This can lead to misunderstandings, miscalculation or determined resistance to deterrent threats.⁷ The Cold War nuclear confrontation is often portrayed today as a stable, predictable, risk-averse relationship of assured destruction. This is a misleading contemporary narrative. The Cold War was highly dangerous, plagued by uncertainty, fuelled by worst-case assumptions and planning with very serious risks of a deliberate or inadvertent cataclysmic nuclear exchange.⁸ General Lee Butler, former head of US Strategic Command with responsibility for all US nuclear weapons, stated in 1998 that: 'While we clung to the notion that nuclear war could be reliably deterred, Soviet leaders derived from their historical experience the conviction that such a war might be thrust upon them and if so, must not be lost. Driven by that fear, they took Herculean measures to fight and survive no matter the odds or the costs. Deterrence was a dialogue of the blind with the deaf'.⁹

A successful nuclear deterrent threat requires those on the receiving end to believe that an opponent might actually use its nuclear weapons if a crisis continues or escalates. In other words, the threat must be credible in the eyes of the deteree. But 'credibility' requires not just the ability to deliver and detonate nuclear weapons, but also a belief in the political will to act given perceived interests at stake, an ability to successfully communicate the ability to deliver nuclear weapons and the will to act to an aggressor, and an understanding of how a particular aggressor can most effectively be deterred.¹⁰ Nuclear deterrence is not a foregone conclusion and there is no certainty of success if the deteree is determined to pursue its chosen course of action, if it doesn't believe the nuclear deterrent threat to be credible, if it thinks it can control the risk of unacceptable

outcomes resulting from its actions, if it thinks it can ride out a nuclear attack, or thinks it can eliminate the nuclear threat through a pre-emptive attack.¹¹

A number of important studies have explored nuclear near misses where our collective luck nearly ran out, not least the Cuban Missile Crisis. There have been incidents where misperception and paranoia could have pushed humanity over the nuclear brink, such as the Able Archer crisis in 1983. Episodes where the idea that the presence of nuclear weapons makes it somehow 'safe' to engage in shooting wars because nuclear deterrence will prevent escalation has been severely tested, such as the India-Pakistan Kargil confrontation in 1999.¹² The deterrent effect of nuclear weapons is therefore contingent. It is not certain and it offers no guarantees.

Nevertheless, advocates of nuclear deterrence point to the fact that nuclear weapons have not been used intentionally or by accident since Nagasaki, therefore the risk of deterrence failing or nuclear organisations going badly wrong is exaggerated. A recent article by economist Carl Lundgren in *The Nonproliferation Review* dismantles this type of nuclear optimism. Lundgren provides a Bayesian statistical analysis of the probability of nuclear war arising from three broad scenarios: an international crisis leading directly to nuclear war; an accident or misperception leading to nuclear use; and an escalation of a conventional war to nuclear use. The Bayesian methodology enables statisticians to generate valid probabilities 'where only limited data are available and assured knowledge is not possible, but important conclusions or inferences must still be drawn in order to make choices or set policy'.¹³ Lundgren's analysis calculates that the 'posterior combined risk of nuclear war during the Cold War (the best estimate after evidence of nuclear crises and mishaps is observed) was 44.3 per cent' and that 'The first sixty-six years of the nuclear age produced a 61 per cent chance of a nuclear war'.¹⁴ He states that this is equivalent to a 2.1 per cent chance per year, or an average frequency of one nuclear war every 47 years.

Lundgren highlights research conducted in the 1980s by political scientist Michael Wallace, mathematician Linn Sennot, computer scientist Brian Crissey on the probability of nuclear war using data from 1978-1983 on US false alarms. They arrive at the conclusion that 'there is an almost 50% chance of a war-threatening false alarm of some type occurring during severe length crisis', defined as a 30-day crisis comparable to the Cuban Missile Crisis.¹⁵ Lundgren concludes: 'Fighting the Cold War with nuclear armaments and nuclear threats was a perilous wager. The probability of a failure resulting in nuclear war exceeded the probability of making an incorrect call while flipping a coin. The world must find a way to unwind this desperate gamble'.¹⁶

By comparison the UK Health and Safety Executive's 2008 Safety Assessment Principles for Nuclear Facilities states that the target for societal risk from a nuclear reactor accident (defined as an accident leading to an immediate or eventual 100 or more fatalities, mainly from very low doses to very large populations) is 1×10^{-5} per annum at the Basic Safety Level (the minimum target for new nuclear facilities or activities) and 1×10^{-7} per annum to meet the Basic Safety Objective (BSOs form benchmarks that reflect modern nuclear safety standards and expectations).¹⁷ The comparison is illustrative as the data for calculating probabilities are so different. Nevertheless, it is instructive that the accepted level of a major nuclear reactor

accident in the UK is a maximum of 1 in 100,000 p.a. with a Basic Safety Level of 1 in 10,000,000 p.a. compared to Lundgren's calculation of a 1 in 50 chance of a nuclear war per year during the Cold War. From an engineering perspective such an expected failure rate would be criminally negligent.¹⁸

The global nuclear order is also evolving. A successful nuclear deterrent threat is a process of convincing an adversary not to engage in a hostile course of action. This requires some understanding of their motivation, world-view, resolve, and cost-benefit calculus.¹⁹ As nuclear weapons proliferate, the practice of nuclear deterrence will become more complex and more difficult. Asymmetries in types of nuclear-armed actor (major powers, regional powers, 'rogue' states, non-state actors), their capabilities, (advanced and survivable nuclear forces or a small, basic 'use it or lose it' nuclear armoury) identities (regional hegemon, defender of a faith, ally, 'civilised'), and intentions (defeat, brinkmanship, coercion, regime change, survival) will increase. The ability to 'know' a nuclear-armed opponent in sufficient depth to have confidence in the efficacy of a nuclear deterrent threat looks set to become more difficult and uncertain.²⁰

As the nuclear world evolves nuclear risk is likely to increase. During the 1990s it was comforting to think that we could continue indefinitely in what the late Sir Michael Quinlan, former Permanent Under-Secretary of State at the UK Ministry of Defence and guru of British nuclear deterrence thinking, labelled in 1993 'a world of much less nuclear salience'. This was based on a small number of nuclear weapon states with nuclear deterrence operating in the background of international relations to maintain international order and stability by making war between the major industrialised powers unthinkable.²¹ The notion of a stable, benign nuclear-armed world with a small number of responsible possessors looked increasingly unrealistic as the 1990s progressed and Indian, Pakistani, and North Korean weapon programmes escalated and, with 9/11, the risk of nuclear terrorism.

We now look likely to face a long-term choice of either a 'high-salience nuclear world'²² with multiple nuclear and near-nuclear weapon states in complex deterrent relationships characterised by asymmetries and uncertainties; or the further stigmatisation and delegitimation of nuclear weapons, leading to their legal prohibition and elimination.²³

A low-salience nuclear world could be stable (if not peaceful or secure) in theory but its time has passed, if it ever existed. A permanently well-managed high-salience nuclear world is an extremely optimistic prognosis. An unstable high-salience nuclear world would present unacceptable danger. A world free of nuclear weapons is the necessary and legitimate path to minimising long-term nuclear risk. As Quinlan himself noted many years later, 'It cannot be right to acquiesce uncritically, for the rest of human history, in a system that maintains peace between potential adversaries partly by the threat of colossal disaster'.²⁴

The inherent and evolving fallibility of nuclear deterrence and the consequences of its failure by accident or design constitute an unacceptable societal risk. Nuclear deterrence only has to fail once for a humanitarian catastrophe to ensue. This nuclear gamble as been steadily 'normalised' by some as safe, secure and benign; it is anything but.

Safety in a national nuclear weapons complex

Nuclear risk also arises from the operation of a complex socio-technological system like a national nuclear weapons complex that produces, deploys and plans the use of nuclear weapons. US political scientist Scott Sagan explored this theme in detail in his 1993 book on *The Limits of Safety: Organizations, Accidents and Nuclear Weapons*. He looked at a number of serious nuclear weapons incidents in the US during the Cold War. He argues that 'normal accident theory' can explain recurrent serious accidents in complex high-technology systems like nuclear reactors, commercial and military aircraft, space programmes, international shipping and large petrochemical plants. Normal accidents refer to a failure in one part of a system (material, human, or organisation) coinciding with the failure of an entirely different part. This unforeseeable combination can cause cascading failures of other parts of the system. Cascading failures can quickly spiral out of control and be unrecoverable. Since there are multiple pathways for cascading failures in complex systems accidents must be treated as part of life, i.e. normal. Redundancy, 'defence in depth', a culture of safety, continuous training, and organisational learning can all help to create high reliability organisations. But infallibility is not possible because safety is one of many competing objectives and layers of redundancy can themselves cause accidents. The *Challenger* space shuttle disaster, the sinking of the Russian ballistic missile submarine *Kursk*, Chernobyl, the *Exxon Valdez*, Bhopal (the world's worst industrial disaster), the Deepwater Horizon oil spill, are all cases in point. The events at the Fukushima Dai-ichi nuclear power plant in 2011 perhaps demonstrate most starkly a cascading unrecoverable failure in the nuclear arena. Sagan argues that normal accidents can be expected to occur in a nuclear weapons enterprise because they are highly complex and tightly coupled systems, meaning small-scale failures are more likely to cascade into unrecoverable larger problems. He argues through a series of case studies that US nuclear command and control systems are complex socio-technological systems prone to 'normal accidents'.²⁵

No nuclear-armed state is immune to this phenomenon, including a state like the UK that is generally considered a mature nuclear power with a stringent and relatively transparent nuclear safety regime to manage a small, secure nuclear arsenal.

The UK's Defence Nuclear Safety Regulator (DNSR) assesses that those responsible for the UK's defence nuclear programme have maintained an acceptable standard of nuclear and radiological safety.²⁶ It also states that 'Nuclear yield can only be achieved when multiple varied inputs are provided to the weapon. These inputs would be experienced only in the unique circumstances of planned ballistic delivery and, if not precisely sequenced, would prevent the weapon from functioning as intended. Inadvertent nuclear yield from a nuclear weapon is not considered credible'.²⁷

Nevertheless, things can and do go wrong. Risk in a nuclear weapons enterprise cannot be eliminated. A survey of regulatory audits and incidents in the UK nuclear weapons complex over just the past few years demonstrates that accidents do occur and that the safety regime can fail or be sub-standard. It shows that this is part of the *routine operation* of a nuclear weapons complex that includes nuclear-powered ballistic missile submarines. The risk of a

very serious 'normal' accident is very small, but not zero, as the following examples illustrate:

Submarine collisions

Since 1979 there have been 16 incidents of collisions and groundings involving Royal Navy nuclear powered submarines for which the Royal Navy holds records.²⁸ Perhaps the most worrying of these was the collision between UK and French ballistic missile submarines on operational patrol in the Atlantic in February 2009 when HMS *Vanguard* collided with FNS *Le Triomphant*. HMS *Vanguard* slowly returned to port for repairs that lasted until June 2009. Excerpts from a review of the collision by the Ministry of Defence's Strategic System Performance Assessment and Analysis Group released under the Freedom of Information Act state 'Nuclear propulsion and weapon safety was not compromised during this incident'.²⁹

A US nuclear-powered submarine came within metres of crashing into rocks off Plymouth with potentially 'catastrophic' consequences, according to a Royal Navy report on the incident. It occurred in December 2006 when the USS *Minneapolis-St. Paul* was leaving the UK's Devonport Naval Base. Two sailors were killed.³⁰ Other collisions include the grounding of the nuclear-armed HMS *Victorious* on the Skelmorlie Bank in the Clyde Estuary in 2000 and the striking of an iceberg by HMS *Tireless* whilst on Arctic Patrol in 2003.

Submarine fires

In 2012 it was revealed that UK submarines, many of them nuclear-powered, had experienced over 266 fires in the preceding 25 years. 243 were small-scale fires dealt with using on-board resources, but 67 of these were on ballistic missile submarines. 20 were medium scale fires requiring use of significant on-board resources and six of these were on ballistic missile submarines. In addition, three fires occurred while the submarines involved were in naval bases, requiring both ship and external resources. One of these was on a ballistic missile submarine.³¹

Safety shortfalls with nuclear-armed submarines

In November 2012 the primary containment of the reactor compartment for HMS *Vengeance* (one the UK's four ballistic missile submarines) was breached during refit work at the Devonport dockyard. The breach occurred after a series of errors but at a stage in the refit programme when the reactor had cooled down from operational temperatures with much lower risk of radiation release.³²

In 2012 it was disclosed at a Ministry of Defence review of safety at the Clyde Naval Base where the UK's nuclear-armed submarines are based that 11 of the bases' 13 activities have been officially declared unsatisfactory. No further information was released.³³

A 256-page Nuclear Site Safety Justification report published in 2010 revealed 22 safety shortfalls for the huge shiplift at the UK's Faslane Naval Base in Scotland where the UK's nuclear-armed submarines are based.³⁴ The shiplift is used to lift 16,000-ton *Vanguard* ballistic

missile submarines out of the water for maintenance with nuclear warheads and ballistic missiles still aboard. It was reported that crane is at risk from earth tremors, high tides, overloading, explosions and failed to meet the Ministry of Defence's own safety targets. It stated that although most risks to the ballistic missile (the Strategic Weapon System) lay in the 'extremely unlikely to negligible category' there were a small number of hazards that carried greater risk. One of these is collapse of the shiplift. The report stated that this could 'cause inadvertent ignition/detonation of missile/SWS ordnance (the nuclear warhead)'.³⁵

Safety shortfalls at the Atomic Weapons Establishment

The UK's Defence Nuclear Safety and Environment Board (part of its national Health and Safety Executive) identified a number of risks in the Defence Nuclear Programme in its 2011 Annual Report. It observed that whilst each risk by itself did not pose an immediate safety or environmental concern, 'Taken together they pose the risk that it will become increasingly difficult to maintain that the defence nuclear programmes are being maintained with due regard for the protection of the workforce, the public and the environment'.³⁶ The DNSEB's latest report for 2012-13 reiterated the challenge of sustaining a sufficient number of suitably qualified and experienced nuclear military and civilian personnel and warned again that this poses 'a significant threat to the safe delivery of the DNP (Defence Nuclear Programme)'.³⁷

A 2009 report by Ministry of Defence's Defence Nuclear Safety Regulator on 'Safety Regulators' Advice on the Selection of the Propulsion Plant in Support of the Future Deterrent: Review Note' stated that 'in a number of areas it is clear that the UK programme currently falls short of current relevant good practice'.³⁸ The report was reviewing nuclear power plant options for the UK's next generation of ballistic missile submarines now in development. Its criticisms referred to the acceptance of a much lower reliability from the main propulsion system to control submarine depth compared to best practice. This carries the risk of an uncontrolled dive from which the submarine could not recover. It also set out concerns about a Loss of [reactor] Coolant Accident (LOCA), which is a breach in the primary coolant circuit that releases fission products into the reactor compartment. The report said the UK compared poorly to US benchmarks for reactor pressure vessel safety of coolant loss from submarine nuclear reactors.³⁹

It was reported in 2012 that the Atomic Weapons Establishment (AWE) at Aldermaston had discovered extensive corrosion in the structural steelwork of one of the older manufacturing buildings at the site. Routine operations were suspended and a site-wide structural survey conducted. The building is thought to be the A45 site that manufactures highly enriched uranium components for nuclear warheads and submarine reactor cores.⁴⁰ The building is a 'class 1' structure – the highest and most important classification for a nuclear structure.⁴¹

It was reported in 2010 that the Atomic Weapons Establishment experienced 4,020 'Abnormal Events' in 2008 and 3,911 in 2009. AWE defines an abnormal event as any action or series of actions that causes a deviation from the planned course of events. They are

classified into seven different categories; five of these are considered to be related to safety. Three in each year were assessed as 'having the potential, in the absence of remedial action, to challenge a nuclear safety system.'⁴²

Fires at the Atomic Weapons Establishment

In August 2010 a solvent fire broke out in an explosives production building at the Atomic Weapons Establishment's Aldermaston site. A report on the fire states that no nuclear materials were involved in the fire and there was no risk of a radiological incident though staff and local residents were evacuated. Electrostatic discharge as solvents were mixed was judged the most likely cause, though this was not part of AWE's previous assessments of the hazards and risks.⁴³ A separate report by the Royal Berkshire Fire and Rescue Service (RBFRS) revealed that the emergency response to the fire was hampered by poor communications, limited resources, and delays in allowing fire-fighters onto the site.⁴⁴ It was later reported that there had been 50 fires at AWE in the preceding two years. AWE said these were all minor.⁴⁵

It was later revealed in a Freedom of Information Act request that Berkshire fire crews were called to AWE Aldermaston at an average rate of four times per week between 2000 and 2011. Peter Burt of the Nuclear Information Service reported 'Over the 11 year period the fire service was called to the site to deal with an explosion, gas leaks, an unexploded shell, staff being overcome by fumes and fire breaking out in a radiation building. There were a total of 2,252 call-outs between 1 April 2000 and 5 August 2011. Of this total, 1,851 were triggered by automatic alarms, the majority of which did not require fire-fighters to attend. However, 158 real fires broke out on site over the period'.⁴⁶ The Health and Safety Executive subsequently prosecuted AWE for safety violations whereupon it was fined £200,000 for breaching the 1974 Health and Safety at Work Act.

In 2007 the UK's Nuclear Installations Inspectorate (NII) expressed serious concerns about safety at AWE Burghfield (AWE Aldermaston's sister site) where UK nuclear warheads are assembled and disassembled. Over 1,000 safety defects were uncovered and annotated in 13 internal reports since 2002, including at least 10 'Category 1' safety shortfalls – the most serious of all.⁴⁷ This created an unacceptable risk of a criticality event causing a nuclear chain reaction. The plant was allowed to continue to operate because the Ministry of Defence insisted its work was vital.⁴⁸ Nevertheless, the NII restricted live warhead work within the plant to a low level and halted it entirely between July 2007 and April 2008. In 2006 the NII reported 'To date AWE has provided little information and implemented only a small amount of remedial work' it had previously identified as necessary. Still, 'The NII fault studies assessor considered the amount of work yet to be done as significant and following a meeting with AWE the licensee provided an updated justification document that again failed to detail the programme to completion of the work'.⁴⁹ It concluded that 'It is recognised that the current facilities fail to meet modern standards and only the design, construction and operation of new facilities will ensure that modern safety standards are met'.⁵⁰ The Ministry of Defence continued to override the NII and put continuous operation of warhead assembly/disassembly process going to meet the government's warhead commitments ahead of

safety.⁵¹ The NII eventually judged the facility safe for normal operations in April 2009 until its next Periodic Review of Safety in 2016.

Unresolved safety concerns with the Trident warhead

The British Trident warhead is an anglicised version of the US W76 warhead. The nuclear warheads are packed around the third-stage rocket motor of the Trident missile. The missile was designed like this to reduce size and mass. This was at a time when modernisation and improvement programmes prioritised military requirements over safety, such as achieving maximum yield to weight ratios for warheads and maximum payloads and ranges for missiles. In 1990 concerns were raised about US nuclear warhead safety and a number of reports were commissioned by the US House of Representatives. These reports highlighted the risk of accidental detonation of the third stage motor causing accidental detonation of the high explosive of one or more of the nuclear warheads packed around it potentially leading to widespread dispersal of plutonium, or even a small nuclear detonation.⁵² The risk is compounded by the fact that the Trident missile uses the most energetic, or volatile, of rocket fuels and the W76 nuclear warhead was not designed to use 'insensitive high explosives' (IHE) to trigger the nuclear explosion. IHE is less prone to accidental detonation, but it has a lower explosive yield than non-IHE. Therefore you need more of it to achieve a required explosive pressure, so you need a bigger warhead, a bigger missile to deliver those warheads the required distance, and so on. The problem has not been resolved and represents a continuing risk both in the US and in the UK.⁵³

Conclusion

This list illustrates the routine nature of accidents and safety shortfalls within a comparatively transparent and regulated nuclear weapons industrial complex. This is an ongoing and an arguably 'normal' feature of operating a highly complex socio-technological system required to perform a host of functions to ensure permanent readiness to move rapidly from peacetime operations to nuclear use.

The risk is also evolving. In March 2013 the Pentagon's Defense Science Board reported that the resilience of most US nuclear weapon systems against a sophisticated cyber attack designed to create and exploit vulnerabilities in strongly protected systems is untested.⁵⁴ General Robert Kehler, head of Strategic Command, told US senators that he did not know whether other countries' nuclear command and control systems were impervious to a cyber attack that could launch a nuclear-armed missile.⁵⁵

Finally, it is likely that other incidents have occurred that have yet to enter the public domain and perhaps never will. It took several years for details of some of the examples outlined above to see the light of day. It took 37 years for the crash at RAF Lakenheath in Suffolk to make it into the public domain when a US B47 bomber crashed into a bunker containing three nuclear weapons whilst on a routine training mission. There have been many more accidents and serious safety lapses in the UK and other nuclear-armed states.⁵⁶

As General Butler, cited above, put it in 1999: 'Missiles that blew up in their silos and ejected their nuclear warheads outside of the confines of the silo. B52 aircraft that collided with tankers and scattered nuclear weapons across the coast and into the offshore seas of Spain. A B52 bomber with nuclear weapons aboard that crashed in North Carolina, and on investigation it was discovered that in one of those weapons, 6 of the 7 safety devices that prevent a nuclear explosion had failed as a result of the crash. There are dozens of such incidents. Nuclear missile-laden submarines that experienced catastrophic accidents and now lie at the bottom of the ocean...I came to appreciate in a way that I had never thought, even when I commanded individual units like B52 bombers, the enormity of the day-to-day risks that comes from multiple manipulations, maintenance and operational movement of those weapons.'⁵⁷

Operating a nuclear weapons complex and deploying nuclear weapons carries great risk. Even if the probability of something going wrong with the technology, organisational procedures, or the practice of nuclear deterrence in a crisis is considered small, the consequences from the deliberate or accidental detonation of even a single nuclear weapon would likely be catastrophic. It is legitimate, in fact it is necessary, to ask whether the deeply contestable benefits of nuclear weapons are worth the risk. Most countries have already asserted that they are not. Most countries concur with this analysis that nuclear weapons are most appropriately viewed as a source of risk, rather than some form of insurance against future security risks. Most countries strongly advocate concrete steps towards nuclear disarmament. Such efforts have been consistently hampered by nuclear-armed states operating in a security construct that is seemingly dependent on their indefinite retention of nuclear weapons.⁵⁸ Only through rapid progress toward a world free of nuclear weapons can we collectively ensure the legitimate protection of states and societies against the risk of unprecedented nuclear violence. The path to a world free of nuclear weapons will involve a number of initiatives, including actions by the nuclear-armed states to dismantle and destroy their arsenals, and the adoption of a legal ban. It is a striking anomaly that nuclear weapons remain the only weapon of mass destruction not yet subject to a comprehensive prohibition. Even without the endorsement of the nuclear-armed states, such a treaty would be an appropriate response to the unacceptable risk posed by nuclear weapons.

ENDNOTES

- 1 J. Forsyth, B. Chance Saltzman, G. Schaub, 'Remembrance of Things Past: The Enduring Value of Nuclear Weapons', *Strategic Studies Quarterly*, 4: 1, 2010, p.75.
- 2 Ministry of Defence and Foreign and Commonwealth Office, *The Future of the United Kingdom's Nuclear Deterrent*, Cm 6994 (London: HMSO, 2006), p.5
- 3 H. Muller, 'Icons off the Mark: Waltz and Schelling on a Perpetual Brave Nuclear World', *The Nonproliferation Review*, 20: 3, 2013, pp.545-65.
- 4 P. Lawrence, 'Strategic Beliefs, Mythology and Imagery', in R. Little and S. Smith (eds.) *Belief Systems and International Relations* (Oxford: Basil Blackwell Inc., 1988), p.143.
- 5 A. Burke, 'Nuclear Reason: At the Limits of Strategy', *International Relations*, 23: 4, 2009.
- 6 J. Lebovic, *Detering International Terrorism and Rogue States* (London: Routledge, 2007), p.4.
- 7 DFI International, *Non-Nuclear Strategic Deterrence of State and Non-State Adversaries* (Washington, D.C.: Defense Threat Reduction Agency, 2001), p.21; R. Jervis, *Perception and Misperception in International Politics* (Princeton, Princeton University Press, 1976).
- 8 See S. Sagan, *The Limits of Safety: Organizations, Accidents, and Nuclear Weapons* (Princeton: Princeton University Press, 1993); P. Pry, *War Scare: Russia and America and the Nuclear Brink* (Westport, CT.: Praeger, 1999); R. Lebow and J. Stein, *We all Lost the Cold War* (Princeton N.J.: Princeton University Press, 1994).
- 9 General G. L. Butler, 'The Risks of Nuclear Deterrence: From Superpowers to Rogue Leaders', speech to the National Press Club, Washington, D.C., 2 February 1998.
- 10 S. Sagan, 'The Commitment Trap', *International Security*, 24: 4, 2000, pp.97-98.
- 11 R. Jervis, 'The confrontation between Iraq and the US: Implications for the theory and practice of deterrence', *European Journal of International Relations* 9: 2, 2003, pp.322-23; A. George and R. Smoke, *Deterrence in American Foreign Policy* (New York: Columbia University Press, 1974), Chapter 17.
- 12 The most recent being E. Schlosser, *Command and Control: Nuclear Weapons, the Damascus Accident, and the Illusion of Control* (New York: Penguin Books, 2013).
- 13 C. Lundgren, 'What are the Odds? Assessing the Probability of a Nuclear War', *The Nonproliferation Review*, 20: 2, 2013, p.362.
- 14 Ibid, pp.371 and 370.
- 15 M. Wallace, B. Crissey, and L. Sennott, 'Accidental Nuclear War: A Risk Assessment', *Journal of Peace Research* 23:9, 1986, p.23.
- 16 Ibid p. 373. For analysis of Cold War nuclear mishaps see A. Phillips, '20 Mishaps that Might Have Started Accidental Nuclear War', Nuclear Age Peace Foundation, January 1998, <www.wagingpeace.org/articles/1998/01/00_phillips_20-mishaps.php>; S. Sagan, *The Limits of Safety: Organizations, Accidents, and Nuclear Weapons* (Princeton: Princeton University Press, 1993), and S. Gregory, *The Hidden Costs of Deterrence: Nuclear Weapons Accidents* (London: Brassey's, 1990).
- 17 Health and Safety Executive, *Safety Assessment Principles for Nuclear Facilities*, 2006 Edition, Revision 1 (1998), Merseyside, UK, p.103.
- 18 See M. Hellman, 'Risk Analysis of Nuclear Deterrence', *The Bent of Tau Beta Phi*, Spring 2008, pp.14-22.
- 19 See W. Bowen, 'Deterrence and Asymmetry: Non-State Actors and Mass Casualty Terrorism', in I. Kenyon and J.Simpson (eds.), *Deterrence and the New Global Security Environment* (London: Routledge, 2006), pp.50-51.
- 20 E. Adler, 'Complex Deterrence in the Asymmetric-Warfare Era', in T.V. Paul, M. Morgan and J. Wirtz (eds.) *Complex Deterrence: Strategy in the Global Age* (University of Chicago Press: Chicago, 2009), pp.88-90.
- 21 M. Quinlan, 'The Future of Nuclear Weapons: Policy for Western Possessors', *International Affairs*, 69: 3, 1993, p.496.

22 R. O'Neill, 'Britain and the Future of Nuclear Weapons', *International Affairs*, 71: 4, 1995, pp.747-761.

23 M. MccGwire, 'Is There a Future for Nuclear Weapons', *International Affairs*, 70: 2, 1004. pp.211-228.

24 M. Quinlan, *Thinking about Nuclear Weapons: Principles, Problems, Prospects* (Oxford: Oxford University Press,2009), p.54.

25 S. Sagan, *The Limits of Safety: Organizations, Accidents, and Nuclear Weapons* (Princeton: Princeton University Press, 1993).

26 Defence Nuclear Environment and Safety Board, 2011 Assurance Report, 2011.

27 Defence Safety and Environment Authority, Defence Nuclear Safety Regulators, 'Japanese Earthquake and Tsunami: Implications for the UK Defence Nuclear Programme', July 2012, p.14.

28 House of Commons, *Official Report*, 2 November 2010, Col. 693W.

29 Ministry of Defence, Information Commissioner's Office Case Reference FS50444068, 27 February 2013, requested by Peter Burt, Nuclear Information Service, UK.

30 'US Nuclear submarine "within metres of disaster" off British coast: report', *The Daily Telegraph*, 21 June 2011.

31 House of Commons, *Official Report*, 3 July 2012, Col. 627W.

32 Health and Safety Executive, Office for Nuclear Regulation, 'Quarterly site report for Devonport Royal Dockyard (Devonport Royal Dockyard Ltd and HM Naval Base Devonport)', November 2012, pp.7-8.

33 Ministry of Defence, Defence Equipment and Support, 'Summary and Forward Actions from HMNB Clyde's Annual Review of Safety (AROS) 2010', October 2010. Reported at R. Edwards, 'Clyde bases plagued by nuclear safety flaws, says the MoD', *The Sunday Herald*, 19 February 2012.

34 R. Edwards, 'Revealed: The 22 Safety Shortfall's of Scotland's Nuclear Crane', *The Sunday Herald*, 3 April 2011.

35 'Shiplift Facility Safety Case', Nuclear Site Safety Justification report, Ministry of Defence, January 2010, Part 5, p.5. Available at <<http://webarchive.nationalarchives.gov.uk/20121026065214/http://www.mod.uk/NR/rdonlyres/1894C841-D02C-4A2F-96C4-5786ED2672FC/0/ShipliftSECTION5a.pdf>>.

36 *Ibid.*, p.2.

37 Defence Nuclear Environment and Safety Board, Annual Report 2012/13, Defence Nuclear Safety Regulator, 2012, p.6.

38 Available at <http://www.banthebomb.org/ne/images/stories/pdfs/successor_ssb_n_dnsr.pdf>.

39 Defence Nuclear Safety Regulator, 'Safety Regulators' Advice on the Selection of the Propulsion Plant in Support of the Future Deterrent: Review Note', DNSR/22/11/2, November 2009. Available at <http://www.banthebomb.org/ne/images/stories/pdfs/successor_ssb_n_dnsr.pdf>.

40 Health and Safety Executive, Office for Nuclear Regulation, "Quarterly site report for AWE Aldermaston and Burghfield", September 2012, p. 4. See Nuclear Information Service, "A45 Corrosion of 'Major Significance' Reveal FOIA Papers", March 2013.

41 Health and Safety Executive, Office for Nuclear Regulation, Chief Nuclear Inspectors Annual Report 2013, p.16.

42 House of Commons, *Official Report*, 22 March 2009, Col. 10W.

43 'AWE Fire Investigation: Key Findings and Company Response Document', AWE, June 2011.

44 R. Edwards, 'Firefighters Criticize Nuclear Weapons Plant Following Serious Fire', *The Guardian*, 31 May 2011.

45 R. Edwards, 'Aldermaston had 50 Fires in Two Years', *The Guardian*, 24 January 2013; House of Commons, *Official Report*, 8 October 2012, Col. 660W.

46 Nuclear Information Service, NIS Update February 2012. Available at <<http://nuclearinfo.org/article/nis-updates/nisupdate-february-2012>>.

47 Health and Safety Executive, HM Nuclear Installations Inspectorate, Site Inspection Report No. 2007/032, May 2007.

48 R. Edwards, 'Nuclear Weapons Plant Should be Rebuilt', *The New Scientist*, No. 2622, 20 September 2007.

49 Health and Safety Executive, HM Nuclear Installations Inspectorate, Unit 3b Division 3 Project Assessment Report No: 33/2006, 'Report to justify the Agreement to the implementation of the Trident modified disassembly process,Burghfield', 2006, p.4.

50 *Ibid.*, p.3.

51 Health and Safety Executive, HM Nuclear Installations Inspectorate, Site Inspection Report No. 40/2006, p.3.

52 'Nuclear Weapons Safety', Report of the Panel on Nuclear Weapons Safety of the House Armed Services Committee, (Drell Report) Committee Print No. 15, December 1990; R. Kidder, 'Report to Congress: Assessment of the Safety of US Nuclear Weapons and Related Nuclear Test Requirements', Lawrence Livermore National Laboratory, July 1991; J. Harvey and S. Michalowski, 'Nuclear Weapons Safety: The Case of Trident', *Science and Global Security*, 1994, Vo. 4, pp. 261-337.

53 I. Bruce, 'Experts Sound Trident Safety Warning', *The Sunday Herald*, 29 October 1992. British American Security Information Council, 'Second Report on British Nuclear Weapons Safety: A Response to the Oxburgh Report', BASIC Report 92.4, 1992.

54 Department of Defence, Defense Science Board, *Task Force Report on Advanced Cyber Threat*, January 2013, p.7.

55 A. Sternstein, 'Officials Worry About Vulnerability of Global Nuclear Stockpile to Cyber Attack', *Global Security Newswire*, 14 March 2013. Available at <<http://www.nti.org/gsn/article/officials-worry-about-vulnerability-global-nuclearstockpile-cyber-attack/>>.

56 For the UK, see Greenpeace UK, 'Aldermaston - Inside the Citadel: An Investigation into Britain Nuclear Bomb Factory', 1993; J. Ainslie, 'The Safety of Trident – An Assessment of the Radiation Risks Associated with the UK Trident Programme', Scottish CND, February 1994; 'The Timebomb That Threatens Britain', *The Observer*, 24 October 1999.

57 General G. L. Butler, Address to Canadian Peaceworkers, Ottawa, 11 March 1999.

58 See Nick Ritchie, 'Legitimising and Delegitimising Nuclear Weapons', in Borrie, J. and Caughley, T., *Viewing Nuclear Weapons Through a Humanitarian Lens* (Geneva: UNIDIR, 2013).