



Royal United Services Institute
for Defence and Security Studies

Conference Report

The 2016 UK PONI Papers

Edited by Emil Dall and Ben Pearce



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Conference Report, November 2016



Royal United Services Institute
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Editors' Note

At the 2016 UK Project on Nuclear Issues (UK PONI) Annual Conference, held at RUSI in June 2016, emerging experts gave presentations on contemporary civil and military nuclear issues. These presentations were then adapted by the experts for this publication. The information contained in the publication is current at the time of writing in early September 2016. The views expressed are the authors' own, and do not necessarily reflect those of the authors' institutions, UK PONI or RUSI.

I. Megatons and Megabytes: The Fallacy of the Nuclear– Cyber Deterrence Comparison

Patrick Cirenza

In the elite policymaking circles of today, it is common to find comparisons between nuclear and strategic cyber weapons, particularly with regard to the usefulness of deterrence theory.¹ Policymakers look to the well-developed theories of nuclear deterrence as a potential panacea for the threats emanating from cyberspace.² This is because strategic cyber weapons are in many respects similar to nuclear weapons: quick; potentially highly destructive; and difficult to defend against. They also look to these theories because nuclear deterrence was the dominant defence paradigm of their upbringing and so they hold the belief that because it worked well in the past it might work well now. However, while this comparison has a superficial allure, it does not withstand rigorous analysis.

This paper seeks to answer the question: Do strategic cyber weapons have the strategic deterrent characteristics of nuclear weapons? If strategic cyber weapons have the same stable strategic deterrent characteristics as nuclear weapons, it may be plausible to make a comparison and base policy on it, as appears to happen at present.³ Conversely, if strategic cyber weapons do not share the attributes of nuclear weapons, it is erroneous to expect that a nuclear deterrence-style framework would work in cyberspace. It is worth noting that this paper uses elements of the US Department of Defense dictionary to define strategic cyber weapons as: ‘malware that irreversibly neutralizes centers of gravity in cyber-dependent economic, military, and political systems and infrastructure’. This definition is important because the destructive power of any cyber threat below that of strategic cyber weapons (such as cyberterrorism, espionage and vandalism) simply does not compare with that of nuclear weapons and would not therefore

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1. *Bloomberg News*, ‘Chinese General with Dempsey Compares Cyber-Attack to Nuke’, 23 April 2013; United States Senate Committee on Foreign Relations, ‘Nomination of John F Kerry to Be Secretary of State’, 24 January 2013; Dmitry Rogozin, ‘Speech at Press Conference in the “WP”’, 28 June 2013, <<https://rg.ru/2013/06/28/doklad.html>>, accessed 17 August 2016.
 2. This paper uses the US Department of Defense definition of ‘deterrence’: ‘The prevention of action by the existence of a credible threat of unacceptable counteraction and/or belief that the cost of action outweighs the perceived benefits’. See US Department of Defense, ‘Department of Defense Dictionary of Military and Associated Terms’, Department of Defense Joint Education and Doctrine Division, J-7, Joint Staff: last updated 15 October 2015, <http://www.dtic.mil/doctrine/new_pubs/jp1_02.pdf>, accessed 23 August 2016.
 3. United States Department of Defense, ‘The Department of Defense Cyber Strategy’, April 2015, <http://www.defense.gov/Portals/1/features/2015/0415_cyber-strategy/Final_2015_DoD_CYBER_STRATEGY_for_web.pdf>, accessed 23 August 2016.

merit an honest comparison. Further, this definition limits the impact of the attribution problem so often cited as the primary problem of cyber deterrence.⁴ As only a handful of states are currently able to wield strategic cyber weapons in an effective manner, the definition limits analysis to an attribution model much closer to the nuclear one. The logic of an eight- or nine-player deterrence problem is far less convoluted than that of an n-player deterrence problem.

Nuclear weapons offer a very clear template (arguably the only template) of how a single weapons technology can provide a stable strategic deterrent. This paper suggests that there are three main characteristics that make nuclear weapons such a deterrent – two technological and one theoretical. The first is the sheer destructiveness of a nuclear weapon, which provides the ability to credibly threaten unacceptable levels of damage on an adversary, a key foundation of deterrence. The second is the credible ability to deliver that destruction. It is virtually beyond question that a well-armed nuclear adversary can make good on its nuclear threats. The third is the public debate over their use, which has played out in government, academia and society and had an essential role in guiding technology and policy towards an outcome of stable strategic deterrence.

Placing this template on strategic cyber weapons leads to the conclusion that the comparison of nuclear and strategic cyber weapons is not a strong one. In terms of destructiveness, strategic cyber weapons do not make the same mark. But, as various world leaders have stated, these weapons could be enormously destructive.⁵ Cyber attacks on the electrical grid, public transportation, the financial system, municipal water and sewage systems, as well as agriculture and medicine supply chains, could, admittedly, have a devastating effect on societies and the economies of the world, particularly the most advanced.⁶ However, even if world leaders are taken at their word, it is difficult to see how the destructive power of strategic cyber weapons can compare with the destructiveness of nuclear weapons. As a consequence, strategic cyber weapons may not be effective strategic deterrents. As US nuclear missileer (member of a missile combat crew), Lieutenant Colonel James Wakefield, put it, ‘Cyber may be able to threaten the

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4. Peter W Singer and Allan Friedman, ‘What About Deterrence in an Era of Cyberwar?’, *Armed Forces Journal*, 9 January 2014; Emilio Iasiello, ‘Is Cyber Deterrence an Illusory Course of Action?’, *Journal of Strategic Studies* (Vol. 7, No. 1, Spring 2014), pp. 54–67; Dimitar Kostadinov, ‘The Attribution Problem in Cyber Attacks’, Infosec Institute, 1 February 2013.
 5. *Bloomberg News*, ‘Chinese General with Dempsey Compares Cyber-Attack to Nuke’, 23 April 2013; United States Senate Committee on Foreign Relations, ‘Nomination of John F Kerry to Be Secretary of State’; Rogozin, ‘Speech at Press Conference in the “WP”’.
 6. Celeste Biever, ‘“Preventable” Failures Caused US Power Blackout’, *New Scientist*, 20 November 2013; Andy Greenberg, ‘Hackers Remotely Kill a Jeep on the Highway – With Me in It’, *Wired*, 21 July 2015; Caroline Baylon with Roger Brunt and David Livingstone, *Cyber Security at Civil Nuclear Facilities: Understanding the Risks* (London: Chatham House, 2015); Adam Stone, ‘Cyberattack: The Possibilities Emergency Managers Need to Consider’, *Emergency Management*, 21 January 2014; Robert Clark, Simon Hakim and Avi Ostfeld (eds), *Handbook of Water and Wastewater Systems Protection* (New York: Springer, 2011), pp. 27–46; US Department of Homeland Security, US Department of Agriculture and US Food and Drug Administration, ‘Agriculture and Food: Critical Infrastructure and Key Resource Sector-Specific Plan as Input to the National Infrastructure Protection Plan’, May 2007; Eileen Oldfield, ‘Cyber Supply Chain Security: A Concern for the Pharmaceutical Industry’, *Pharmacy Times*, 18 December 2014.

way we live or the way we do business, but nuclear weapons threaten the fact that we live at all'.⁷ While this could change in the future with advances in technology, it would be a mistake to think – and base policy on the assumption – that cyber weapons are as destructive as nuclear.

Strategic cyber weapons most resemble nuclear weapons in terms of their delivery speed, as they can deliver payloads around the world in milliseconds. The US National Military Strategy for Cyberspace Operations states that strategic cyber weapons can 'deliver effects at speeds that were previously incomprehensible'.⁸ General Keith Alexander, former director of the NSA and commander of Cyber Command, noted in his 2010 testimony to the US Congress that 'time and distance are less relevant in the cyber domain than in any other'.⁹ Additionally, against a determined adversary with enough time and resources, it is nearly impossible to stop a strategic cyber weapon either through defence of the target or by trying to destroy the computer that the adversary is using, as it is easily replaceable. A key difference that exists at the moment is that users of strategic cyber weapons cannot be assured of on-demand capability, because delivery is reliant on vulnerabilities in an adversary's system. As a consequence, a potential victim can frustrate an attacker in the short term in cyberspace through patching vulnerabilities – however, UK Prime Minister Stanley Baldwin's adage, that 'the bomber will always get through', holds just as devastatingly true for cyberspace as it might have done for the nuclear age.¹⁰ Consequently, should the destructiveness of strategic cyber weapons increase sufficiently, highlighting the delivery aspect of their nature could assist in developing their strategic deterrence potential.

The debate over whether users should treat strategic cyber weapons differently from other weapons is still very much in its infancy. There are not yet any writers on cyber warfare comparable to the prominent nuclear deterrence scholars Bernard Brodie or Thomas Schelling, and it is possible that there may never be. General Michael Hayden, former head of the NSA and CIA, said, 'No one has yet begun to write the *On Thermonuclear War* for cyber conflict'.¹¹ Admiral James Ellis, former commander of US Strategic Command, says the debate is too 'diluted' and characterises it as being 'like the Rio Grande, a mile wide and an inch deep'.¹² A primary cause of this problem is that the open source debate (to which the public has access) is not as closely linked with the closed source debate as the nuclear debate was and is. In its present form, the debate about strategic cyber weapons is not likely to inform the development of technology and policy in a direction that is conducive to strategic deterrence.

7. Author interview with James Wakefield, Stanford, 12 April 2015.

8. US Department of Defense, 'National Military Strategy for Cyberspace Operations (U)', December 2006, <<http://nsarchive.gwu.edu/NSAEBB/NSAEBB424/docs/Cyber-023.pdf>>, accessed 23 August 2016.

9. Keith B Alexander, 'Statement of General Keith B Alexander', testimony given to House of Representatives Committee on Armed Services, 23 September 2010.

10. Gov.uk, 'Past Prime Ministers: Stanley Baldwin', <<https://www.gov.uk/government/history/past-prime-ministers/stanley-baldwin>>, accessed 18 August 2016.

11. Author interview with Michael Hayden, Stanford, 10 March 2015.

12. Author interview with James Ellis, Stanford, 22 May 2015.

This paper has argued that strategic cyber weapons in their current form do not sufficiently share the strategic deterrent characteristics of nuclear weapons. However, there are three ways that this may change in the future.

The first is that strategic cyber weapons mature into a strategic deterrent comparable to nuclear weapons. For this to happen, cyber defences would need to become effective enough to preclude small states, non-state actors and individuals from using strategic cyber weapons. At the same time, the weapons themselves would need to develop further to ensure both delivery and attribution. Finally, cyber-reliant technology would have to be adopted to ensure that the weapons could be as destructive as nuclear weapons. From a deterrence perspective, this would be the optimum outcome, since it would mean that cyber actors might never use strategic cyber weapons and would wield them only as a deterrent, to further stabilise the international system, as with nuclear weapons. But this scenario is unlikely, as all of these things would have to occur at the same time.

The second way in which the situation might change is that strategic cyber weapons might not become a strategic deterrent, but still become a considerable force – possibly even one capable of mass destruction. In this future, strategic cyber weapons become incredibly destructive and technological advances result in them being accessible to many actors, while attribution capability remains limited. This is probably the worst outcome and also the most likely given the current trends.

The third possibility is that strategic cyber weapons do not become a strategic deterrent, or even a major weapon capable of mass destruction, because leaders have exaggerated and fundamentally misunderstood their threat and the technology does not develop further. As Martin Libicki at the RAND Corporation said, 'We have nothing to fear in cyberspace but fear itself'.¹³ This is a good scenario, but also the least likely given the amount of investment that cyber actors are pouring into the development of strategic cyber weapons.

Given the circumstances, it would be a grievous and potentially dangerous mistake to base policy on the assumption that strategic cyber weapons could constitute a strategic deterrent in the same way as nuclear weapons. However, there is potential for further insight to be gained from studying comparisons of nuclear and strategic cyber weapons. While this paper has looked at the cyber–nuclear analogy in terms of deterrence, it would also be worthwhile to examine comparisons relating to arms control, non-proliferation and non-use norms and nuclear terrorism. It is also important to periodically revisit the cyber–nuclear deterrence analogy as the technology evolves. Strategic cyber weapons are dangerous and could significantly impact the lives of every person on the planet. If it is possible to prevent their use through a framework that already exists, it should be done. If not, then it is necessary to think of another way to handle the threat.

13. Author interview with Martin Libicki, Washington DC, 20 March 2015.

II. The UK's Nuclear Options After Brexit

Daniel Davies

Civil nuclear policy, while not featuring prominently during the EU referendum debate, will be affected by the result. This paper assesses the underappreciated ramifications of the Brexit vote for the nuclear field and the distinct challenges posed to the government, especially legislative voids, negotiating continued access to regional bodies and striking new trade deals. It argues that the government must exploit the opportunities and reduce the risks presented by Brexit in order to protect the future of nuclear energy, industry and research in the UK. It concludes, however, that in order to protect investment during a period of planned nuclear growth, the overarching priority for the government must be to minimise uncertainty while it negotiates an exit from the EU.

Regulation

Standards and practices in the UK are unlikely to change, as they have tended to exceed those stipulated by international obligations. However, aside from the EU, triggering Article 50 of the Lisbon Treaty will signal the UK's departure from the oft-forgotten European Atomic Energy Community (Euratom). The Euratom Treaty, signed in March 1957, and its associated regulations form a large chunk of UK nuclear law. As such, a legal void will open in nuclear regulation in Britain.

Initially, the government will have to decide what should be rewritten into domestic law and whether to amend nuclear laws that the UK is currently obliged to enact as a result of EU directives. However, leaving Euratom presents a more complex regulatory challenge. The majority of nuclear safeguards in the UK are currently conducted by Euratom. To continue to fulfil international safeguarding obligations and those stipulated by bilateral cooperation and trade agreements, the UK will need to replace Euratom's role in the UK's safeguarding system. While this presumably means a greater role for the International Atomic Energy Agency (IAEA), the UK's current safeguard agreement with the agency (INFCIRC/263) will first have to be rewritten, because Euratom is also a party.

Existing outside of binding European legislation and oversight could aid new nuclear projects. Decisions regarding siting, facility authorisation and waste management could be expedited as the UK will no longer have to seek approval from the European Commission. The UK's nuclear industry could also benefit under IAEA safeguards, which are less disruptive to the operation

of nuclear sites than those conducted by Euratom.¹ Fewer challenges in European courts, such as those claiming the Hinkley Point C strike price breached state aid rules, will also certainly reduce delays and investment risks.² Finally, the UK can avoid EU law from ‘spilling over’ into other areas, as with the attempts to apply the Euratom Treaty’s health and safety legislation to military activities,³ or developing without due consideration, as was criticised in the UK’s 2012 Balance of Competences Review.⁴

Institutions

On leaving Euratom, the UK will also automatically lose access to mechanisms for information sharing, developing best practices and facilitating research between member states. Other areas of collaboration could also be lost, such as membership of the European Nuclear Safety Regulators Group (ENSREG), which encourages improvements to standards in nuclear safety, waste management and decommissioning, and the Euratom Supply Agency, which ensures regular supplies of nuclear fuels and medical isotopes. Severing ties to such elements of regional cooperation would be damaging for UK industry, research and leadership in the field.

International, rather than regional, mechanisms could fill the gap to some extent. The IAEA has information sharing frameworks, such as the Incident and Emergency System, and offers international means to develop best practice in safety, security, decommissioning and waste management. However, European collaboration is particularly salient for the UK as neighbouring countries share similar levels of nuclear development, working procedures and challenges. Lessons learned from building European pressurised reactors in France and Finland, for example, are of particular interest to the UK’s projects using this design.

Continued access to European programmes for British researchers, such as the European Commission’s Joint Research Centre’s nuclear projects, is also invaluable for British expertise. Although the government has announced that it will underwrite European-funded research projects planned to continue beyond the UK’s departure from the EU, programmes such as the Culham-based Joint European Torus project on nuclear fusion will need longer-term guarantees.⁵

It would not be impossible to maintain elements of the collaborative relationship with the EU. The UK’s past investment, expertise and infrastructure should reduce the costs of retaining

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1. Daniel Davies, ‘Brexit Effects: The Future of Safeguards in the United Kingdom’, *Trust and Verify* (Issue 153, Summer 2016).
 2. Austria vs. Commission, Case T-356/15, ‘Action brought on 6 July 2015 – Austria v Commission’, European Court of Justice, Luxembourg, 6 July 2015.
 3. Commission of the European Communities vs. United Kingdom of Great Britain and Northern Ireland, Case C-65/04, ‘Judgment of the Court (First Chamber)’, European Court of Justice, Luxembourg, 9 March 2006.
 4. HM Government, *Review of the Balance of Competences between the United Kingdom and the EU: Energy Report* (London: The Stationery Office, December 2012), p. 70
 5. David Gauke, ‘European Union Funding’, letter to the Rt Hon David Davis MP, 12 August 2016, <https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/545767/CST_letter_to_SoS_for_DExEU_August_2016.PDF>, accessed 22 August 2016.

access to European collaboration in the nuclear field. Moreover, non-EU states can access Horizon 2020, the EU's €80 billion (£71.5 billion) research and innovation programme, and have participated in regional stress tests of reactors following the Fukushima disaster in March 2011. The challenge, however, is political. Domestic pressures to 'leave Europe' and the diplomatic costs associated with negotiating access could be problematic. For instance, the UK could face similar pressures to Switzerland, which had Horizon 2020 funding withdrawn during a row with the EU over immigration.⁶

In this regard, the UK should maintain regional collaboration whenever possible to protect leadership in research, expertise and practices. The government should assess which elements of regional cooperation are sufficiently beneficial to warrant the potential costs of negotiating continued membership. Continued membership of Euratom would be overly politically challenging, as its decision-making apparatus is integrated into the EU. Retaining full or associate membership of Horizon 2020 or ENSREG, however, is more feasible. In this regard, the UK need not sacrifice all the benefits of European cooperation and collaboration.

The Single Market

At the time of writing, the government has not changed the prominent role planned for nuclear in the UK's energy mix, despite conducting a security-related review into Hinkley Point C. The priority must therefore be to retain and attract investment for the planned 16 GW of new nuclear capacity during the period of uncertainty brought about by Brexit, despite partners in such projects suggesting that the UK's relationship with Europe will not affect cooperation.⁷

Any investment lost while leaving the EU, such as from the European Fund for Strategic Investments, must be found elsewhere. Although the Hinkley Point C delays have not helped matters and could jeopardise Chinese interest in developing the Bradwell site, there is clearly a growing interest outside Europe in UK nuclear projects, including in the US and Japan, that could be strengthened by the regulatory changes described above. However, while leaving the EU may provide opportunities for beneficial trade deals with non-European partners, the UK will still require access to and investment from the European market. Any tariffs on services and materials brought to the UK, and restrictions to the required movement of labour and skills, could penalise current European collaboration on new nuclear builds.

The nuclear industry more broadly also has interests in both European and non-European markets. A small modular reactor industry, as outlined in the Spending Review and Autumn Statement 2015, would benefit from advantageous trade agreements in the US, China and Russia.⁸ By contrast, any service-based industry, such as decommissioning, would benefit from continued access to the single market in services.

6. Jon Henley, 'Whatever You Do, Don't Become Switzerland, Swiss Academics Tell UK', *The Guardian*, 11 November 2015.

7. *World Nuclear News*, 'The Brexit Effect on UK Nuclear', 24 June 2016.

8. National Nuclear Laboratory, 'Small Modular Reactors (SMR) Feasibility Study', December 2014, p. 28.

Reducing Uncertainty

These three elements of the UK's relationship with Europe (Regulation, Institutions and the Single Market) will pose different challenges for the government when trying to protect the UK's nuclear industry: filling the legal void left by European law; negotiating continued membership of some European institutions; and striking trade deals beneficial to the entire nuclear industry. In negotiating these challenges, there are clear opportunities for the UK, as well as risks. The immediate risk, however, is lingering uncertainty as the UK prepares its exit from the EU and subsequently engages in trade negotiations. This uncertainty will delay or deter investment, hurting the nuclear industry in the process and jeopardising new nuclear builds.

As such, while planning to exploit the opportunities above, the government should act to reduce uncertainty during Brexit. It can clarify its plans as to which aspects of European regulation will remain incorporated in domestic law and begin to investigate how major reforms, such as the application of safeguards in the UK, could be enacted. The same can be said for continued collaboration with non-EU countries and the government's plans for nuclear industry outside the EU, although these rely more heavily on negotiations. Moreover, although engaging in trade negotiations before the UK's departure from the EU is illegal, the government can specify areas in which it will seek non-European partners and investment, such as in nuclear energy. By doing so, the government can maintain competitiveness and leadership in the field in the immediate term before exploiting the opportunities offered by Brexit in order to secure the UK's nuclear future.

III. Big Projects, Big Challenges: Government Governance of the *Successor* Programme

Maria Szczyglowska

When complete, the *Successor*-class¹ of submarine is expected to be the most technologically advanced submarine in the history of the Royal Navy.² Replacing the *Vanguard*-class of submarines, *Successor* will be purpose-built to carry Trident missiles and provide a continuous at-sea deterrent. With a commission date in the early 2030s and initial estimated costs of £20 billion, the *Successor* programme is one of several major government-funded programmes currently underway.³ Yet with costs spiralling to over £31 billion, with an additional £10 billion contingency fund set aside,⁴ and estimated lifetime costs of over £167 billion,⁵ this programme is under intense scrutiny. Indeed, in November 2015 it was widely reported that then chancellor George Osborne expressed concerns that the Ministry of Defence did not have the skills to deliver the new submarines on budget and sent an ultimatum to the prime minister at the time, David Cameron, that he would support continued funding of the UK deterrent only if the project was given to a new body that reported directly to the Treasury, thus stripping the Ministry of Defence of overall control of the submarine programme.⁶ Projects of this magnitude clearly need to have a well-defined, effective structure of governance to succeed and it is this structure of governance that this paper explores through comparison with another of the government's major programmes, Crossrail.

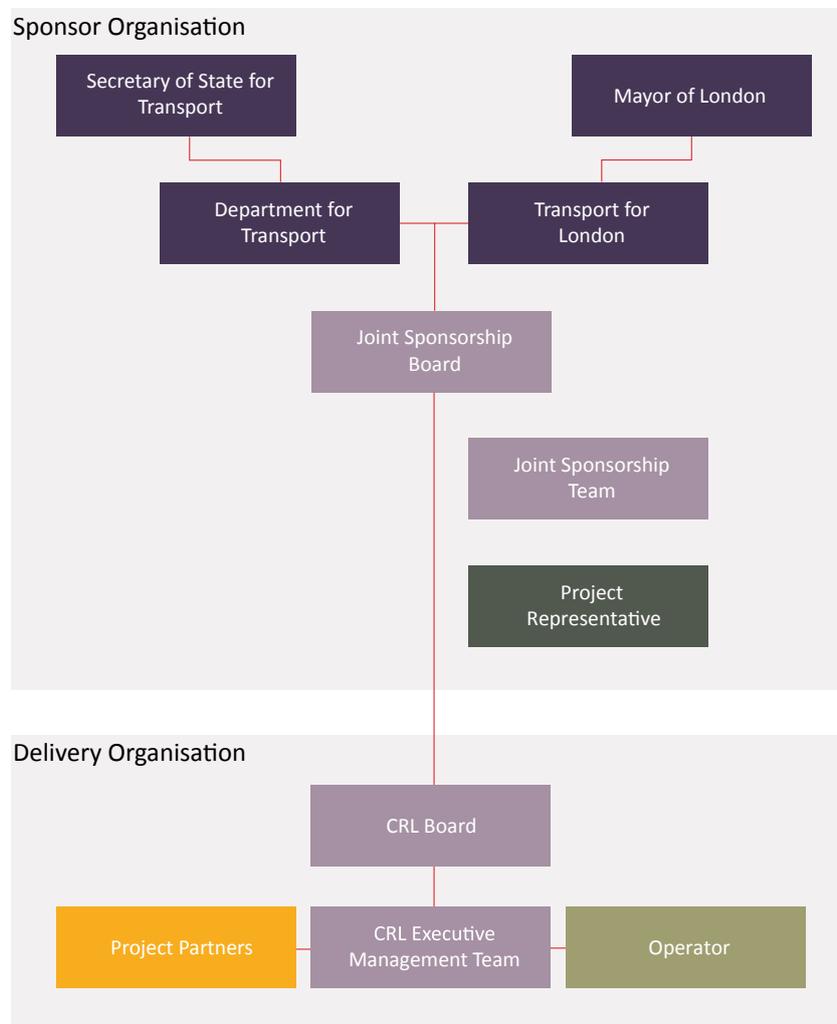
Mega-Project Governance: Crossrail

When complete, Crossrail will provide a high-capacity rail network for London and the UK's Southeast for an estimated cost of £14.7 billion.⁷ This ten-year major infrastructure programme

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1. Editor's note: '*Successor*' was the name for the Royal Navy's new ballistic submarines programme until the first boat was named in October 2016; they are now called '*Dreadnought*-class'. This paper was presented before the name had changed.
 2. George Allison, 'Successor Class Submarine: A Guide', *UK Defence Journal*, 15 April 2015.
 3. HM Government, 'The Future of the United Kingdom's Nuclear Deterrent', Cm 6994 (London: The Stationery Office, 2006).
 4. HM Government, *National Security Strategy and Strategic Defence and Security Review 2015*, Cm 9161 (London: The Stationery Office, 2015).
 5. Jon Stone, 'The Cost of Replacing Trident is Really £167bn, New Figures Suggest', *The Independent*, 25 October 2015.
 6. Laura Hughes, 'George Osborne Issues Treasury "Ultimatum" Over Trident', *The Telegraph*, 12 November 2015.
 7. See <<http://www.crossrail.co.uk/about-us/funding>>, accessed 17 August 2016.

has yet to open its first station, but has already been widely praised as a success. Recently, the Crossrail Learning Legacy was established as a way to pass on good practice and lessons learned for future infrastructure projects of similar magnitude. According to senior delivery leaders at the Department for Transport, one of the major factors for this success has been that ‘the project team set up a capable delivery body with clearly established roles and responsibilities for the many parties involved’.⁸ Indeed, this governance structure has been cited as aiding ‘robust delivery of a government funded mega-project in a complex stakeholder environment’.⁹ This complex governance and delivery structure is shown below in Figure 1 in a simplified form.

Figure 1: Simplified Crossrail Governance and Delivery Structure (adapted by author).



8. Cabinet Office, ‘Major Projects Authority Annual Report 2014–15’ (London: The Stationery Office, June 2015).

9. Chris Croft, Martin Buck and Simon Adams, ‘Lessons Learned from Structuring and Governance Arrangements: Perspectives at the Construction Stage of Crossrail’, Crossrail Learning Legacy, April 2016.

The key point from this figure is the clear split and independence between the sponsor and delivery organisations. The sponsor organisations, the Department for Transport and Transport for London, are responsible for making the case for investment, securing funding, specifying the project's outputs, and ensuring that the project benefits are delivered. The delivery organisation, Crossrail Limited (CRL), is the organisation responsible for ensuring the project is delivered as per the sponsor's requirements. By having this clear split, the structure allows for roles and responsibilities to be clearly defined and accountability to be well known.

Sponsor Organisations: Department of Transport and Transport for London

Because Crossrail has two sponsors, a Joint Sponsor Board was established as the forum where joint decisions about the project would be made. In the early stages, the Joint Sponsor Board managed the development of the programme through a series of review points.¹⁰ At each of these review points, the programme was reviewed by the Treasury's Major Projects Review Group, ensuring that specified milestones were achieved and that the programme maintained a viable business case in order to continue.

The Joint Sponsor Board was established to manage the relationship of the sponsors and the CRL Board at a working level, and to ensure that CRL implemented the decisions of the Board as intended.

A project representative was also appointed to provide independent advice on the programme and to assist with its smooth running. This included: advising the sponsors on any increased risk of exceeding budget and timescale; providing independent informed advice to the sponsors on progress in terms of time, cost and quality; providing sponsors with an oversight and analysis of any changes in scope; and monitoring CRL's compliance with undertakings and assurances.¹¹ This layer of independent advice provided by the Project Representative gives additional confidence to stakeholders and the programme's wider community in the programme and the value for money it provides. It also gives greater transparency to the workings of the delivery organisation and to the rationale behind decision-making.

Delivery Organisation: Crossrail Limited

The management and implementation of Crossrail is the ultimate objective of CRL, the delivery organisation. Responsibility for ensuring the delivery of the programme falls to CRL's board, an independent body, responsible for the overall direction and management of CRL. Its ability to provide assurance to the sponsor organisations that the programme is being adequately managed is dependent on the structures, procedures and processes put in place. These include an appropriate organisational structure, clear reporting procedures and internal audits. One of the keys to the success of Crossrail is that these procedures and processes were established early in the programme, agreed by the sponsor organisations and implemented at all levels.

10. Crossrail Governance Organisation for Delivery, see <https://www.london.gov.uk/sites/default/files/gla_migrate_files_destination/CrossRail-Evidence.pdf>, accessed 17 August 2016.

11. *Ibid.*

In order to facilitate the day-to-day running of Crossrail and to manage the complex network of stakeholders, an executive management team was established. The team provides the engineering and programme management and the interface with the operator and the industry partners.

Mega-Project Governance: *Successor*

In the case of the *Successor* programme, there is currently no clear division between the programme sponsor and the delivery organisation, with both roles being filled by the Ministry of Defence. This lack of separation has led to speculation from critics as to the robustness of the ministry's internal Investment Approvals Committee, which provides advice, assistance and scrutiny on large ministry-approved programmes.¹² In light of ever increasing costs to the programme, this can also lead to questions about the true value for money of the *Successor*-class programme, particularly given that the decisions made in the 2013 Trident Alternatives Review were based upon the original £15–20 billion estimates.¹³ In order to counter this and draw upon the lessons learned from Crossrail, a proposed governance structure for the *Successor* programme is shown in Figure 2.

Sponsor Organisation: Ministry of Defence

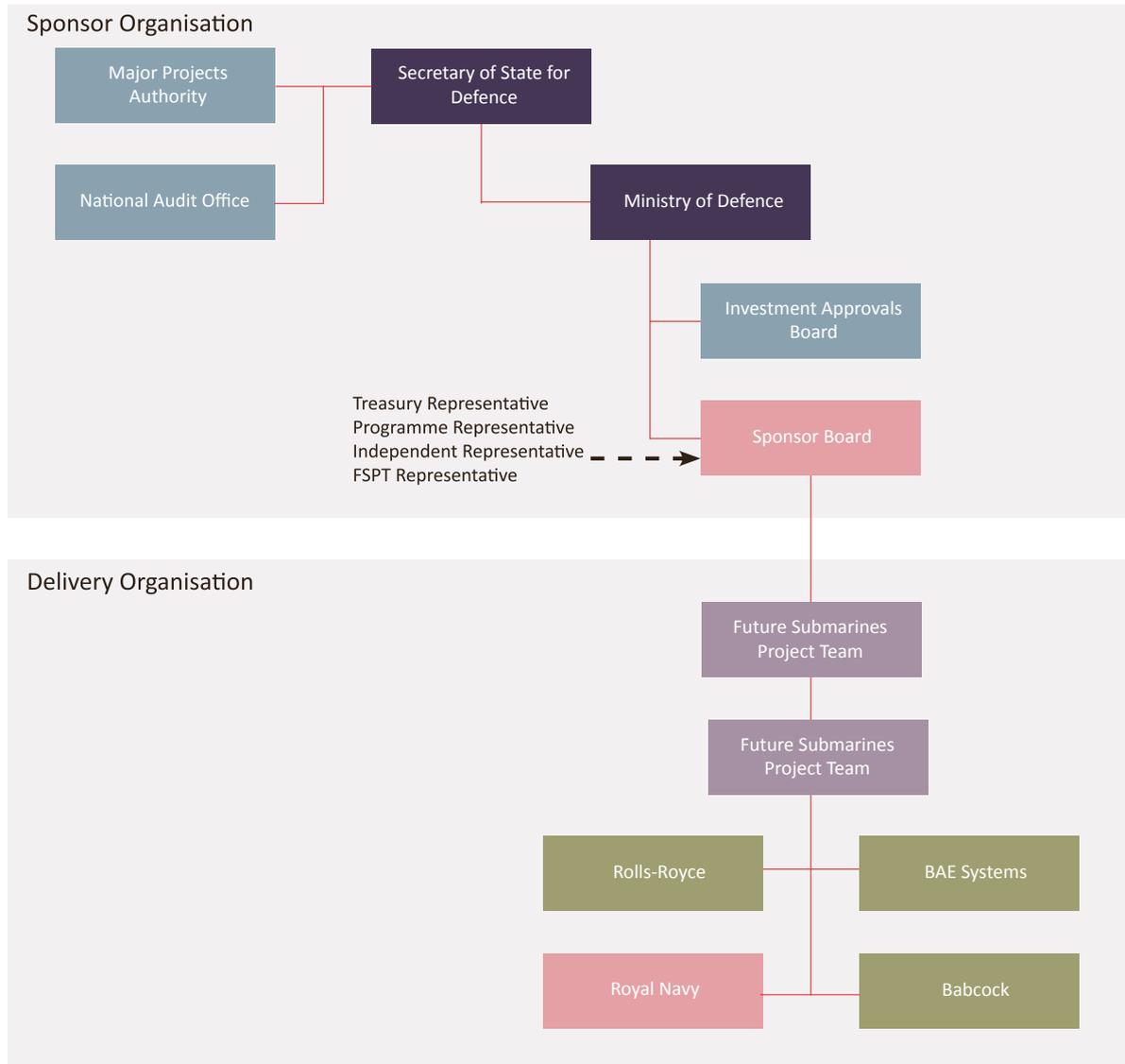
It is proposed that the sponsor organisation for the *Successor* programme will remain as the Ministry of Defence, with independent assurance continuing to be provided by the National Audit Office, Major Project Authority and the ministry's Investment Approvals Board.

A new sponsor board would then be established to act as the single sponsor for all aspects of the Defence Nuclear Enterprise, including the *Successor* programme. This board would be the key interface with the delivery organisation, led by the Future Submarines Project Team. It is suggested that this board includes representatives from the Ministry of Defence, the Future Submarines Project Team and independent representatives including, but not limited to, a programme representative and representation from the Treasury. It would be through this route that the Treasury would have representation and communication rather than through a board or body specifically run by them. This would allow the programme to be driven by the sponsor's requirements, and go above and beyond just the political considerations. Inclusion of independent members provides an increased level of assurance that the sponsor and delivery organisations are acting in the best interest of the investors – ultimately UK tax payers.

12. Ministry of Defence, 'JSP 507 Investment Appraisal and Evaluation Part 1: Directive', Version 6.0, January 2014.

13. HM Government, 'Trident Alternatives Review' (London: The Stationery Office, 2013).

Figure 2: Proposed *Successor* Programme Governance



Delivery Organisation: Future Submarines Project Team

In the proposed governance structure, the delivery organisation would be the Future Submarines Project Team. As with CRL, their objective would be the overall delivery of the *Successor* programme as defined by the Ministry of Defence and they would be accountable for that delivery. Key to this is the autonomy that the Future Submarines Project Team would have from the Ministry of Defence by being a separate legal entity and not part of its larger organisation. Given previous concerns over the ministry’s current ability to deliver the *Successor*

programme,¹⁴ this new delivery organisation would also have the authority and ‘freedom to recruit and retain the best people to manage the submarine enterprise’.¹⁵

The Submarine Enterprise Performance Programme already manages industrial partner relationships and is key to the Ministry of Defence’s aims of saving money and improving performance. This is a long-term partnership between the Ministry of Defence and the three main contractors engaged in the design, construction and maintenance of its submarines: BAE Systems, Rolls-Royce and Babcock. This partnership aims to provide incentives to improve the effectiveness of programme delivery by sharing cost savings between the Ministry of Defence and contractors and through closer collaborative working between all partners.¹⁶ It is proposed that the Royal Navy is added to the Submarine Enterprise Performance Programme. As the final operators of the submarines and with years of experience operating the existing fleet, the importance of the Royal Navy’s representation throughout the lifetime of the programme is vital.

Taking the lessons learned from Crossrail, it is crucial that the clear split between delivery organisation and sponsor is in place, with roles and responsibilities of each party and industrial partners well defined. This then drives clear lines of accountability and removes ambiguity from the programme. The establishment of well-defined processes for managing the programme through its lifetime should also be completed at the earliest opportunity to ensure that regular reviews of progress can take place, with expectations set to reflect the political, economic and financial position at the time.

Conclusions

Following the Parliamentary vote on the future of Trident in July, during which the motion was backed by an overwhelming majority,¹⁷ it has become clear that the *Successor* programme has strong political support. Yet with uncertain economic times ahead as a result of the UK’s vote to leave the EU, it will take more than political will to ensure overall success. The governance of this programme, whatever guise it takes, will be integral to its success between now and the commission date in the early 2030s. It is vital that it has a simple structure, such that the project delivery terms can be well defined and understood by both the sponsor and delivery organisations, as this will both incentivise – and hold to account – the parties involved. This should be aided by clear roles and responsibilities for all involved, including industrial partners. Finally, it is key that there is open and transparent communication between all parties, and at every level, to allow for a fluid project that can be adapted to the unpredictable programme landscape of the next fifteen years.

14. Hughes, ‘George Osborne Issues Treasury “Ultimatum” Over Trident’.

15. HM Government, *National Security Strategy and Strategic Defence and Security Review 2015*.

16. National Audit Office, ‘Progress With the Successor Submarine Programme: National Audit “Ministry of Defence Major Projects Report 2012”’, January 2013.

17. Rowena Mason and Anushka Asthana, ‘Commons Votes for Trident Renewal by Majority of 355’, *The Guardian*, 18 July 2016.

IV. Casualty Modelling Challenges

Jennifer Smith

Casualty modelling provides an assessment of how a nuclear detonation will affect a population. A casualty is defined as a person who is either injured or killed by a nuclear detonation. It is difficult to model how many casualties are generated in a detonation as it depends on many factors, such as which nuclear effects are included in the model and what data are available. The accuracy expected from the model is also a driving factor for which effects are included and what data are required.

There are four main nuclear effects that cause casualties: blast; thermal radiation; initial radiation; and fallout. The blast is a shockwave that causes a sharp increase in pressure followed by a pressure decrease that can cause high velocity winds behind it. Thermal radiation is the light and heat produced by the nuclear fireball. Initial radiation is that which is released at the time of the detonation and the fallout is caused by particles that are swept up into the detonation, irradiated and then deposited some time later.

This report discusses the casualty-causing nuclear effects, how they are modelled and the challenges involved in modelling them. It will discuss whether all the effects can be modelled accurately, whether there is any need for them to be and how much resource should be applied to further refinement of nuclear casualty models.

Blast

The effect on casualties of a nuclear weapon blast is fundamentally the same as the effect of that of a conventional weapon, although a nuclear weapon is typically larger and thus the number of casualties is usually greater. The fact that the blast effects are the same is advantageous for modellers of nuclear casualties as these are well understood from the use of conventional weapons throughout history. Primary blast casualties can be estimated relatively easily by judging where the blast overpressure (the increase in pressure caused by the blast wave compared to ambient pressure) is sufficient to cause various casualty effects, such as ruptured eardrums or lung collapse. The number of people subjected to a certain overpressure can be estimated by determining the area that will experience that overpressure and the population within this area. This methodology does not account for shielding by buildings or constructive interference of the blast wave.

The secondary and tertiary blast effects on a population are harder to model than the primary effects. Secondary effects are caused by debris hitting a person, which in turn causes injury or

death. This can range from being crushed inside a building that collapses or suffering lacerations from glass shards created when a window is destroyed by the blast wave. Tertiary effects are the effects of the trauma caused when a person moved by the blast wave collides with an immovable structure. In order to model these accurately, the effect of the blast on the structure and where the population is in relation to the structure also need to be modelled. This requires significantly more data for accurate modelling, as the population location and the type and placement of any structures need to be known.

Thermal

The effect of thermal radiation produced by a nuclear weapon is heavily dependent on where the person is in relation to the fireball and whether there is a protective barrier. Thermal radiation effects can be diminished if there is any form of attenuating barrier between the fireball and the person, including structures, windows and clothing. In order to accurately assess the casualties from thermal radiation, assumptions must be made about the population's behaviour. Otherwise, the exact location and attitude of every individual must be known. This level of detail simply is not available, so assumptions are required to estimate how the population is situated.

Thermal radiation can cause fires, which in turn can create a significant number of casualties long after the detonation. Whether a fire starts is based on a complex set of factors, such as the weather conditions before and at the time of the detonation and the amount of flammable fuel available. If there is a lot of atmospheric water and the available fuel is wet then a fire is less likely than if there has been a dry period or the fuel is within buildings. The spread of the fire depends on the atmospheric conditions – a strong wind can cause the fire to spread a long distance from the location of the original detonation. A lack of wind means the fire might extinguish quickly once the fuel sources are exhausted.

Initial Radiation

Initial radiation is emitted at the time of the detonation and is comprised of neutrons and gamma radiation. The exact quantities of each type of radiation depend on the nature of the weapon and what materials are used within it. In order to predict the casualties, the weapon type must be assessed, although this information may not be easily accessible.

The radiation dose a person receives depends on their exposure to the weapon. If a person shelters in a basement or the centre of a large building then he or she can be shielded from the worst of the initial radiation, although may be more at risk from other factors such as building collapse. The location of a person is therefore an important factor when assessing casualties from initial radiation.

Fallout

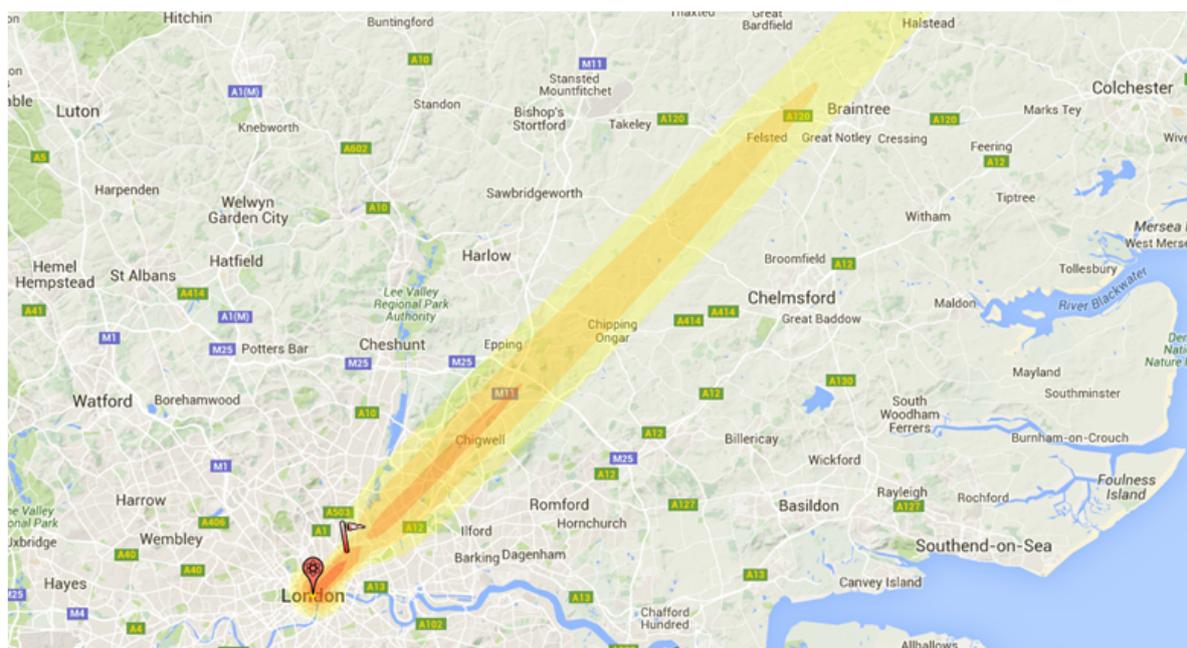
Nuclear fallout is the slow-time deposition of particles that have been swept into the fireball and irradiated. Fallout does not always happen after a nuclear detonation, as it depends on the

size of the weapon and how high the detonation occurs above ground level as this determines the amount of material swept up into the fireball. If fallout does occur, it can cause a large proportion of the total casualties.

The number of casualties caused by fallout depends on the location of the population compared with the fallout deposition and the behaviour of the population before, during and after the nuclear detonation. If the population is warned in advance of the detonation and remains in shelter, this will produce a different number of casualties to a population that is not warned and continuing with normal business on the streets.

The deposition of the fallout depends on the size of the particles that are deposited and the weather conditions. Figure 3 shows an example fallout plume created by an open source model. This is a simplistic model, but it demonstrates how important the weather and, in particular, the wind direction is to the fallout deposition. The plume primarily covers rural areas that are unlikely to contain a dense population, but if the wind had been slightly more westerly then the plume would fall across the Essex towns of Romford, Chelmsford and Colchester. This would greatly increase the predicted number of casualties. Using a projection of the mushroom cloud is a very simplistic model because the wind does not remain constant at all altitudes and this will affect the profile of the deposition. A simple model provides an assessment of the extent of the fallout but does not provide reliable casualty figures. Note that this model is not a Defence Equipment and Support-approved tool and has been used for illustrative purposes only.

Figure 3: Basic Example of a Fallout from a Nuclear Detonation



Source: Image created using open-source modelling code NUKEMAP, created by Alex Wellerstein (Stevens Institute of Technology, New Jersey), <<http://nuclearsecrecy.com/nukemap/>>, accessed May 2016.

Conclusion

Casualties from a nuclear detonation are difficult to accurately model due to unpredictable variables such as the weather and population variability. The exact behaviour of the population is a large factor in how they will be affected by a nuclear weapon and this creates unknown values for the input data. Assumptions must be made to account for the unknowns and a key skill of a modeller is to assess the uncertainty and its effects on the assumptions that can then be applied to modelling results.

However, is a high level of modelling fidelity required? If the model is to be used to gain a broad understanding of the effects of a nuclear detonation given a set of probable statistics, such as the prevailing wind and ambient population, then a high fidelity may not be needed as broad trends will be sufficient. Conversely, a high fidelity model with inaccurate input data could provide a false sense of confidence in its results, unless the uncertainties are clearly accounted for and displayed.

There is no denying that nuclear weapons are among the most destructive tools available in terms of casualty figures. Understanding the exact numbers of casualties is unlikely to be as important as understanding their scale, as it is this that causes them to be such effective deterrents.

V. H-Bombs and the Home Front: Implications of North Korea's Nuclear Weapons in a *byeongjin* World

Alison Evans and Karl Dewey

In January 2016, North Korea took the world by surprise and conducted its fourth confirmed nuclear test, triggering a seismic event measuring 5.1 on the Richter scale.¹ Despite describing it as an 'H-Bomb' – commonly understood to mean a thermonuclear weapon – North Korea is not known to have the infrastructure to create such weapons.² In addition, the yield was almost identical in magnitude to the 12 February 2013 test, described by Pyongyang as 'a miniaturised, light-weight, diversified, and precision nuclear bomb'.³ Both nuclear tests had yield estimates of 6–9 kilotons (kt). Given that opponents must believe that nuclear capabilities are credible, why is North Korea peddling such far-fetched statements?

Rather than external adversaries, perhaps the answer lies in a domestic audience: since Kim Jong-un's succession to head of state in November 2011, North Korea's rhetoric and the incidence of violent events – particularly during joint US-South Korea military exercises – have increased in both frequency and severity. This is indicative of two trends: a consolidation of power under Kim Jong-un, and specifically the power of the ruling Korean Workers' Party (WPK) relative to that of the military; and a hardening of Pyongyang's national security stance, including the development of nuclear weapons ahead of conventional hardware.

Kim Jong-un's New Order

Under Kim Jong-il's rule, the need to ensure regime survival in the face of widespread famine led to the creation of the *seon'gun* (military first) policy, which prioritised the allocation of scarce national resources to the military. In addition to material support, however, he also elevated the cabinet and the military to the same political level as the WPK, marking a large shift in the country's internal dynamics. Until that point, both institutions had reported to the party.⁴ As

1. BBC News, 'North Korea "H-bomb Test": What Do We Know?', 6 January 2016, <<http://www.bbc.co.uk/news/world-asia-35240193>>, accessed 22 November 2016.
2. Robert Kelley and Nick Hansen, 'Trick or Tritium: North Korea H-bomb Claims Examined', *IHS Jane's Intelligence Review*, 9 August 2016.
3. James Hardy, Sarah McDowall and Sebastien Falletti, 'North Korea Conducts Third Nuclear Test', *IHS Jane's Defence Weekly*, 12 February 2013.
4. Jae-Jung Suh (ed.), *Origins of North Korea's Juche: Colonialism, War, and Development*, (Lanham, MD: Rowman & Littlefield, 2013)

Kim Jong-un has consolidated authority however, there has been another shift in the internal composition of power and an increase in ruling party influence over the military. Both these trends support the central leadership's position of power as manifested in two major political restructurings.

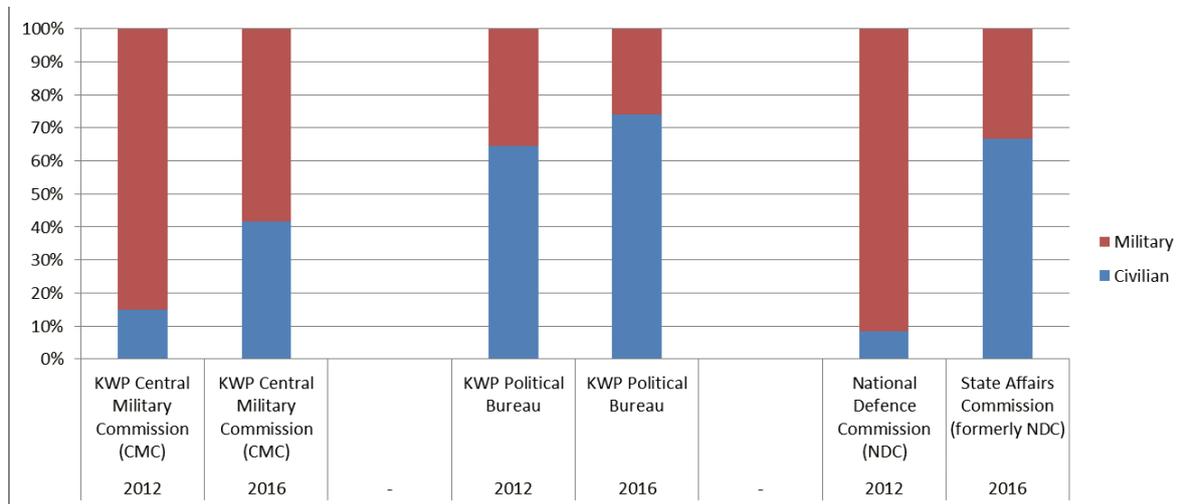
The Consolidation of Power in the Party Relative to the Military

The first restructuring was in March 2014, when North Korea's parliament, the Supreme People's Assembly (SPA), held legislative elections. In North Korea, parliamentary elections are held every five years and these were the first since Kim Jong-un took power. Over 80% of the SPA's seats are occupied by WPK members and bureaucrats, and only 17.2% are held by uniformed military members, slightly less than in 2009. Moreover, appointment of specific individuals through the elections indicated that Kim Jong-un had moved to decrease the military's autonomy in matters such as the armed forces, the nuclear sector and economic policy. One notable appointment was of Hwang Pyong-so as director of the Korean People's Army (KPA) General Political Bureau. Hwang has held political positions in the KPA and is believed to be a close adviser of Kim Jong-un.

Similarly, in April this year, major changes to the top organs of the state at the KWP congress indicated a return to a stronger party relative to the military. For example, 55% of the 235 members of WPK's Central Committee were new. The Central Committee's Political Bureau, the country's highest decision-making body, also reduced its number of KPA members from eleven in 2012 to seven in 2016 (see diagram below). The high turnover of seats, and the increasing number allocated to the party over the military, highlights the trend towards more centralised power at the highest echelons. Those closest to Kim Jong-un, including Hwang Pyong-so and Premier Pak Pong-ju, are also present here.

During the April Congress, the party's Central Military Commission (CMC) saw the most change. The CMC is in charge of the party's military policies and guidance. Its number of seats and the vice-chairman position were cut: military members occupied seventeen out of 20 seats in June 2012 compared with seven out of 12 in May 2016 (see diagram below). The variety of military members was also reduced to include only those of highest rank. Importantly, three seats are now held by non-military members. Of note in particular is Pak Pong-ju, thought to have been instrumental in the introduction of policies recognising grey markets in the agricultural sector, as well as in depreciating the currency – indicating that he is more likely to support economic reform in the future, too. His position on the CMC will provide the party with direct insight into military operations, resource allocation and strategy. All these changes make the CMC a more elite and party-dominated group.

Figure 4: Distribution of Seats in North Korea’s Top Decision-Making Bodies



Party Dominance and the Shift to a More Assertive National Security Stance

This five-year trend towards more power centralisation in North Korea’s politics has also been reflected in the country’s policies. Kim Jong-un announced his core policy of *byeongjin roseon*, or a ‘route to parallel progress’, during a speech in March 2013. The ‘parallel progress’ refers to developing both North Korea’s economy and military at the same time. Outside North Korea, some Pyongyang-watchers hoped this would lead to a prioritisation of economic development and fewer violent incidents, but this has not been the case. Rather, it is likely that this policy was aimed at appeasing hard line factions in the leadership while facilitating the transition to party dominance. If anything, there has been an increase in violent incidents on the peninsula – particularly around semi-annual US–South Korea joint military exercises – since the November 2010 shelling of Yeonpyeong Island, the March 2010 sinking of South Korea’s *Cheonan* corvette and Kim Jong-un’s 2011 inauguration.

Similarly, prior to the April Congress, there was speculation that North Korea would announce a notable shift in policy – towards economic reform as a priority over military might. However, Chinese- or Vietnamese-style economic reforms were not outlined at the congress. Instead, there was an emphasis on ‘strength’ and striving for advances both economically and militarily. This makes sense because economic growth supports a strong military. The desire to balance economic and security priorities was also reflected in the June 2016 renaming of the National Defence Commission, one of North Korea’s highest decision-making bodies, as the State Affairs Commission.

The *byeongjin* policy has thus proved to mean not so much a decrease in the importance of the military, but simply a redistribution of resources and political emphasis towards economic growth. The next phase of this is probably a transition from conventional weapons and forces

towards nuclear and cyber capabilities. This emerging trend has been borne out in the past year's multiple missile and nuclear device tests, as well as cyber attacks on a variety of foreign institutions attributed to North Korea.

Claims and Capabilities

The fact that North Korea claims it has an 'H-Bomb' is significant, in that it indicates the nation's sense of security as a 'nuclear power' able to carry out more conventional weapons attacks or missile tests. However, it is still necessary to ask why Pyongyang would seek such weapons.

The term 'hydrogen bomb' is not well defined, but is commonly understood to mean a thermonuclear device. It is seen as having a mega-tonne yield and is able to destroy large cities. The 'H' in 'H -Bomb' could also refer to the hydrogen isotopes in a boosted weapon, which is also capable of producing a yield several times higher than early simple fusion weapons. Both of these weapons types may be appealing to North Korea as their Scud-based rockets are thought to be very inaccurate. To ensure that targets are hit, they may seek to increase the accuracy of their missiles, increase the yields of the weapons, or both.

Thermonuclear or boosted technology also allows engineers to decrease the weight and diameter of a warhead. This, in turn, allows warheads to be carried on smaller delivery systems, including smaller multiple independently targetable re-entry vehicles for submarine-launched ballistic missile systems (SLBMs). Indeed, the W68 Poseidon, which had the largest single production run of any US nuclear warhead, was a thermonuclear weapon with a reported yield of only 40–50kt.⁵ North Korea is unlikely to have the technology for multiple (guided or unguided) warheads, although it may be appealing to Pyongyang as they represent a possible solution to overcoming missile defence systems, which the US, Japan and South Korea are all stepping up in the region. North Korea is already seeking to improve the survivability of its deterrent and is making significant advances in its KN-11 SLBM programme. Therefore, by increasing the number of warheads per missile, it increases the potency of each missile and the costs for the enemy of each missed intercept.

While there are hints that North Korea has begun to explore materials that could have applications for thermonuclear weapons,⁶ there is no concrete evidence to confirm the extent of Pyongyang's research or its application to its weapons programme.⁷ This contrasts with previous North Korean behaviour, where international visitors were invited to see new nuclear technology, such as the country's centrifuge plant in 2010.⁸ Furthermore, the only firm observation of the January 2016 test – the seismic signature – which measured 5.1 on the Richter scale, looks remarkably similar to previous tests, such as the second test's 4.7 or the third confirmed test, which measured 4.9.

5. Robert Kelley and Nick Hansen.

6. *Ibid.*

7. *Ibid.*

8. Siegfried S Hecker, 'A Return Trip to North Korea's Yongbyon Nuclear Complex', *NAPSNet Special Reports*, November 22, 2010, <<http://nautilus.org/napsnet/napsnet-special-reports/a-return-trip-to-north-koreas-yongbyon-nuclear-complex/>>, accessed 15 September 2016.

While the tests could be masked,⁹ North Korea's desire to demonstrate its strength makes this unlikely. Discounting the seismic signature leads to the conclusion that the claim of an 'H-Bomb' is solely North Korean propaganda.

Conclusion

Although there are good reasons why Pyongyang may seek larger-yield weapons, it is unlikely to have the technology to develop them. Instead, it is the symbolic value of the claim about an 'H-Bomb' test that makes it appealing to the elites. These weapons represent the most destructive nuclear force and project images of strength and power, so claims of their development highlight the success of the 'military first' policy in building the strongest of deterrence forces to protect the country.

In doing so, however, North Korea's leadership also signals that the military's role has been fulfilled to a certain extent, supporting the justification of their relative demotion within the country's bureaucracy.

The centralisation of power under Kim Jong-un, and through the WPK, is positive in that it indicates stability in terms of policy and politics. However, this relative stability is unlikely to lead to a safer or more predictable security environment in Northeast Asia. On the contrary, military strength – specifically nuclear weapons capability – is seen as a guarantor of North Korea's national security.

North Korea does not have thermonuclear nuclear weapons, but the frequency of associated tests – and therefore the speed of their development – has increased. It is therefore also likely that use of conventional weapons on the peninsula will become more frequent, as North Korea feels shielded by its supposed nuclear umbrella and as Kim Jong-un's leadership continues to take a more aggressive national security stance.

9. Lynn R Sykes, 'Dealing with Decoupled Nuclear Explosions under a Comprehensive Test Ban Treaty', in Eystein S Husebye and Anton M. Dainty (eds), *Monitoring a Comprehensive Test Ban Treaty*, NATO ASI Series (Vol. 303), pp. 247–293.

VI. The UK Nuclear Skills Gap: Implications for Nuclear Knowledge

Helen Blue¹

The UK Nuclear Challenge

Several major nuclear projects are planned in the UK over the next decade. Nuclear new build aims to deliver 16GW of new nuclear energy by 2030, equal to approximately twelve new reactors at five sites in the UK.² The submarines sector must focus on the timely build of *Astute*-class submarines as well as the design and build of the *Successor*-class programme. Decommissioning challenges include the removal of radioactive waste from the Sellafield site; the decommissioning of reprocessing facilities;³ and the research and development of a deep geological disposal facility for nuclear waste. This is in addition to the decommissioning and active management of several UK reactor plants.

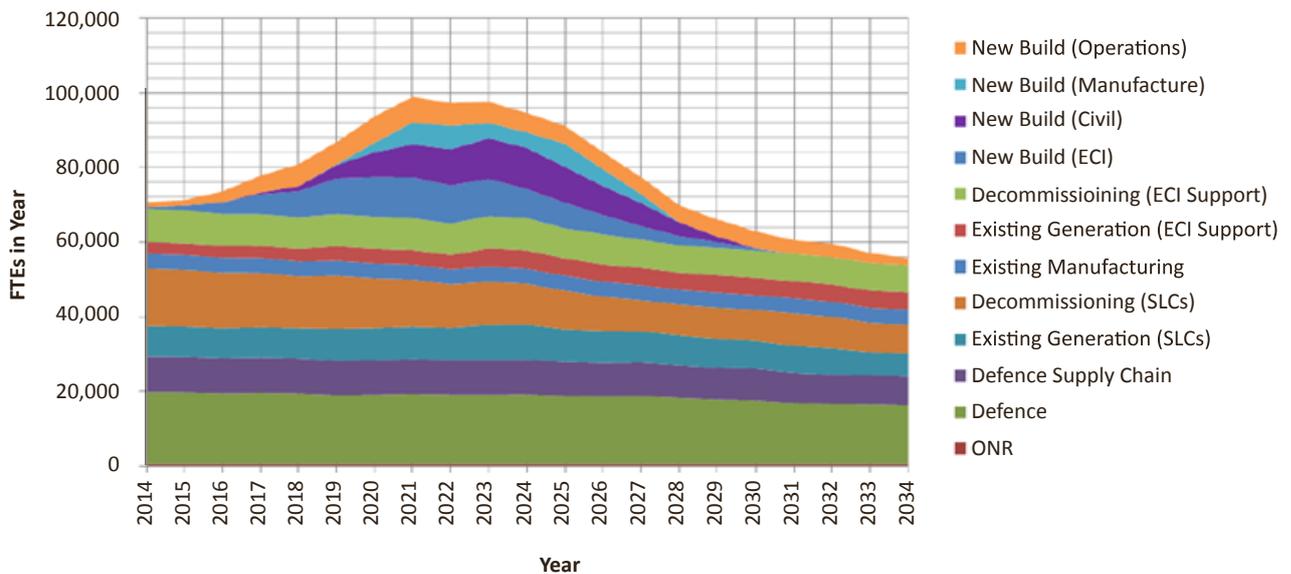
In 2015, the UK government added to these challenges by committing to invest at least £250 million in an ambitious programme of nuclear research and development.⁴ One element of this investment is a competition, managed by the Department for Business, Energy and Industrial Strategy, to find the best value Small Modular Reactor design for the UK. This competition aims to enable the UK to be a global leader in innovative nuclear technology.

All these are major political and infrastructural projects, which require not only substantial investment and both public and government support, but also a substantial workforce. Figure 5 shows the projected workforce demand in the nuclear industry over the next twenty years.⁵

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1. Presented to the UK PONI Annual Conference 2016 as 'Training Engineers Not Jedi. Why Yoda Was Mistaken'.
 2. HM Government, 'The UK's Nuclear Future', BIS/13/627, 2013.
 3. Nuclear Decommissioning Authority, Sellafield Ltd and Nuclear Management Partners, 'Sellafield Plan', Issue 1, August 2011. <http://www.sellafielddsites.com/publications/sellafieldplan/Sellafield_Plan.pdf>, accessed 23 August 2016.
 4. Department of Energy and Climate Change, 'Small Modular Reactors: Competition, Phase One: Guidance', URN 16D/045, 17 March 2016. <https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/508616/SMR_Competition_Phase_1_Guidance.pdf>, accessed 23 August 2016.
 5. *Ibid.*

Some estimates show that for the construction of new nuclear projects alone, the industry will need 60,000 new recruits.⁶

Figure 5: Civil and Defence Nuclear Workforce Demand



Clearly, the current nuclear workforce cannot support all these projects. The industry needs to consider how it will recruit the required number of suitably qualified and experienced persons.

The Current UK Nuclear Workforce

The shortage of personnel in the UK nuclear industry is further compounded by the age of the current UK nuclear workforce: research shows that 70% of skilled nuclear workers will retire by 2025.⁷ In recent years, the industry has largely come to terms with its ageing workforce. However, what has not been successfully achieved is the passing on of knowledge between employees. This has led to a skills gap, and there is a real danger of nuclear knowledge loss and corporate amnesia.⁸ The industry must therefore carefully consider how current knowledge and experience can be captured and shared. One method is to look at the major knowledge threats a skills gap creates:

6. Andrea Leadsom, 'Realising the Vision for a New Fleet of Nuclear Power Stations', speech given at the 8th Nuclear New Build Forum, London, 20 April 2016, <<https://www.gov.uk/government/speeches/realising-the-vision-for-a-new-fleet-of-nuclear-power-stations>>, accessed 9 November 2016.
7. Andrew Gale and Nawal Prinja, 'Mind the (Nuclear Skills) Gap', *Manchester Policy Blogs*, University of Manchester, 18 August 2015.
8. Phil Tinline, 'Too Good to be Forgotten – Why Institutional Memory Matters', *BBC News*, 21 March 2016.

1. **Time to Competency:** It is generally considered that a worker becomes competent after three to five years in a job. A large number of new recruits are the newly graduated who, according to this definition, are not yet competent. Those with the most experience do not have enough time to pass on their entire working knowledge to those who are new.
2. **Competition:** When a worker is competent, competition for this resource is high, both within the nuclear industry as well as outside it.
3. **Breadth:** Many modern workers move jobs more often than their predecessors. This allows them to gain a breadth of knowledge and experience of the industry. However, the nuclear industry is poor at capturing the knowledge of workers before they make this move.

Knowledge Management

In order to overcome the present challenges to the UK nuclear workforce, including a growing skills gap and an ageing workforce, careful understanding of how knowledge may be passed on is required. Knowledge management processes should become an integral part of the UK nuclear industry.

Knowledge can be split into two categories: tacit and explicit. Tacit knowledge is experience based and is difficult to pass on through written words or drawings. Explicit knowledge can be easily recorded in manuals, user guides or reports. The traditional method of passing on specialist knowledge within a trade was to hire an apprentice. The apprentice would work with the master, sometimes for decades, until he took over and the cycle restarted. However, this method of knowledge-sharing was slow and required someone to stay in the same job for many years, perhaps even decades, in order to complete the process. In modern workplaces, these two factors can no longer be assumed to be present, so new ideas for sharing knowledge must be implemented.

The IAEA defines knowledge management as ‘an integrated, systematic approach to identifying, acquiring, transforming, developing, disseminating, using, sharing, and preserving knowledge, relevant to achieving specified objectives’.⁹ This definition leaves scope for knowledge management techniques to be customised to tackle the three problems previously discussed. The two main aspects on which a knowledge-capture exercise should focus: what specifically does a team want to know and how will a team use the information once it is collected.

Considering the aforementioned knowledge threats, the following knowledge management techniques may be adopted by the UK nuclear industry:

1. **Time to Competency:** The time it takes to become competent can be reduced by making simple tasks, processes and data easy to find. Data stored logically and with easy access can maximise the time a worker spends on a day job. Sharing knowledge

9. Tatiana Karseka, Knowledge Management Fundamentals, IAEA School of Nuclear Energy Management, June 2012, <<https://www.iaea.org/nuclearenergy/nuclearknowledge/Knowledge-Management-Workshops.html>>, accessed October 14 2016.

through guides and presentations from colleagues (including experienced, competent and graduate workers) provides a range of perspectives and experiences. Graduates should also be encouraged to share their knowledge, as some enter the industry with specific nuclear training.

2. **Competition:** Line managers should never assume an employee will be in a job for several years, or stay until retirement. A line manager should plan for any member of their team to leave. It is vital that line managers ensure that succession plans are in place and that these are shared with the team.
3. **Breadth:** Communities should be created where information is shared with other teams and areas of the business, facilitated by technical presentations, mentoring, and workshops.¹⁰

Conclusion

The skills gap in the nuclear industry can be adequately addressed only through the effective use of knowledge management. This should be implemented at all levels of experience – knowledge management is far more than just an exercise completed before someone retires. Companies must ensure time is allocated for their staff, including experts, to have the opportunity to capture and share their professional knowledge regularly. This is the only way to secure the knowledge of the nuclear industry for current and future projects.

10. Ronald Young (ed.), *Knowledge Management Tools and Techniques Manual* (Tokyo: Asian Productivity Organization, 2010).

VII. Nuclear Fuel Banks: Supply Security in Theory and Practice

Cristina Varriale and Ben Pearce

In August 2015, the International Atomic Energy Agency (IAEA) signed an agreement with Kazakhstan to open the world's first internationally owned bank of low-enriched uranium (LEU) fuel. The idea of international nuclear fuel banks has developed gradually over decades and they are now finally materialising, with the IAEA fuel bank expected to begin operations in 2017. This has been welcomed by many as a first step in the establishment of assured nuclear fuel supplies to all safeguard-compliant member states of the IAEA. For others, though, the idea is seen as a potential threat to their right to domestically enrich uranium. However, in practical terms, the LEU fuel bank only guarantees supplies of uranium hexafluoride, the raw feed material that is machined into useable reactor fuel. So for those states without established domestic fuel fabrication facilities, the risk still remains that politically motivated attempts to disrupt energy supplies could extend beyond the supply of LEU and could also affect fuel fabrication services, potentially undermining the utility of the current fuel bank model. This paper argues that while the introduction of the IAEA fuel bank constitutes a significant step towards ensuring states' rights to civil nuclear technologies, through the increased provision of a fuel supply assurance that is independent of political state-based relationships, further fuel cycle considerations still need to be addressed for full security to be realised.

The idea of a multilateral nuclear fuel supply was first suggested by President Dwight D Eisenhower during the 1953 Atoms for Peace initiative, but lost traction during the Cold War, until revived by former IAEA Director-General Mohamed ElBaradei in 2003.¹ The IAEA fuel bank is designed to be able to provide an independent back-up supply of uranium hexafluoride enriched up to 4.95% – an easily transportable chemical form of uranium, which can be used in civil nuclear programmes in the event that the usual supply is disrupted and fuel cannot be obtained from the commercial market.

Fifteen years after Eisenhower's idea, the Non-Proliferation Treaty (NPT) put legal limits on the uses of nuclear science; while it prohibited the development of nuclear weapons, it outlined under Article IV that all states have an inalienable right to peaceful uses of nuclear science, such as for the purposes of energy and medicine. However, as limitations on access to dual-use nuclear technologies have increased, many states have come to cite the NPT as an unfair treaty which perpetuates a technological divide and restricts new nuclear states from developing indigenous capabilities. It is perceived that as fuel supply guarantees increase, the need for newly developed indigenous facilities will correspondingly decrease. As such, the non-nuclear

1. Thomas Lorenz and Joanna Kidd, 'An Uncertain Future for International Fuel Banks', *Bulletin of the Atomic Scientists* (Vol. 66, No. 3, May 2010), p. 44.

weapons states, many of which are associated with the non-aligned movement, perceive the fuel bank to be a mechanism to further limit their access to peaceful nuclear technology, sustaining the technological monopoly of the few.² By having a constant back-up supply of LEU available through the IAEA, states believe that they are intentionally dissuaded from pursuing dual-use enrichment facilities, which provide the capability to produce the LEU fuel needed for the most common nuclear power reactors. Although enrichment technology is not a prerequisite for all nuclear power, removing the right to access such technology would encroach on sovereignty and damage Article IV of the NPT and thus the broader treaty.

Although respect for sovereignty is paramount to the success of the NPT, concerns about encroachment fail to consider the larger aim of the IAEA fuel bank, which provides a back-up supply, as opposed to a primary supply, of fuel for civil reactors.³ The IAEA will provide fuel in circumstances where LEU cannot be obtained from the commercial market,⁴ such as instances of political disruption or a breakdown in relations between states. Thus, states' rights to develop or expand their nuclear fuel cycles under relevant IAEA safeguards will not be lessened by the assurance of a constant independent fuel supply.⁵ Indeed, the IAEA fuel bank takes steps to correct the disparities which its critics argue the NPT created, ensuring greater supply security and correspondingly lower vulnerability to the uncertainties of fluctuating international relationships between states. The implementation of the IAEA bank is not synonymous with the abandonment of the development of new enrichment capabilities.⁶ The IAEA Board of Governors has also noted that the insurance it provides does not impose a limitation on states' nuclear fuel choices,⁷ nor does it remove their right to develop enrichment capabilities. Thus, by providing a back-up fuel supply, the IAEA fuel bank in theory reinforces states' sovereign rights to access peaceful nuclear fuel, without diminishing their rights to develop indigenous peaceful facilities.

While this is a positive step in principle, representing an attempt to reinstate equality under the NPT, it must be acknowledged that the IAEA fuel bank alone cannot fully guarantee supply security. Although the LEU supply is politically independent, before it can be used it has to be transported across Russian territory. The IAEA has aimed to limit Russia's ability to manipulate the process via the signing of a transit accord, but whether or not Moscow adheres to the agreement may well depend on broader political relations, especially with the designated end user. It is this reliance on Moscow which has the potential to weaken the fuel bank's perceived political independence.

2. *Ibid.*, p. 46.

3. Khaled Toukan, 'For a Fuel Bank, Fairness is Paramount', *Bulletin of the Atomic Scientists*, Development and Disarmament Roundtable, 29 August 2012.

4. *World Nuclear News*, 'IAEA and Kazakhstan Agree to Create Nuclear Fuel Bank', 27 August 2015.

5. Tariq Rauf and Zoryana Vovchok, 'A Secure Nuclear Future', *IAEA Bulletin* (Vol. 51, No. 1, September 2009), p. 12.

6. Yusuke Kuno, 'Multilateral Nuclear Approach to Nuclear Fuel Cycles', in Amir Zacarias Mesquita (ed.), *Current Research in Nuclear Reactor Technology in Brazil and Worldwide* (Rijeka, Croatia: InTech, 2013), p. 288.

7. Tariq Rauf, 'From "Atoms for Peace" to an IAEA Nuclear Fuel Bank', *Arms Control Today* (Vol. 45, No. 8, October 2015), p. 16.

Another major consideration is the practicality of the fuel bank's model of supplying only LEU and not further fuel cycle services. It is likely that in the event of political disruption, *all* nuclear fuel cycle services would be withheld from the recipient state – for example, a foreign supplier may stop delivering nuclear fuel assemblies for a reactor.

This is significant because the fuel bank as proposed provides a proxy only for *enrichment* services – supplying enriched uranium hexafluoride in canisters – but not for the subsequent elements of the fuel cycle which are required before this material can be used within a reactor. The fuel bank only currently removes the imperative for a state to be capable of *enriching* independently in the event of political disruption that might lead to the interruption of its usual supply, while not necessarily providing the end goal of energy security.

Fuel fabrication, the process of converting uranium hexafluoride into useable reactor fuel, is a significant element of the front-end fuel cycle, representing around 20% of the overall cost of reactor fuel, requiring advanced, bespoke machinery, and being subject to regulations at both reactor and state level. Each reactor design has a particular specification for fuel assemblies that can be safely and efficiently used. This represents a significant element of a reactor's design.

The market for fuel fabrication services is large and has significant overcapacity, with Western fuel fabrication capacity reportedly outstretching requirements by 40%.⁸ This position is exacerbated by the continued loyalty of operators to their existing suppliers, which sometimes allows otherwise uncompetitive fuel fabrication facilities to continue operating.

Studies have demonstrated that this overcapacity means that in the event of a *technical* disruption to a supplier facility, in which, for example, the entire production capacity of a single facility were to be terminated, the market would have the capacity to compensate without significant delay, and another plant or fabrication supplier would be able to meet the shortfall before the next required reload of fuel, in the case of all but the most obscure reactor designs.⁹

However, continued consolidation of the fuel fabrication market and the rise in integrated fuel supply contracts, in which the reactor construction, operation, fuel supply and even in some cases waste disposal are combined upfront into the purchasing agreements of nuclear power plants, has meant that some reactor designs are particularly exposed to the potential for *political* disruption of supply.

A 2012 study by Pacific Northwest National Laboratory reported that those states reliant on fuel supplies from Russia and the US¹⁰ are subject to 'markedly high' market vulnerability in the event of political disruption. This is due to the centralised production of the Water–Water

8. Nuclear Engineering International, 'Fabrication: Is It Different?', 31 August 2015.

9. A M Seward et al., 'Redundancy of Supply in the International Nuclear Fuel Market: Are Fabrication Services Assured?', Pacific Northwest National Laboratory, October 2011. <http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-20861.pdf> accessed 23 August 2016.

10. Amy Seward, 'Fuel Fabrication Market Assessment – Modelling Technical and Political Outages in the Fabrication Sector', WNA Annual Symposium London, 13–18 September 2012.

Energetic Reactor (VVER) fuel that is used in Russian-designed reactors and the large number of facilities that are based in the US, or owned by US companies.

This lack of market diversity has also recently been identified in a 2016 report¹¹ by the Euratom Supply Agency as a significant obstacle for energy security in Eastern Europe – where eighteen VVER reactors currently operate. Their findings suggest that the integrated fuel-supply agreements used by VVER operators, in which all front-end fuel cycle services are provided by Rosatom,¹² lead to difficulties in diversifying the supply of fuel.¹³ This lack of market diversity has led to the stalling of the proposed construction of two VVER-1200 reactors at the Paks Nuclear Power Plant in Hungary;¹⁴ Ukraine is seeking alternative fuel supply arrangements for its reactors and the Temelin site in the Czech Republic has contracted Westinghouse Sweden to supply fuel for its VVER-1000 reactors. TVEL, the Russian state provider of fuel fabrication and supply, has allegedly described this position as a ‘near monopoly’,¹⁵ although it looks likely to change in the near future.

Changing provider is, however, slow and complex,¹⁶ and is estimated to take ‘a few years’ within the European regulatory regime, where expertise in fuel fabrication technology already exists. It can be delayed by concerns on the part of operators and regulators who are accustomed to, and have a relationship of trust with, their existing suppliers and are apprehensive about the quality and reliability of potential new fuel providers.¹⁷ Much of their concern stems from the fact that an unexpected disruption to their lead times could lead to outage.

It must be considered that if a fuel bank is to fulfil its function as the supplier of last resort,¹⁸ then for states without domestic fuel fabrication facilities, or those without diverse options for the supply of fuel fabrication services, simply providing a reliable supply of uranium hexafluoride may not in itself be sufficient to overcome an interruption in power supplies.

However, a number of further steps can be taken to consolidate the positive progress for fuel cycle security offered by the fuel bank model. Through the expansion of multilateral or international approaches to all front-end fuel cycle activities, states could be assured that their supplies of fuel could be invulnerable to political disruption providing they had not violated existing safeguards. Alternatively, the diversification of fuel fabrication services across the various

11. European Commission, ‘Commission Staff Working Document: Nuclear Illustrative Programme Presented Under Article 40 of the Euratom Treaty for the Opinion of the European Economic and Social Committee’, COM(2016) 177 final, 4 April 2016.

12. Rosatom is the Russian state nuclear vendor and a major player in the export of nuclear reactors.

13. *Ibid.*

14. VVER-1200 reactors currently have only one fuel supplier, Russia’s TVEL.

15. Will Dalrymple, ‘Ukraine: Stuck in Civil Nuclear Cold War’, *Nuclear Engineering International*, 26 March 2014.

16. Mark Dye, Jan Höglund and Ulf Benjaminsson, ‘Diversification of the VVER Fuel Market’, *Nuclear Engineering International*, 30 September 2015.

17. Graham Stack, ‘Use of Controversial Nuclear Fuel Triggers Safety, Supply Concerns’, *Kyiv Post*, 29 April 2010.

18. IAEA LEU Bank, <<https://www.iaea.org/ourwork/leubank>>, accessed 17 August 2016.

reactor types could contribute to the same end; if higher demand existed for Western-supplied fuel for Eastern-designed reactors and vice versa, then this model of supply security would be enhanced. Finally, when states consider potential vendors for reactor supply, they should also consider (in cases where the potential for disruption exists) the options for diversification of fuel supply. Internationally owned fuel banks represent a positive step towards achieving increased supply security of LEU for states concerned by the prospect of political manipulation. By reducing the political insecurities associated with reliance on foreign fuel supplies for nuclear power, the LEU fuel bank goes some way to re-establishing and recognising states' rights to peaceful nuclear energy. However, many challenges still remain. True supply security, in the absence of indigenous capabilities, can be realised only through the further multilateralisation of the front-end nuclear fuel cycle.

VIII. Nuclear Arms Control: Optimising Verification Processes Through Formal Modelling

Paul Beaumont¹

Arms control agreements are important tools that help nations to manage their security relationships with each other, particularly by reducing the risk of arms races, and which in some cases seek to eliminate particularly destructive classes of weaponry entirely.

One role of the Atomic Weapons Establishment (AWE) is to provide decision-making support to the UK government on any potential nuclear arms treaty the UK may enter into. An arms control agreement would inevitably involve some level of verification mechanism or regime to ensure compliance with the treaty (for example, inspections, deployment of monitoring equipment, etc.). Although verification in a treaty is not mandatory, without any form of verification there would be no deterrent to any state that wished to ‘cheat’ the treaty. The design and implementation of verification processes are complicated, intrusive and expensive, however, which imposes limits on the scale of that deterrent. This tension has led to the development of tools that would model, analyse and optimise verification processes in this domain.

Arms control verification processes do not in practice allow for the parties involved to gather complete information about each other. Instead, each must make decisions about whether or not other parties are complying with their obligations on the basis of limited information. States will often, and in some circumstances must – in order to be compliant with the nuclear Non-Proliferation Treaty (NPT) – withhold some information. They must also make decisions during negotiations about the verification regime to be used, and how and when to use the tools at their disposal for the implementation of that regime. The need to make decisions under circumstances of uncertainty is therefore a core element of the arms control verification problem. The AWE’s approach to providing decision-making support in the face of this uncertainty is to use mathematical models to capture their degree of belief in events or propositions, and their confidence in such beliefs. Our work extends and combines the mathematical modelling concepts and verification approaches the AWE wishes to use, such that they can cope with the inherent lack of available data in this domain, and potentially be used to support policy-makers in practice.

1. This paper was based on research conducted with Michael Huth, Imperial College London, and N Evans and T Plant, Atomic Weapons Establishment.

In particular, we explore representative, quantitative models of an arms control process in which two parties engage in mutual nuclear arms reduction and verification activities. The models on which the project focuses mirror those used in the UK–Norway Initiative’s² experimental setup, and involve use of a radiation detector to determine the radioactive make-up of an item under inspection. The detector itself has its output masked behind an ‘information barrier’ (to prevent the release of sensitive information about the exact composition of the material), and returns only a binary result indicating whether a particular isotopic threshold for a material of interest is met or not. The tolerances and settings for the detector that lead the information barrier to produce these results are pre-agreed by states party to the treaty. When considering the results, weapons inspectors must assess whether they believe the machine could have been tampered with; whether the item under scrutiny contains weapons-grade material, but not the technical capacity to use that material as a weapon; whether a bogus radiation source has been used; and whether or not they ‘trust’ the state whose materials they are inspecting. Exact quantification of some of these beliefs may be difficult and uncertainty in other results motivates the development of a methodology that copes with this lack of concrete data.

Our approach is to model the beliefs of each party and the various inspection control processes in a type of software known as a Satisfiability Modulo Theories (SMT) solver. This offers a general purpose approach to the automated analysis of mathematical models. We ‘assert’ the equations that make up the model in the SMT solver and deal with uncertainty in (or absence of) data by expressing variables we are uncertain about as being below the specifications of parameters. In other words, we do not have to choose particular values for parameters – such as the number of nuclear weapons that one of the parties holds – if these are not known. Instead, we define a range of possible values (such as $low < x < high$), which represent the boundaries of possibility (the minimum and maximum number of warheads), or leave the value totally unconstrained.

In doing so we are able to answer pertinent questions such as ‘given uncertainty in our treaty partner’s initial weapon stockpile, with scheduled inspections every six months and three other unscheduled inspections per year, what timing for unscheduled inspections leads to the minimum difference between our partner’s declaration and our assessment of their actual arsenal?’. The results to such a query would be returned along the lines of ‘for all x covered by the range $low < x < high$ where x represents our treaty partner’s initial weapon stockpile, assuming our model of how beliefs and weapon numbers change over time is correct, then we would be best holding inspections in months four, sixteen and eighteen, [say ...] to achieve our goals’.

Similarly, we model the inspection process itself in detail, and if we observe no tamper abnormalities on the detectors we can ask, ‘where there is uncertainty over whether a body scanner checking for other sources of radiation is working correctly or not, what effect does this have on the likelihood of a detector reporting positively that it believes nuclear material is

2. In early 2007, representatives from the UK Ministry of Defence, the UK Atomic Weapons Establishment, several Norwegian laboratories and the non-governmental organisation VERTIC (Verification Research, Training and Information Centre) began work on the technical verification of nuclear arms control, <<https://www.gov.uk/government/publications/uk-norway-initiative-on-nuclear-warhead-dismantlement-verification--2>>, accessed 15 August 2016.

present?'. We can then test our model against this uncertainty, report back the range of results, and compute how sensitive to change the results are.

These new modelling and analysis methods allow for a much more sophisticated approach to modelling arms control: we have harnessed a supercomputer to analyse more than 134 million possible inspection timelines, allowing the software to compute an inspection schedule over a treaty lifespan of more than two years for which performance against one or more measures of interest is optimised. The models and results can then be studied and their expected outcomes assessed to assist in decision-making regarding proposed arms control regimes.

IX. Reducing the Lifetime of Nuclear Waste: How Long-lived is Too Long?

Matthew Gill¹

One of the great debates surrounding nuclear energy is how we should manage and deal with the waste generated. Nuclear waste is hazardous for hundreds of thousands of years. As a result, nuclear waste disposal poses technical and social challenges for generations to come. One solution may be to employ transmutation techniques. This project modelled possible transmutation fuel cycles, in a UK context, to determine if the lifetime of waste can be reduced to a more acceptable level, and thus overcome one of the greatest hurdles of nuclear energy.

Background

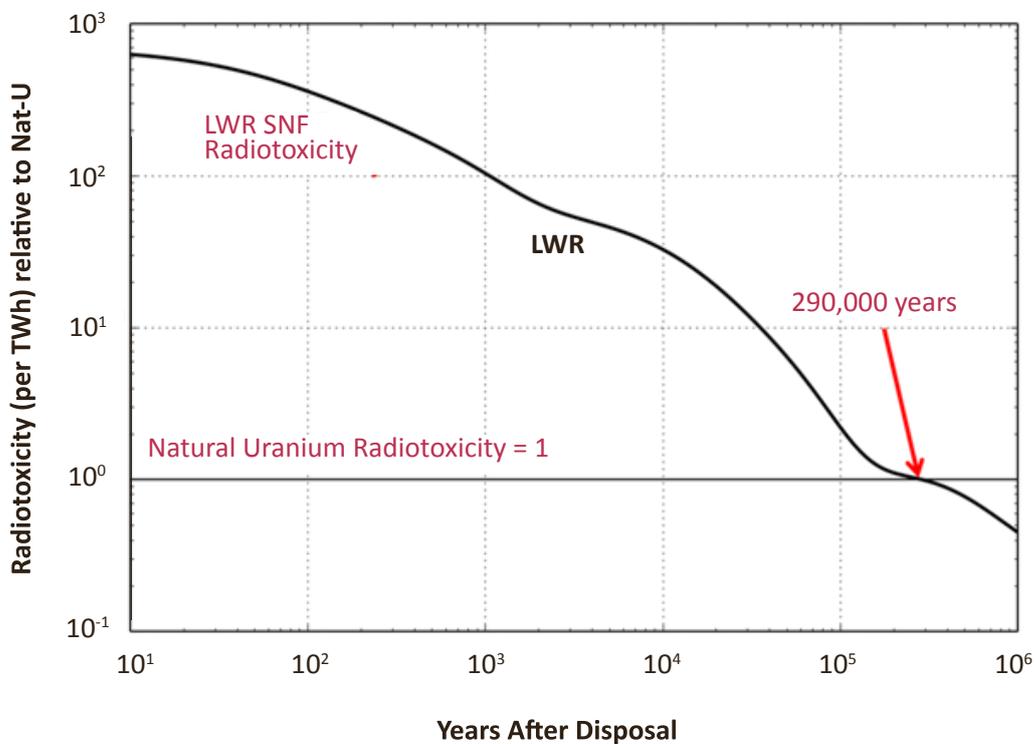
Products from spent nuclear fuel (SNF), or nuclear waste, must be safely disposed of for several hundred thousand years. Otherwise, the escape of these products into the biosphere could result in high ingested doses for the surrounding population. The potential harm of ingesting this material is described as the radiotoxicity of spent nuclear fuel. Figure 6 (below) illustrates how the radiotoxicity of SNF decays over time; it takes approximately 290,000 years for the radiotoxicity of spent fuel to decay to the same level as natural uranium. Natural uranium is described as possessing a safe level of radiotoxicity, as waste would present the same hazard as the initial raw material.²

Currently, the UK plans to dispose of its nuclear waste in a geological repository. Internationally, this is the most common solution for waste disposal, with the US, Finland and Sweden progressing the furthest with the development of geological disposal facilities. One concern with this approach is that isolating waste from the biosphere for 290,000 years is a longer timescale than any other engineering project. Under normal repository conditions, this is feasible,³ but

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1. This paper was based on research conducted with Tim Abram and Robbie Gregg.
 2. International Atomic Energy Agency, 'Fissile Material Management Strategies for Sustainable Nuclear Energy,' Tech. Rep. 1288, 2005. <http://www-pub.iaea.org/MTCD/publications/PDF/P1288_web.pdf>, accessed 11 November 2016; L H Baetslé, 'A Comparative Systems-Analysis Approach on Fuel Cycles with Partitioning and Transmutation', in 4th Information Exchange on P&T, 1996. <<https://www.oecd-nea.org/pt/docs/iem/mito96/session-1/BaetsleS1.pdf>>, accessed 11 November 2016; Werner von Lensa, Rahim Nabbi and Matthias Roszbach (eds), *RED-IMPACT. Impact of Partitioning, Transmutation and Waste Reduction Technologies on the Final Nuclear Waste Disposal*, (Tech. Rep. 24083), 2008.
 3. Baetslé, 'A Comparative Systems-Analysis Approach on Fuel Cycles with Partitioning and Transmutation'.

over long timescales uncertainty increases. A repository could become compromised, either by a natural occurrence (earthquake, ice age) or human intrusion (intentionally or accidentally),⁴ with the potential for releases to the biosphere. The lifetime of waste is a difficult problem scientifically and in terms of public perception. Eurobarometer polls have shown that waste, and its lifetime, is one of the main public concerns surrounding the acceptability of nuclear power.⁵

Figure 6: Radiotoxicity of Conventional Light Water Reactor (LWR) SNF over Time, Shown Relative to the Radiotoxicity of Natural Uranium that Would be Used to Fuel it.



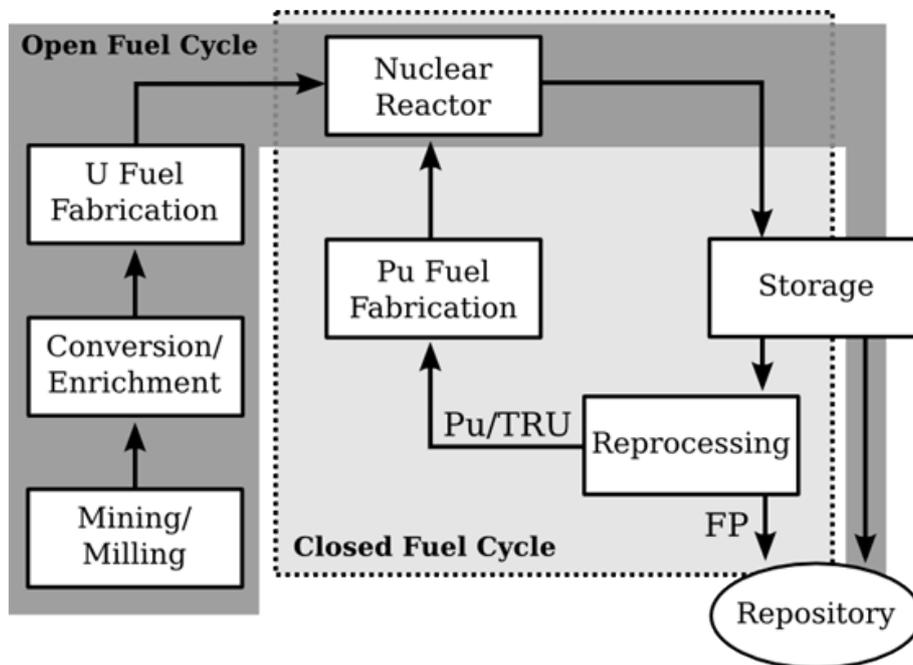
One response is to develop fuel cycle technology that can shorten the lifetime of nuclear waste to 1,000 years. Over 1,000 years it is less likely that human intrusion or natural occurrences will take place.

Transmutation is a method of reducing the lifetime of nuclear waste. Transmutation fuel cycles separate the long-lived components of nuclear waste (transuranics or TRUs) from the short-lived components (fission products), continuously recycling the long-lived components in a closed fuel cycle through a fast reactor (see Figure 7). Unlike current reactor technology, fast

4. von Lensa, Nabbi and Roszbach, 'RED-IMPACT. Impact of Partitioning, Transmutation and Waste Reduction Technologies on the Final Nuclear Waste Disposal'.
5. OECD Nuclear Energy Agency, 'Public Attitudes to Nuclear Power', (Nuclear Development, No. 6859), 2010.

reactors can transmute, or burn, TRUs, gradually reducing the stockpile of long-lived waste. This concept has been modelled extensively but not demonstrated in practice.

Figure 7: Flow Diagram Representing Conventional Open Fuel Cycle and Closed Fuel Cycle, Showing How TRUs are Recycled in a Closed Transmutation Fuel Cycle.



This paper aims to answer three questions:

1. Is it feasible to reduce the lifetime of waste to 1,000 years?
2. If not, is it feasible to reduce the lifetime of waste to 10,000 years?⁶
3. How many years of fuel cycle operation would be required to achieve a substantial reduction in the UK's nuclear waste lifetime?

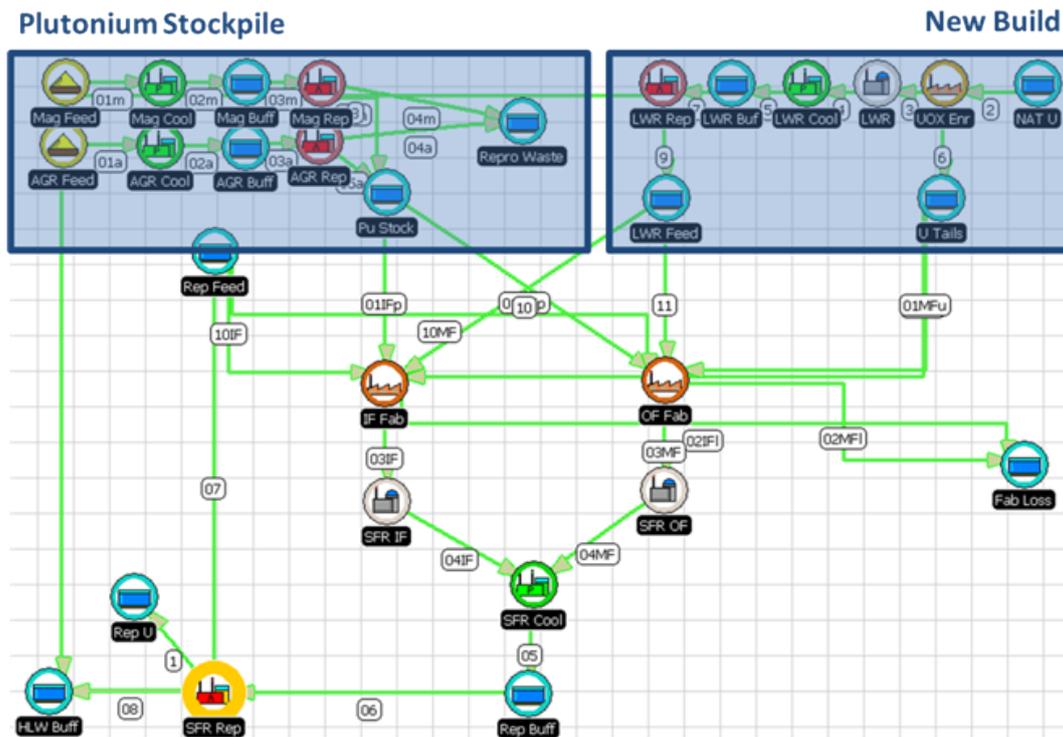
This paper considers only the lifetime of nuclear waste. Transmutation fuel cycles have other benefits which are outside of the scope of this paper, but are discussed fully elsewhere.⁷ These include:

1. Reducing repository size.
2. Producing electricity from waste.
3. Using uranium resources sustainably.
4. Maintaining skills and knowledge in advanced reactor technologies.

6. 10,000 years is not ideal, but as it is an order of magnitude reduction in waste lifetime it is considered to be a significant reduction.

7. Matthew Gill, 'The Potential Impact of Fast Reactors and Fuel Recycling Schemes on the UK's Nuclear Waste Inventory', PhD Thesis, University of Manchester, 2016.

Figure 8: Transmutation Fuel Cycle, as Modelled Using the National Nuclear Laboratory's Fuel Cycle Analysis Code Orion



Source: R Gregg, 'ORION User Guide', (National Nuclear Laboratory Commercial, no. 4), 2014.

Fast Reactor Design

1GWth sodium-cooled fast reactors (SFRs) were modelled and optimised for transmutation. SFRs were selected over alternative fast reactor technology as there has been more experience building and operating SFRs, both internationally and in the UK. This gives SFRs a higher technology readiness level (TRL) than alternative fast reactors, where TRL is a measure of deployability.

Figure 8 shows the fuel cycle model utilised in this study. Two inputs were considered: the UK's plutonium stockpile and spent fuel from 16GWe of new build reactors.

Fuel Cycle Parameters

Two transmutation fuel cycles were modelled, using the National Nuclear Laboratory's fuel cycle analysis code Orion. These two fuel cycles are summarised as a high TRL fuel cycle and a more advanced, lower TRL fuel cycle, shown in Table 1. Each parameter in the lower TRL fuel

cycle was selected to improve performance in terms of reducing waste lifetime. However, each technology area in the lower TRL fuel cycle (metallic fuel, recycling all TRUs, short cooling times) requires considerable development before it will be commercially deployable.

In addition, two timescales were considered for each fuel cycle:

- 150 years of SFR operation.
- Approximately 500 years of SFR operation, until the fuel inventory was reduced to the point where no additional reactors could be operated.

Over both timescales, as many SFRs are operated as is feasibly possible, limited only by the quantity of stockpiled TRUs.

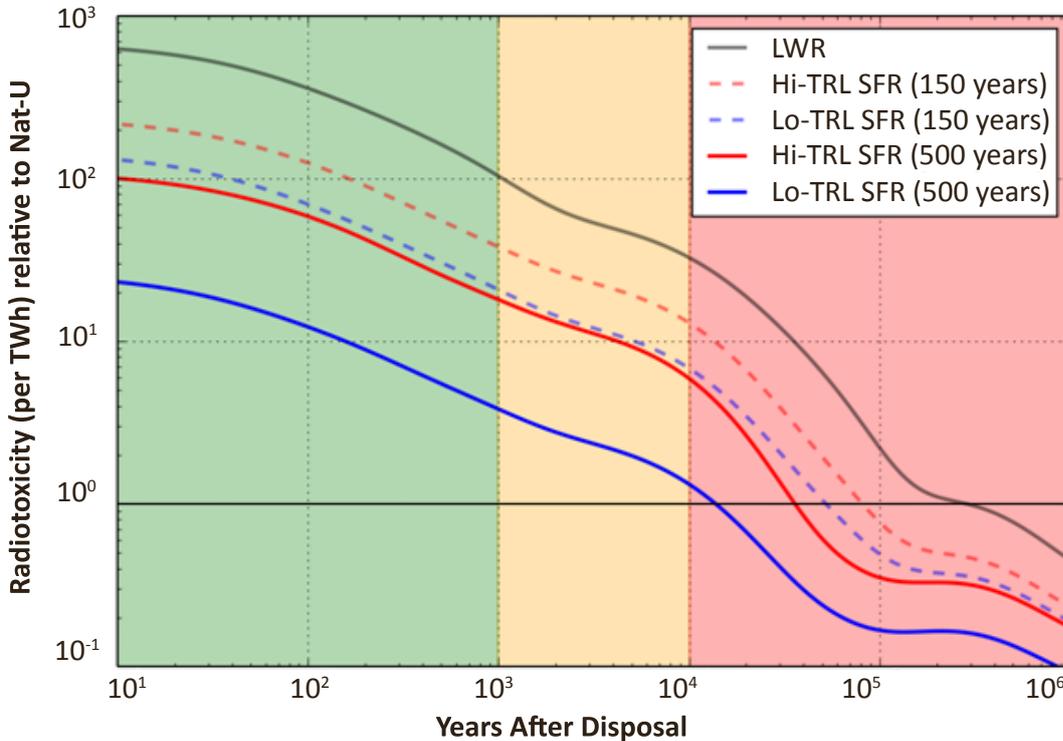
Table 1: Overview of the Two Transmutation Fuel Cycles Modelled

	Fuel	Long-lived TRUs Recycled	SNF Cooling Before Reprocessing
Low TRL	Metallic	Np, Pu, Am, Cm	One Year
High TRL	MOX	Pu, Am	Ten Years

Waste Lifetime at the End of the Fuel Cycle

As reported previously, the project modelled transmutation fuel cycles, with the purpose of seeing whether the lifetime of nuclear waste could be reduced.

Based on this modelling, Figure 9 shows the radiotoxicity of the final waste inventories for each scenario and how they vary over time. The lifetime of radiotoxicity for each scenario is summarised in Table 2. With 150 years of fuel cycle operations, both high and low TRL fuel cycles result in waste lifetimes greater than 10,000 years. As such, 150 years of transmutation fuel cycle operation is not long enough to get the required reduction in waste lifetime. With 500 years of fuel cycle operations, there is a more significant decrease in waste lifetime. However, waste lifetimes are still in excess of 10,000 years, which is an order of magnitude greater than the 1,000-year target.

Figure 9: Radiotoxicity of Final Waste Inventories Over Time, Relative to Natural Uranium

* Under 1,000 years is colour-coded green as this would be a successful result, 1,000–10,000 years is amber as this would be an acceptable improvement, and greater than 10,000 years is red, which is not acceptable.

Table 2: Lifetime* of Final Waste Inventories for Each Transmutation Fuel Cycle and SNF from Current Reactor Technology

	Years of Fuel Cycle operation	
	150 Years	500 Years
Low TRL	52,000 years	14,000 years
High TRL	81,000 years	36,000 years
LWR SNF	290,000 years	

* Lifetime is described as the time it takes for SNF to decay to the same level as natural uranium.

As the results of this study show, it is not feasible to reduce waste lifetime to 1,000 years. It would take more than 500 years of fuel cycle operation, continuously recycling TRUs, to reduce

waste lifetimes to this level.⁸ This poses three key questions for future work in this area which are outlined below.

How Long-lived is Too Long?

The best-case scenario resulted in a waste lifetime of 14,000 years. This may be too long to be widely considered as a significant improvement in waste lifetime.

How Long a Fuel Cycle is Too Long?

One hundred and fifty years of fuel cycle operations, continuously recycling TRUs, does not result in a significant improvement in waste lifetime, and imagining the implementation of 500 years of fuel cycle operations seems unreasonable given that a commitment to this energy policy would need to be honoured for hundreds of years.

How Would This Affect Public Opinion?

Results show that it is not possible to achieve a short waste lifetime in a short timescale, even when as many fast reactors are operated as feasibly possible. As such, feasible operating timescales may not reduce waste lifetimes to a level that would be acceptable to the public.

Conclusions

None of the fuel cycle scenarios modelled was able to reduce the lifetime of UK waste to the 1,000 year target.

For a transmutation fuel cycle to reduce the lifetime of UK waste to less than 1,000 years would take more than 500 years of fuel cycle operations, continuously recycling TRUs and operating as many fast reactors as feasibly possible. Achieving a significant reduction in waste lifetime within 150 years is not feasible.

Transmutation is not a quick fix for issues surrounding the lifetime of nuclear waste. While waste lifetime can be reduced, it cannot be lessened to levels where a compromised repository scenario is no longer a concern.

There are other benefits to transmutation fuel cycles, which are out of the scope of this paper, but discussed in the complete work.

8. This would only be feasible by reducing the size of the reactors as the inventory of material in the fuel cycle is reduced.

X. Transparency and Outreach in Civilian Nuclear Endeavours

Katherine Bachner

It is no surprise that transparency and outreach with the public can be a critical consideration in civil nuclear activities. Civilian nuclear programmes differ greatly from most other commercial endeavours, and this attracts more scrutiny from stakeholders. Whether the nuclear endeavour is a power plant, research reactor, waste storage plan or other peaceful application, the public is often interested in its planning. This paper examines the impact of public transparency in the implementation of civilian nuclear endeavours, focusing specifically on exploratory nuclear waste digging that took place in rural France several decades ago. This paper seeks better to understand the impact of being transparent with, and involving the public through, outreach and education, in the discussion and decision-making that surrounds nuclear installation planning and implementation. The central question is: does transparency surrounding public discourse on civilian nuclear initiatives lead to greater acceptance of their development?

In France, the public generally accepts large-scale technological infrastructure projects, including nuclear power programmes. However, there has been a backlash against nuclear waste siting. The objections were overcome by assessing and understanding the concerns of the local residents, and by explaining better the reasons behind the plans.

France has a tradition of a public supportive of civilian nuclear power projects, and the country currently derives approximately 75% of its electricity from nuclear energy.¹ France launched its civilian nuclear energy programme in a bid for energy independence and security after OPEC hiked the price of oil in the 1970s, commonly referred to as the oil shock. The sudden, unpleasant realisation that energy security meant (for France) energy independence, reinvigorated in 1973 the civilian nuclear programme that was already underway. French policymakers saw nuclear energy as the only answer to the question of energy security. Between 1977 and 1999, the French authorities oversaw the installation of 59 nuclear power plants (NPP), beginning with Fessenheim in 1978 and ending with Civaux-2 in 2002.² This allowed France to not only satisfy its own domestic electricity needs, but also to export electricity throughout Europe.³

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1. World Nuclear Power Association, Nuclear Power in France, <<http://www.world-nuclear.org/information-library/country-profiles/countries-a-f/france.aspx>>, accessed 14 October 2016.
 2. Euronews.com, 'Spotlight on France's Oldest Nuclear Power Plant', 25 March 2011, <<http://www.euronews.com/2011/03/25/spotlight-on-france-s-oldest-nuclear-plant>>, accessed 22 November 2016.
 3. Jon Palfreman, 'Why the French Like Nuclear Energy', *PBS Frontline*, June 2011.

As France continued on the civilian nuclear journey in the 1970s, the country experienced a remarkably smooth transition into nuclear-generated electricity and the installation of tens of nuclear power reactors – with some notable exceptions, including violent protests.⁴

Acceptance, or pride, in large technical projects is a key factor for this smooth transition. France, according to various researchers, has a history of large, centrally managed technical projects, which are generally held in high regard by the French populace. According to Claude Mandil, the former director general for Energy and Raw Materials at the Ministry of Industry,⁵ ‘French people like large projects. They like nuclear for the same reasons they like high speed trains and supersonic jets’.⁶ Science has a long history of support by the French establishment. This is illustrated by the foundation of the *Académie des sciences*, established by Louis XIV in 1666, to encourage the spirit of scientific research. An ingrained cultural appreciation of scientific pursuits certainly fostered a positive public perception of nuclear power. Another factor influencing public opinion positively is a general tendency, when compared with the US, to trust technocrats. A PBS *Frontline* interview in the 1990s found that in the Civaux region of southwestern France, attitudes towards technocrats and scientists in charge of nuclear power installations included such sentiments, as the [Russians] were not up to the task, ‘[B]ut the French scientists and engineers are’.⁷ Polls indicate that the French remain largely supportive of nuclear power. Some of this support may also be attributable to a highly effective advertising campaign undertaken in the 1970s and 1980s. Advertisements on television linked nuclear power with the electricity needed to make modern life possible.⁸ A related factor that reflects some level of commitment to nuclear transparency, was the offer in the 1990s by nuclear plants to take citizens on tours, an offer many people took up.

The discussion above indicates that much of the acceptability of nuclear power in France was derived from a cultural preponderance to accept technology and technocrats, and a pragmatic understanding of the link between modern inventions and a modern standard of living. The important exception referred to earlier – the break in the successful public acceptance campaign undertaken by the French authorities – came with the advent of a need for nuclear waste storage (an essential consideration for any civilian nuclear programme).

According to researchers, the French authorities in the early years of the civilian programme did not give much thought to any potential public concern over the problem of waste. The extremely small quantity of waste produced per a family of four (about the size of a cigarette lighter after 20 years of energy consumption) may have contributed to the fact that the technocrats

4. Dorothy Nelkin and Michael Pollak, *The Atom Besieged: Antinuclear Movements in France and Germany* (Cambridge, MA: MIT Press, 1982).

5. His tenure at that post was from 1990–1998.

6. Palfreman, ‘Why the French Like Nuclear Energy’.

7. *Ibid.*

8. Jean-Pierre Chaussade and Philippe Ansel, ‘Impact of French Advertising Campaign,’ *Pime 93*, January, 1993. <www.iaea.org/inis/collection/NCLCollectionStore/_public/36/018/36018041.pdf>, accessed 11 November 2016.

did not really consider this as a potential public relations nightmare. Therefore, in the 1980s, exploratory holes were dug in some rural regions of France.⁹

The general population was not pleased by this decision, with riots and protests erupting. The very regions that had proudly sought to have nuclear power plants located within their boundaries were those that fought against becoming sites for waste depositories. In this case, the public sentiment was arguably not a result of a lack of transparency, but rather, a lack of any perceived benefit for those communities.¹⁰ Another important distinction that likely led to hostility towards nuclear waste depositing in the rural regions was the perception that this waste disposal would be permanent. People felt that the authorities were dumping garbage under the homes of the people in rural regions, and then abandoning them.¹¹ While the cheapest solution to the problem was to bury the waste materials under the earth's surface, Socialist Party National Assembly member Christian Bataille noted, 'the idea of burying the waste awoke the most profound human myths. In France we bury the dead, we don't bury nuclear waste ... there was an idea of profanation of the soil, desecration of the Earth.'¹² The concept of ruining the earth for future generations played a large role in public concerns.¹³

Officials took into account the negative cultural response to 'permanent' waste disposal, and introduced the much more palatable notion of reversibility and 'stocking'. The difference between permanent storage and stocking may seem like semantics to some, but to those in the affected regions, the temporary stocking of nuclear waste in a way that would allow it to be accessible to future scientists and engineers made all the difference. Although the technical experts complained about the added expense of a nuclear stocking room (as opposed to a nuclear graveyard), in the end it proved to be much more than a semantic difference. It could also be argued that it allowed France to continue its highly profitable, useful and accepted civilian nuclear programme despite the hurdle of opposition to nuclear waste siting. While the first response to exploratory digs was rioting and protests, the change from permanent disposition to the reversible stocking policy prompted regions to apply to host underground laboratories that could deal with nuclear waste in the future.

A combination of cultural predisposition towards civilian (and military) nuclear endeavours, combined with canny politicians and technocrats whose fingers seem to have been sufficiently on the French cultural pulse regarding the waste issue helped to avert what could have been disastrous, insurmountable challenges to the French civilian nuclear programme.

9. *Nuclear Monitor*, 'The History of the French Waste Policy,' Issue 550, 15 June 2001, <<https://wiseinternational.org/nuclear-monitor/550/history-french-waste-policy>>, accessed 11 November 2016.

10. Palfreman, 'Why the French Like Nuclear Energy'.

11. Robert Jan van den Berg and Herman Damveld, 'A Survey on Public Participation, Decision-making, and Discussions in Eight Countries', *CORA*, January, 2000.

12. Palfreman, 'Why the French Like Nuclear Energy'.

13. Fabienne Pehuet Lucet, Comments made at the Brussels EU Consortium on Nonproliferation and Disarmament, November 2015.

Conclusion

Transparency and outreach have yielded results in the world of civilian nuclear power, and can improve the smoothness and success of a civil nuclear undertaking.

A further conclusion is that, in addition to transparency, information sharing and stakeholder engagement, general cultural norms and attitudes should be analysed, fully understood and taken into account as part of the stakeholder engagement and nuclear transparency process. If these crucial steps are taken at the beginning of the process, the technical hurdles that may arise later will be much easier to focus on and solve, knowing that the community stands behind the project and that the engineers implementing it are taking the opinion of local communities seriously. Success hinges on knowing one's audience, knowing what matters to him or her and appealing to that set of sensibilities with transparency and integrity.

XI. South Korea's Nuclear Policy and the Controversy Over the Claims for Nuclear Sovereignty

Zie Eun Yang

South Korea's nuclear policy has revolved around the strategic visions of disarmament, non-proliferation and a peaceful use of nuclear energy. These have long been the major objectives of its nuclear policy, which aims to curb North Korea's nuclear ambitions while enhancing South Korea's economic and military capability. Nuclear safety and security, both relatively new goals of South Korea's nuclear policy, began receiving significant attention in the aftermath of the Fukushima accident of March 2011 and a growing threat of nuclear terrorism, as clearly addressed in a series of nuclear security summits.¹

South Korea launched its nuclear energy programme in 1959, and started the operation of its first nuclear power plant in 1978. Thanks to the transfer of nuclear technology during the mid-1980s by the US and France, South Korea could achieve technical self-reliance in the 1990s, and finally emerged as an advanced nuclear state and nuclear exporter in the 2000s.² For most of its history of nuclear energy, South Korea has committed itself to global non-proliferation efforts by actively participating in multiple international regimes and focusing on a peaceful civilian use of nuclear energy.³ However, South Korea's suspected nuclear activities in the 1970s and the 2000s and its greatly volatile security situation still provide the basis for evaluating Seoul's non-proliferation credibility.

In the 1970s, under the military dictatorship of then President Park Chung-hee, South Korea sought to develop an indigenous nuclear weapons programme in response to US plans to withdraw its forces from South Korea.⁴ This was amid rising fears of further North Korean military provocations, with South Korea still lagging behind the North both economically and militarily. Under strong US pressure, however, South Korea's nuclear weapons programme was suspended in 1976.⁵ In 2004, the South Korean government voluntarily reported to the International

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1. Foreign Minister Yun Byung-se, keynote speech given at a symposium concerning the 2014 Hague Nuclear Security Summit in Seoul, 12 March 2014.
 2. Mark Holt, 'US and South Korean Cooperation in the World Nuclear Energy Market: Major Policy Considerations', *CRS Report*, 21 January 2010.
 3. NTI, 'Countries: South Korea', <<http://www.nti.org/learn/countries/south-korea/>>, accessed 15 May 2016.
 4. Byung-Kook Kim and Ezra F Vogel (eds), *The Park Jung Hee Era: The Transformation of South Korea* (Cambridge, MA and London: Harvard University Press, April 2011).
 5. Although there is some controversy over when South Korea abandoned its nuclear weapons programme, it is commonly known that Park promised the US to terminate it in 1976. Meanwhile,

Atomic Energy Agency (IAEA) that some of its scientists conducted unreported small laboratory-scale enrichment and reprocessing experiments, in 1982 and 2000 respectively. The scientists extracted 0.086g of plutonium and enriched 0.2g of uranium in their laboratory, claiming that those experiments were purely for research purposes.⁶ This led to a comprehensive IAEA investigation into the experiments, yet it also sparked a domestic debate in South Korea about whether excessive restrictions had been imposed on South Korea's nuclear research and development activities. This debate was reignited when the negotiations for revising the Korea–US nuclear cooperation agreement were embarked upon in recent years.⁷

Rise of Nuclear Sovereignty Claims

In an effort to enhance its non-proliferation credibility, South Korea has made a series of declarations (such as the 1992 Joint Declaration on Denuclearization of the Korean Peninsula and the 2004 Four Principles on the Peaceful Use of Nuclear Energy). Through these, Seoul declared that it would not pursue a nuclear weapons programme. It has also actively participated in global non-proliferation regimes. In this sense, South Korea's recent claims for 'nuclear sovereignty' are viewed by both foreign and domestic observers as an expression of deep frustration and disappointment with its international status. Seoul is also unhappy with tight restrictions on its nuclear activities and its strong sense of insecurity is due to a hostile North Korea and other larger powers, most of which are nuclear weapons states.⁸

Claims over nuclear sovereignty have taken many different forms, one of which is supportive of an indigenous nuclear capability, which seems the least feasible for South Korea because its massive political and economic costs greatly outnumber potential benefits. Also, some supporters call for the reintroduction of non-strategic nuclear weapons to the Korean Peninsula. This does not seem feasible either, due to the robust US stance against this, negative implications for South Korea's relations with its neighbours and the inconsistency with Seoul's previous declarations on non-proliferation. There are still others who assert that South Korea should acquire enrichment and reprocessing capabilities to enhance its industrial competitiveness and international status as an advanced nuclear state.⁹ From a realistic perspective, however, all these claims seem to be hardly acceptable considering South Korea's unique security environment and strengthened US non-proliferation efforts.¹⁰

it has long been argued that South Korea's nuclear weapons programme in the 1970s was intended to pressure the US to retract its plan to withdraw from South Korea.

6. Sang hyun Lee, 'South Korea's Nuclear NonProliferation Policy: Focusing on ROK-US Nuclear Cooperation', *Sejong Policy Studies* (Vol. 6, No. 1, 2010), pp. 73–112.
7. In June 2015, South Korea and the US agreed on a revised nuclear cooperation agreement as their previous 1974 Korea-US Atomic Energy Agreement had expired in March 2014. Despite South Korea's strong desire to include permission from the US to conduct enrichment and recycling of nuclear materials, strict US constraints on sensitive nuclear technologies were not lifted or relaxed in the revised agreement.
8. World Nuclear Association, Nuclear Power in South Korea, <<http://www.world-nuclear.org/information-library/country-profiles/countries-o-s/south-korea.aspx>>, accessed 12 May 2016.
9. Bong-Geun Jun, 'Overcoming Narrow (Nuclear) Sovereignty Claims (translated into English)', *Asia Economy Daily*, 13 January 2015.
10. Despite South Korea's desire to win US permission to access sensitive nuclear technologies for its commercial interests and energy security, it is highly unlikely that the US would approve such a

Divergent Public Attitudes and Expert Analyses

In South Korea, there are divergent public attitudes towards claims for nuclear sovereignty. Until recently, nuclear sovereignty claims had been largely ignored as they were thought to be the wish of a very limited number of conservative politicians and commentators. Yet North Korea's ongoing nuclear provocations, and an increasing public awareness of the negotiations for the recently revised nuclear cooperation agreement with the US, have led to active public debates over nuclear issues. Supporters of nuclear sovereignty stress the need for marginal self-defence to protect the country from North Korean threats amid failed international efforts to curb Pyongyang's nuclear ambitions and increasing doubts about the credibility of US extended nuclear deterrence.¹¹ On the other hand, the opponents of nuclear sovereignty insist that these claims will greatly undermine South Korea's non-proliferation credentials and impose massive political and economic costs on the country.¹²

With regard to these debates, some foreign experts believe the desire for nuclear sovereignty among some South Koreans stems from fears over their perceived security situation and South Korea's international status. Toby Dalton views nuclear sovereignty claims as a reflection of South Korean frustration over what is perceived as an unfair and unbalanced relationship with the US. Mark Fitzpatrick similarly argues that the claims are fuelled by South Korean nationalism and its resentment over US discrimination between Japan and South Korea.¹³ But the claims for nuclear sovereignty vary according to the situation. The nuclear threats and military provocations from Pyongyang serve as major incentives for the claims, while the challenges to the credibility of US nuclear deterrence, with its smaller engagement in East Asia, even increase South Koreans' sense of insecurity and vulnerability. What constrains South Korean claims for nuclear sovereignty most should be their compliance with international non-proliferation norms and regulations, and commitments to the alliance and nuclear cooperation agreement with the US. More importantly, however, as a highly globalised state greatly dependent on international trade, going nuclear is not a viable option for South Korea.

Implications

South Korea's nuclear sovereignty claims could have considerable implications for its nuclear policy as well as future nuclear cooperation with the US. Claims for nuclear sovereignty and the pursuit of national interests can be either compatible or conflicting, depending on the situation. If South Korea's security situations were to become extremely unstable and/or the public perceives it is facing discrimination, such debates could be reignited.

request for fear of establishing a bad precedent for its non-proliferation efforts.

11. Mark Fitzpatrick, *Asia's Latent Nuclear Powers: Japan, South Korea, and Taiwan* (London: Routledge, 2016), pp. 58–63. Some advocates of nuclear sovereignty argue that the restrictive provisions of the Korea–US nuclear cooperation agreement pose a major obstacle for enhancing the competitiveness of Korea's nuclear industry.
12. Philip Iglauer, 'Nuclear Weapons for South Korea', *The Diplomat*, 14 August 2014.
13. Toby Dalton and Alexandra Francis, 'South Korea's Search for Nuclear Sovereignty', *Asia Policy* (No. 19, January 2015), pp. 115–136; Mark Fitzpatrick, *Asia's Latent Nuclear Powers: Japan, South Korea, and Taiwan*, pp. 23–94.

In addition, nuclear sovereignty claims might have negative effects on South Korea's alliance with the US. There are several American observers who perceive the claims as a challenge to the US-led global nuclear order, and some strong advocates of non-proliferation even equate nuclear sovereignty with claims for developing nuclear weapons. Such suspicions were reflected during the negotiating process of recently revised South Korean–US nuclear cooperation, which placed Seoul's enrichment and reprocessing activities under strong restrictions. In this regard, these claims might also affect the future course of US nuclear cooperation, not only with the East Asian countries, but also globally.

About the Authors

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