IRREVERSIBLE NUCLEAR DISARMAMENT

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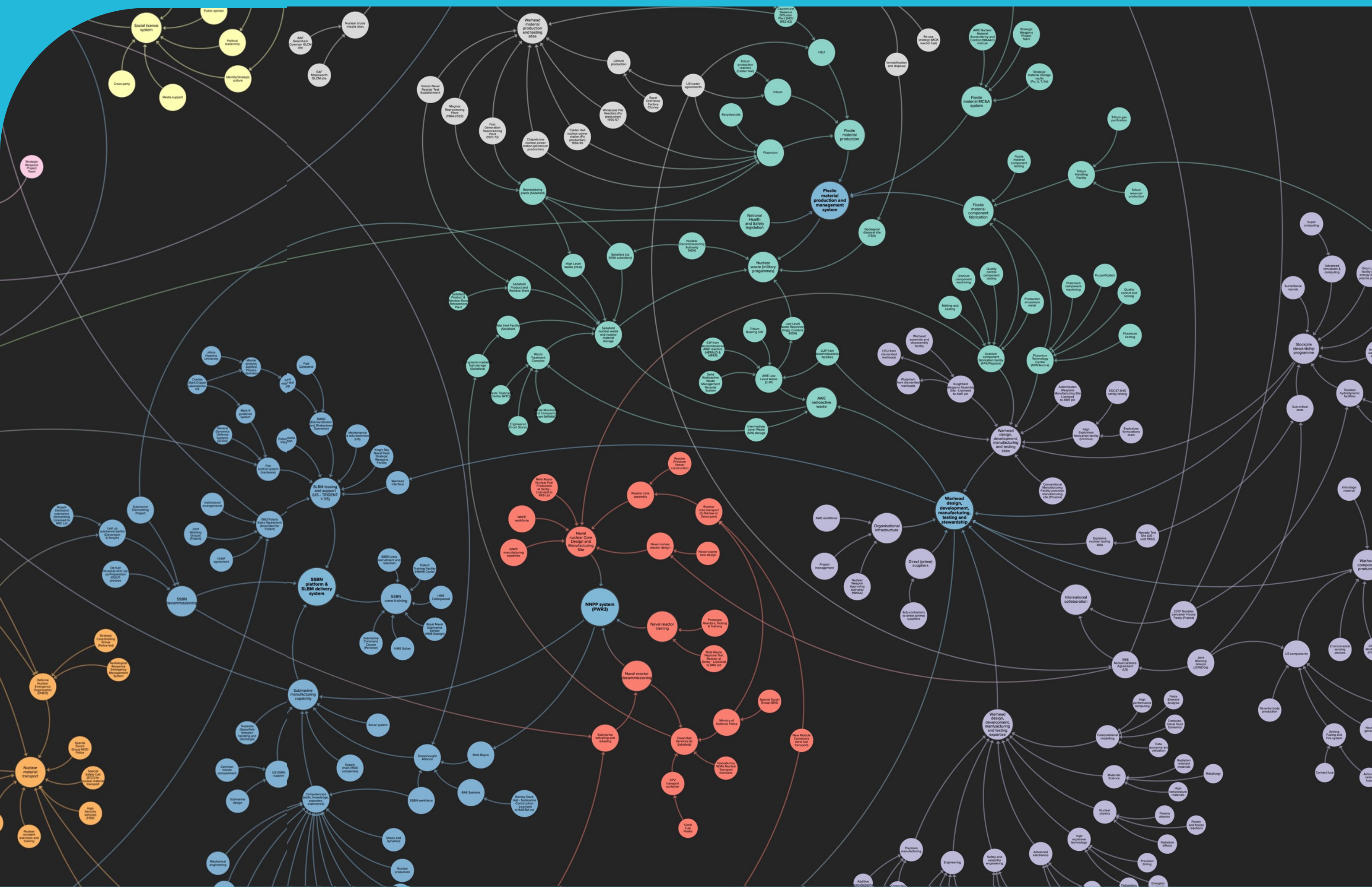
York IND Research Report#4

May 2024



MAPPING THE UK NUCLEAR WEAPONS COMPLEX AND IRREVERSIBLE NUCLEAR DISARMAMENT

York IND Working Paper#4

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MAPPING THE UK NUCLEAR WEAPONS COMPLEX AND MAXIMISING THE IRREVERSIBILITY OF A NUCLEAR DISARMAMENT PROCESS

In 2019 the UK and Norway began to take a serious look at what 'irreversibility' might mean in the context of nuclear disarmament following years of work on nuclear disarmament verification. This led to a multi-year project on 'irreversible nuclear disarmament' that has generated a lot of new research and ideas that have been discussed in workshops and conferences and published in reports and journal articles.

The purpose of this report is to develop a more detailed understanding of what 'irreversible nuclear disarmament' might look like when applied to a mature nuclear weapons complex, such as the United Kingdom's.[1] The UK is a particularly useful case because a substantial amount of information is available and the complex is relatively small compared to those of the United States and Russia.

This report is therefore based on a detailed mapping of the UK nuclear weapons complex, and this has done two things: 1) it has generated new insights into the concept and practice of irreversibility in relation to nuclear disarmament, and 2) it enables us to 'see' a nuclear weapons complex as a system of systems that requires a lot of work to reproduce over time such that it will become increasingly difficult to put it back together once it starts to come apart through a disarmament process.

The report has been shaped by an interactive workshop in March 2024 with current and former experts from within and without the UK nuclear weapons complex. The purpose was to identify knowledge gaps, intervention points, and insights into maximising irreversibility through three exercises: 1) unpacking what the UK 'nuclear weapons complex' entails; 2) hypothesising the processes by which it could plausibly come apart, and 3) speculating as to conditions and processes whereby a basic complex could be reconstituted, perhaps to deploy an emergency capability.

Post-its expanding and organising the main subsystems of the UK nuclear weapons complex

[1] The only example to date of national nuclear disarmament is South Africa. Its nuclear weapons complex at the time was very limited and has been studied in detail as part of this programme.

Part one: Irreversibility and nuclear disarmament

Why 'nuclear weapons complexes'?

Irreversibility in relation to nuclear disarmament is understood in a practical rather than an absolute sense, since disarmament will never be completely irreversible. Initial work on irreversibility developed the notion of a spectrum based on the time, cost and difficulty of rearmament. The basic premise here is that the deeper and wider the scope of nuclear disarmament and denuclearisation, the more significant the challenges of reversal and the further down the spectrum to 'maximum' irreversibility.

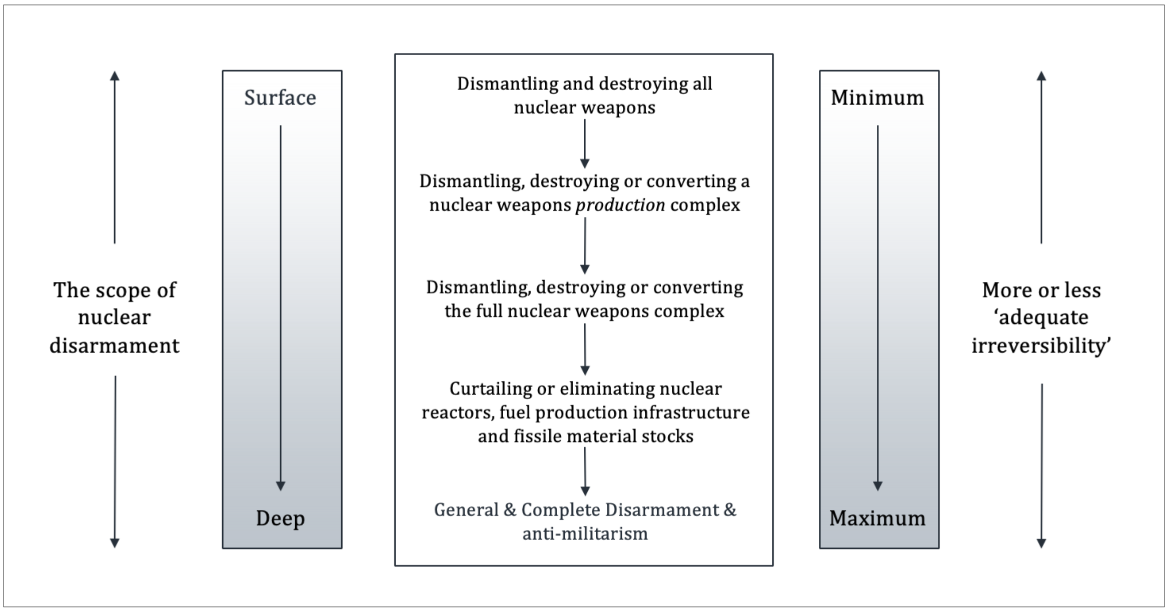

Figure 1: A spectrum of irreversibility in relation to the depth of nuclear disarmament.

A focus on *maximising* the irreversibility of a nuclear disarmament process means engaging with the structures that enable a state to produce and deploy nuclear weapons. From this standpoint, the referent of disarmament is a state's nuclear weapons *complex* rather than just nuclear weapons or fissile material.[2]

In earlier work, I suggested that a nuclear weapons complex can be usefully understood as a large socio-technical *system.* The concept of 'Large Technical Systems' (LTS) comes from Science and Technology Studies. This scholarship has studied the emergence and embedding of LTS. A small group of STS scholars has more recently started to explore the deliberate destabilisation and dismantling of such systems and the phase out or abandonment of technologies. This is a process of disrupting, or unravelling, the linkages between five sets of elements that comprise a socio-technical system:

1. Materials (objects, infrastructures, hardware, bodies)
2. Competencies (explicit and tacit knowledge, skills, training, experiences).
3. Meanings (belief systems, identities, shared understandings, discourses)

[2] This is not to suggest that an effective nuclear disarmament process must involve the complete unmaking of a nuclear weapons complex, only to note that the irreversibility of such a process would be maximised by doing so.

4. Institutions (patterns of practice, organisational forms, organisational cultures).
5. Money flows (financing, profits, taxation, investments, major expenditure)

When links are disrupted or broken between these elements *and* the elements themselves start to disintegrate and be forgotten and become unfamiliar, then re-emergence of the system, or reversing its unravelling, becomes really difficult.

A 'nuclear weapons complex' can therefore be defined as "**the set of materials, competencies, meanings, institutions and money flows that are necessary to enable a state to safely and securely design, develop, manufacture, deploy, deliver, maintain and decommission nuclear weapons"**.[3]

If we get to a point at which the ability of a state to reverse a disarmament process by reassembling even a basic nuclear weapons complex has eroded to the extent that the time, cost, difficulty and value of doing so has become a political non-starter, then we might say that disarmament has become structurally embedded.

Maximising the irreversibility of nuclear disarmament is therefore about the 'unmaking' over time of a nuclear weapons complex understood as a large socio-technical system within a society.

The 'unmaking' part is where the novelty lies. There's some, but not much, work on 'unmaking' LTS. Most systems analysis is about mapping systems and finding out what makes them hang together, or using systems analysis to produce roadmaps for addressing new problems.[4] Very little systems analysis has explored purposeful 'unmaking' of systems.

'Time' is included because it is clearly a key factor in maximising irreversibility in two senses. First, sustaining a national nuclear weapons complex over time takes effort and it won't endure by itself. It takes organisational work, knowledge, money, and political will to bring a nuclear weapons complex together and sustain it. If these dilute over time, then a nuclear weapons complex as a socio-technical system will start to fray. Second, scholarship on processes of discontinuation and phase-out shows that these processes can be more or less complete and that elements of a LTS that has come apart are unlikely to completely disappear for a long time. Instead, what is left are *remnants* of materials, competencies, meanings and institutions for some transitional period. But research suggests that the longer

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[3] This is a broader definition than that used by the UK government, which describes the 'defence nuclear enterprise' as a 'national endeavour' across four categories of people, submarines, missiles and warheads, and safety and security. Defence Nuclear Enterprise (2024). Delivering the UK's Nuclear Deterrent as a National Endeavour. CP 1058. Available at <https://assets.publishing.service.gov.uk/media/6622702b49d7b8813ba7e576/Defence_Nuclear_Enterprise_Command_Paper_v6.pdf>. The defence nuclear enterprise has been summarised by MOD as "the federation of organisations and arrangements that enables, maintains, and delivers the continuous at sea deterrent (CASD) and submarine forces". Ministry of Defence (2023). What is the Defence Nuclear Enterprise (DNE)?. *Medium*. January 4 . Available at <https://defencehq.medium.com/what-is-the-defence-nuclear-enterprise-dne-cb43246c015d>. The UK National Audit Office described the UK 'Nuclear Enterprise' as "a network of programmes, equipment and people, often referred to as the Nuclear Enterprise (the Enterprise). Its work includes designing, producing and maintaining submarines and nuclear warheads, and providing the necessary estate, people and support". National Audit Office (2018). The Defence Nuclear Enterprise: A Landscape Review. HC 1003 Session 2017-19, p.5.

[4] E.g. Delaney W. (2015). *Perspectives on Defense Systems Analysis The What, the Why, and the Who, but Mostly the How of Broad Defense Systems Analysis*. MIT Press, Cambridge MA.

the process goes on, the more that rearmament will mean *re-inventing* materials, competencies, meanings and institutions, rather than just *re-activating* them.

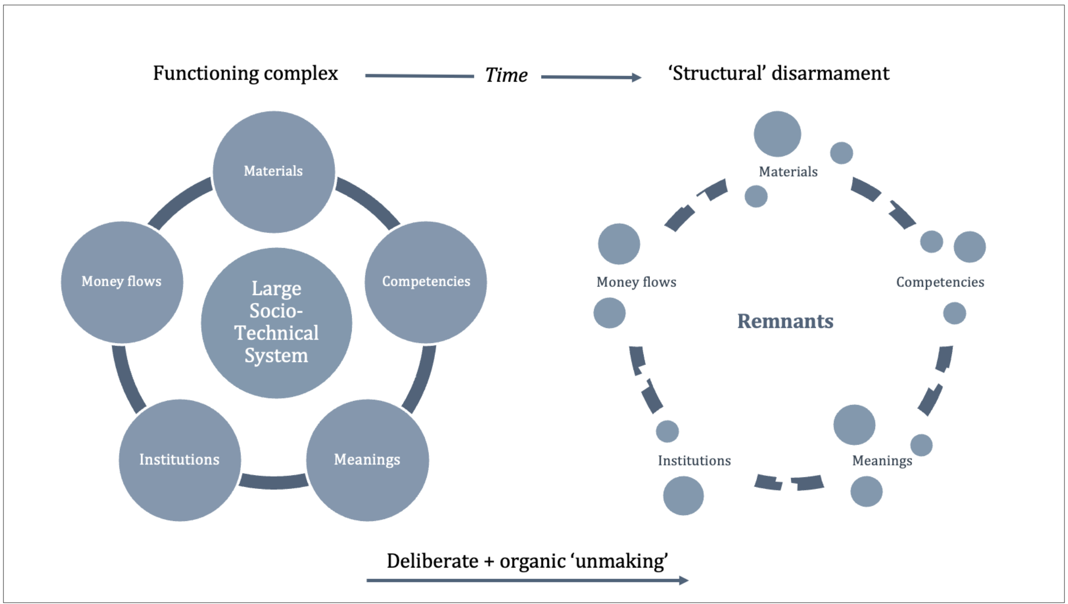


Figure 2: Unmaking a large socio-technical system

The most important remnants of a nuclear weapons complex that has come apart will be the fissile material from the weapons programme. A central issue is therefore the process for rendering military fissile materials unusable for weapons purposes and the process of *irreversibly* placing fissile materials declared excess to military requirement under international safeguards.

A second remnant will be retention of a body of expertise on nuclear weapons and military fissile materials to: 1) conduct and regulate the safe dismantling and elimination of nuclear weapons and production sites and disposal of fissile material, and 2) to retain a body of nuclear weapons expertise for purposes such as counter-nuclear proliferation and counter-nuclear terrorism.[5] This has implications for the unevenness of a nuclear disarmament process in relation to irreversibility.

Uneven irreversibility

The practical process of dismantling nuclear weapons, disposing of military fissile material and decommissioning or converting nuclear weapons complex production sites will take time and, because of this, progress towards maximising irreversibility will not be linear, but more likely move through a series of phases. How states move through these phases and how long they take will depend on the size and complexity of the nuclear arsenal and nuclear weapons complex, whether disarmament is a unilateral, bilateral or multilateral

[5] The latter might be imagined as a nuclear equivalent to the chemical and biological defence facility at the UK's former chemical weapons production site at Porton Down. The facility researches the detection, identification, treatment and decontamination of weaponised nerve agents and viruses.

process, the extent and role of verification, and how the value and legitimacy of nuclear weapons changes for a disarming state.

The workshop activities informing this report suggest that maximising irreversibility in a nuclear disarmament process will move through four phases:

1. Initial disarmament steps that can be made very difficult to reverse and are readily observable.
2. A longer period of warhead dismantlement and fissile material safeguarding using nuclear weapons complex facilities.
3. End of warhead dismantlement and final fissile material denaturing and disposition and the destruction or conversion of nuclear weapons complex facilities.
4. Environmental clean-up of sites, diminishing expertise and all remaining fissile material and fissile material sites under international safeguards (Figure 3).

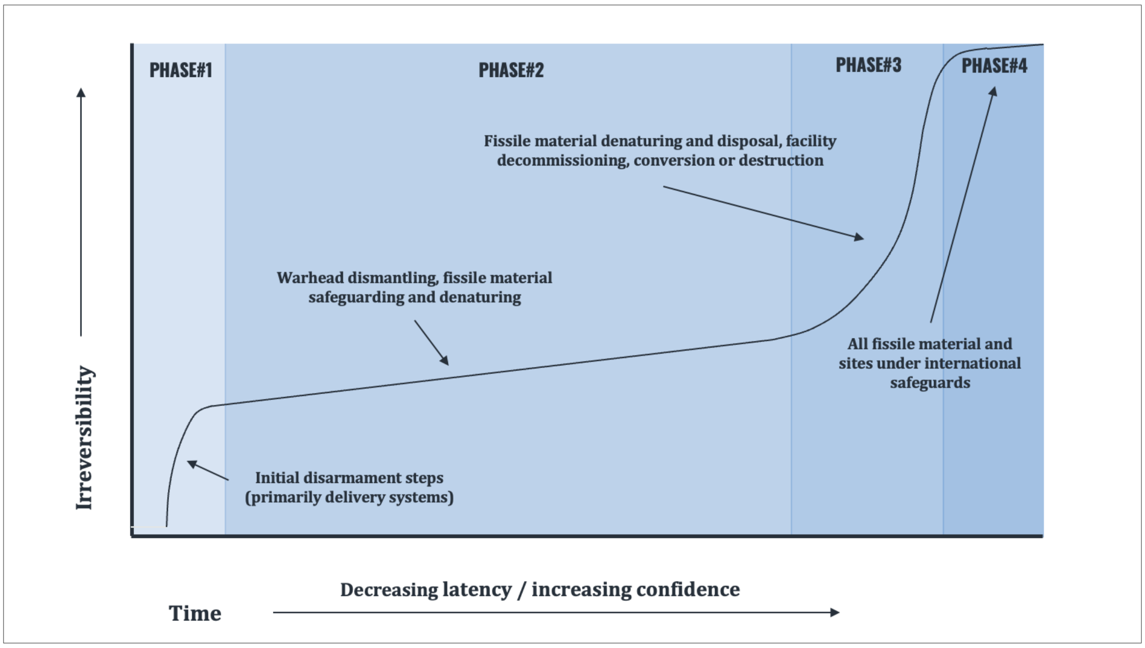


Figure 3: Four phases of irreversibility in nuclear disarmament

One important outcome of this is that observable changes associated with maximising irreversibility could come much later in a disarmament process because significant parts of a nuclear weapons complex will need to be sustained to *do* the disarmament.

These might be supplemented by three further steps where relevant:

5. Termination of enrichment and reprocessing for civil nuclear fuel production and decommissioning of sites.
6. Termination of naval nuclear propulsion plant production and naval nuclear fuel production, decommissioning of remaining NNPPs and reactor and fuel production sites, and disposal of spent fuel cores.
7. Termination of nuclear energy production and decommissioning of reactors.

Mapping the UK nuclear weapons complex

There has been surprisingly little analysis of what a nuclear weapons complex *is*. As noted above, for the purposes of this exercise, a nuclear weapons complex is defined as "the set of materials, competencies, meanings, institutions and money flows that are necessary to enable a state to safely and securely design, develop, manufacture, deploy, deliver, maintain and decommission nuclear weapons". When we look at mature nuclear weapons complexes we can see that they are complicated systems of systems.

The report is based on a detailed mapping of the UK nuclear weapons complex and its interrogation by workshop participants. The map identifies nine main subsystems that comprise the UK complex, as follows, all of which encompass materials, competencies, meanings, institutions and money flows:

1. Fissile material production and management system (Fissile Material)
2. Warhead design, development, testing, production, maintenance and surveillance system (Warhead)
3. Submarine and missile delivery infrastructure (Delivery)
4. Naval Nuclear Propulsion Plant system (Reactor)
5. Operational regime (Operation)
6. A safety and security regulatory regime (Regulation)
7. Policy and doctrine infrastructure (Policy)
8. Ideational system of meaning that makes sense of nuclear weapons (Meaning)
9. Legacy nuclear weapons sites, materials and materials (Legacy)

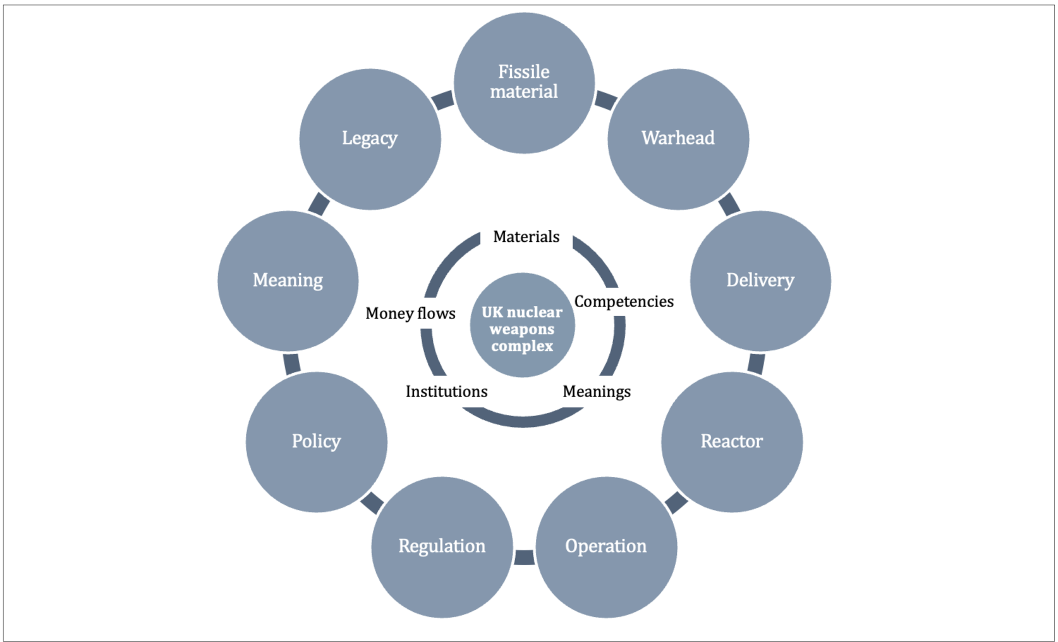
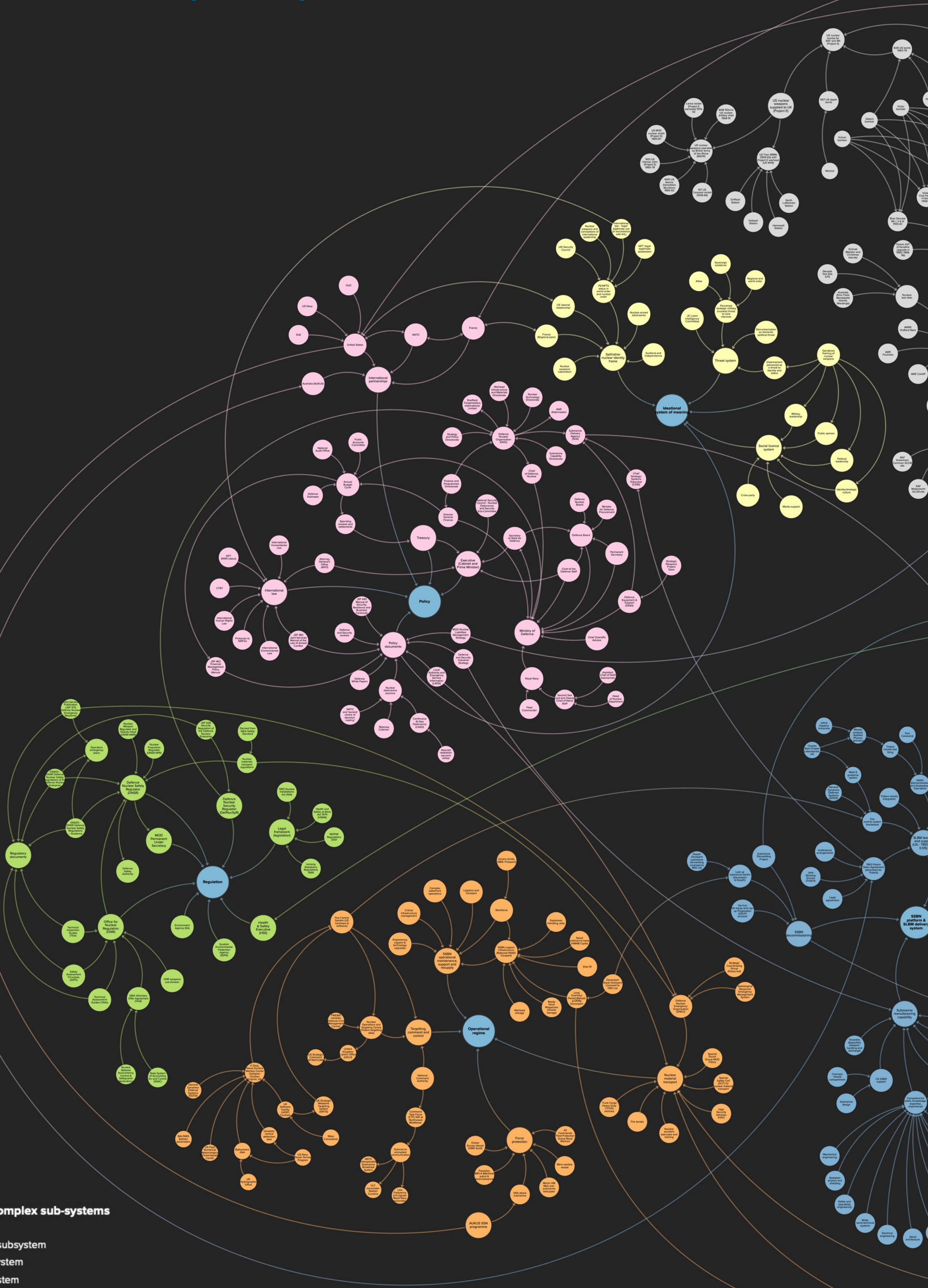


Figure 4: UK nuclear weapons complex subsystems

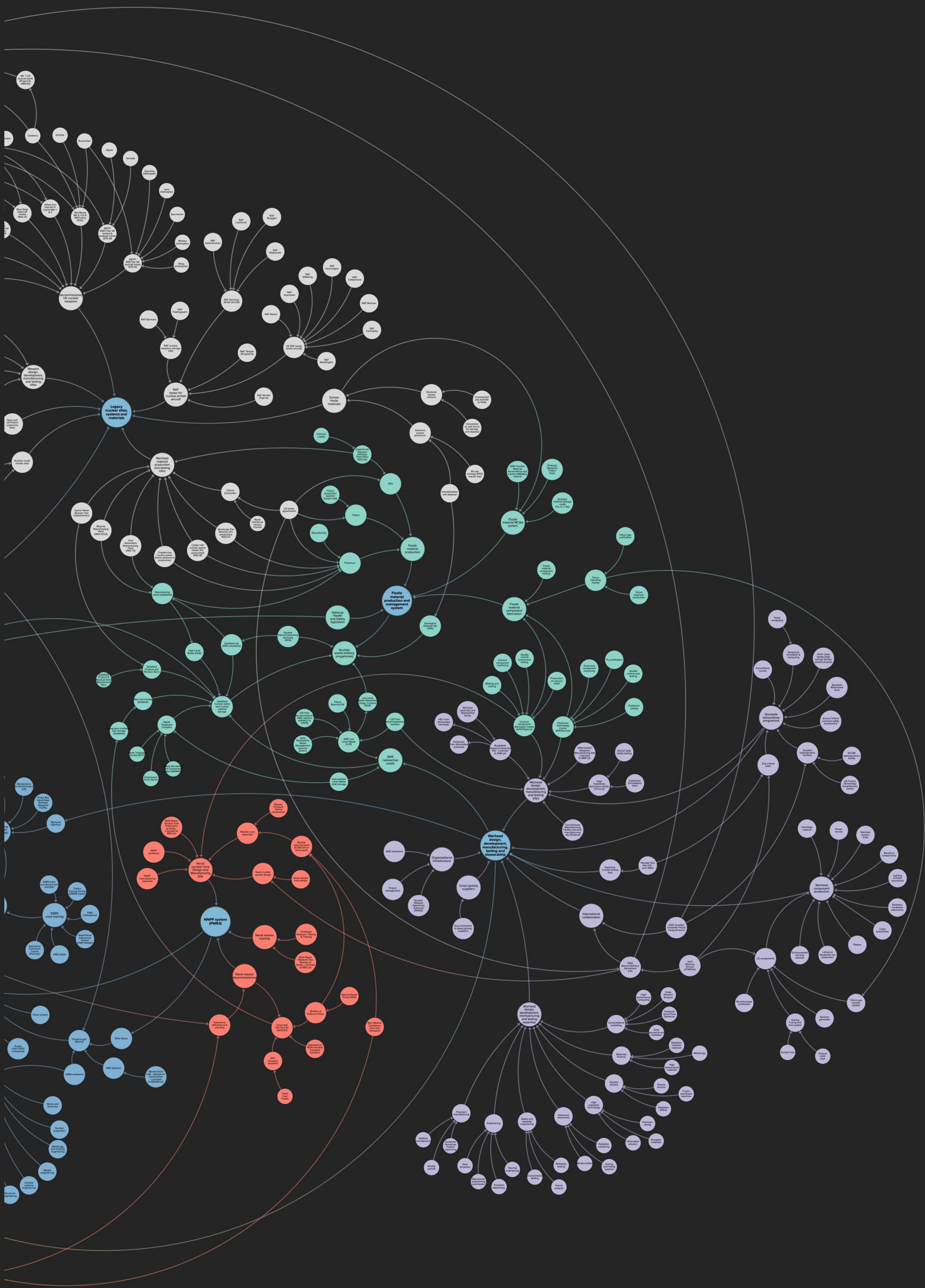
The full nuclear weapons complex system is available here: https://kumu.io/neritchie/nwcx#uk-nwcx-map/final-version

The UK nuclear weapons complex



Nuclear weapons complex sub-systems

- - - - Opposite
- Fissile material subsystem
- Ideational subsystem
- Warhead subsystem
- NNPP subsystem
- Delivery subsystem
- Operational subsystem
- Regulation subsystem
- Policy subsystem
- Legacy subsystem



Decommissioned UK nuclear weapons
Weapon design, development, manufacturing and testing sites
Legacy nuclear sites, systems and materials
RAF bases for nuclear armed aircraft
Excess fissile materials
Warhead material production and testing sites
Fissile material production
Fissile material production and management system
Fissile material MC&A system
Fissile material component fabrication
Nuclear waste (military programmes)
AWE radioactive waste
Warhead design, development, manufacturing, testing and stewardship
Warhead design, development, manufacturing and testing sites
Stockpile stewardship programme
Warhead component production
Warhead design, development, manufacturing, testing expertise
Naval nuclear Core Design and Manufacturing Site
NNPP system (PWR3)
Naval reactor training
Naval reactor decommissioning
SSBN crew training
Organisational infrastructure
International collaboration

System builders

Studies of LTS tend to start with 'system builders': those actors that bring together a diverse set of actors and ideas in a large coalition whose interests have been successfully aligned with, or provide essential support for, the system's core technological output, for example safe, secure, deployed, and deliverable nuclear weapons.

The primary system builders of the UK nuclear weapons complex are the Ministry of Defence and the UK's indigenous nuclear submarine production industry, centred on BAE Systems. Since the original Trident nuclear submarine-building programme in the 1980s and 1990s these two actors have become co-dependent, each relying exclusively on the other for supply and demand. Secondary system builders are the UK Treasury, the Atomic Weapons Establishment (AWE), the US nuclear weapons complex, and the UK workforce at naval nuclear reactor, submarine and warhead production and maintenance sites. These actors sit at the heart of the UK nuclear weapons complex.

A nested nuclear weapons complex

The UK nuclear weapons complex as a large socio-technical system is itself nested in a wider set of LTS in society that support it. It is important to consider these for three reasons:

1. In terms of the 'remnants' of a nuclear weapons complex after a disarmament process that could provide the foundations for re-establishing a nuclear weapons complex.
2. For considering where to draw boundaries around a 'nuclear weapons complex' and therefore what to include and exclude in a nuclear disarmament process.
3. To understand how interlinkages with other LTS might support or impede a nuclear disarmament process.

More broadly, consideration of the wider LTS' in which a nuclear weapons complex is nested allows us to ask questions about what stabilises nuclear infrastructures and what it is that nuclear infrastructures condense out of. I have provisionally identified five broader systems within which the UK nuclear weapons complex is nested:

1. UK nuclear complex (civil and NNPP)
2. Non-nuclear defence and intelligence complex
3. Scientific, industrial and educational base
4. US-UK-European security relationship
5. National role conceptions

It is likely that those systems within a society that enable a nuclear weapons complex will undergo changes through a disarmament process that can be monitored, for example by monitoring changes in resource flows.

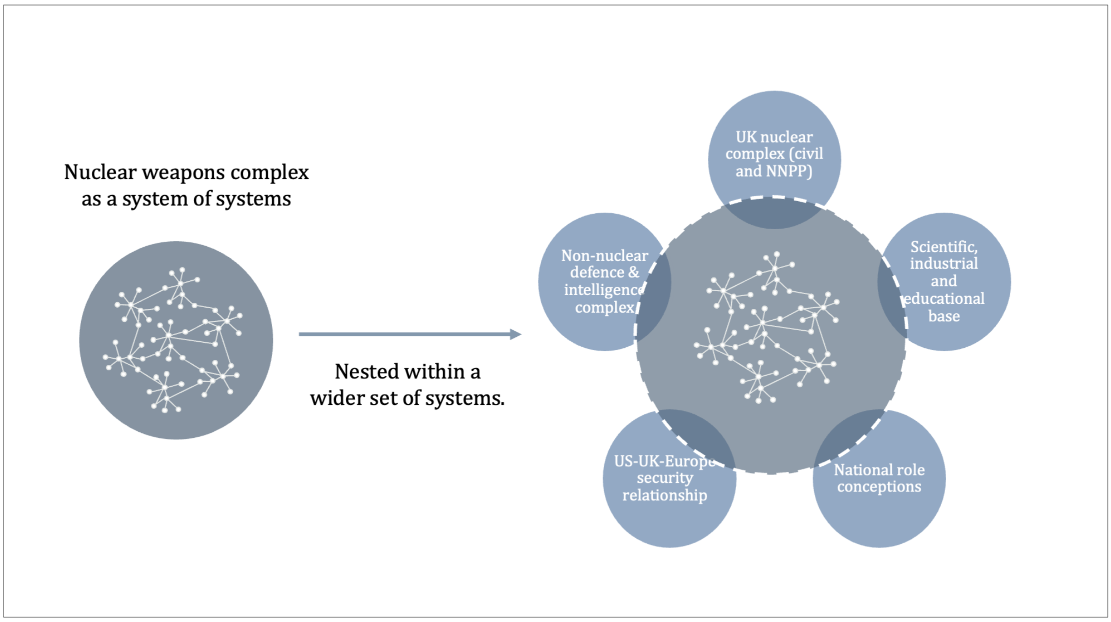


Figure 5: UK nuclear weapons complex nested in broader systems

Bounding a nuclear weapons complex

Where we draw boundaries around what counts as a 'nuclear weapons complex' determines what is included and excluded from our understandings of irreversibility in nuclear disarmament. This report argues that the referent of irreversibility should be the 'nuclear weapons complex' as defined above on the basis that maximising the irreversibility of something is based on 'unmaking' the structures that enable it. Where we draw boundaries also affects how we might verify a disarmament process and indicators of irreversibility.

We can bound a nuclear weapons complex in broader and narrower ways that relate to the spectrum of irreversibility and disarmament in Figure 1. For example:

1. Nuclear delivery systems (the central focus of East-West nuclear arms control).
2. Nuclear warheads (explored in the 1990s through work on a START III agreement).
3. A nuclear weapons *production* complex (this is how 'nuclear weapons complex' is generally conceived in the US).[6]
4. A full nuclear weapons complex (the definition used in this report)
5. A national 'fissile material complex' (capturing a state's fissile material in military and non-military programmes, notably naval nuclear reactors, energy production reactors and nuclear fuel cycle sites).
6. The broader set of LTS within which a nuclear weapons complex and wider fissile material complex are nested.

[6] For example, Woolf A. & Werner J. (2021). The U.S. Nuclear Weapons Complex: Overview of Department of Energy Sites. *Congressional Research Service*. Washington, D.C.

Re-establishing a nuclear weapons complex

We can hypothesise that the further down a disarmament and irreversibility spectrum a state goes the *less* likely it is that a re-established nuclear weapons complex will look like the pre-disarmament nuclear weapons complex. This is because too much will have come apart, been destroyed, or dissipated and too much will have to be re-*invented* rather than re-started to imagine a re-established complex looking like the mature pre-disarmament complex that had evolved over decades.

As with irreversibility, we can therefore imagine a spectrum of *reversibility* in which decision-making factors (economic, domestic political, diplomatic, information, regulatory, threat assessment) are shaped by understandings of the time, cost, difficulty, and urgency of re-establishing some form of capability. The proliferation literature provides us with useful concepts and examples and we can draw on these to describe four stages for illustrative purposes:

1. **Virtual nuclear capability:** re-establishing and re-integrating a set of materials, competencies, meanings, institutions and money flows to enable production of nuclear weapons within months or years.
2. **Threshold nuclear capability:** re-establishing and re-integrating a set of materials, competencies, meanings, institutions and money flows to enable production of nuclear weapons within weeks or a few months.
3. **Symbolic or emergency nuclear capability**: re-establishing a minimum infrastructure to manufacture a small number of nuclear weapons and at least a rudimentary delivery system.
4. **Robust nuclear capability**: re-establishing a robust nuclear weapons complex to manufacture 10s or 100s of nuclear weapons for assured delivery by secure second strike systems (a 'nuclear weapons complex 2.0').

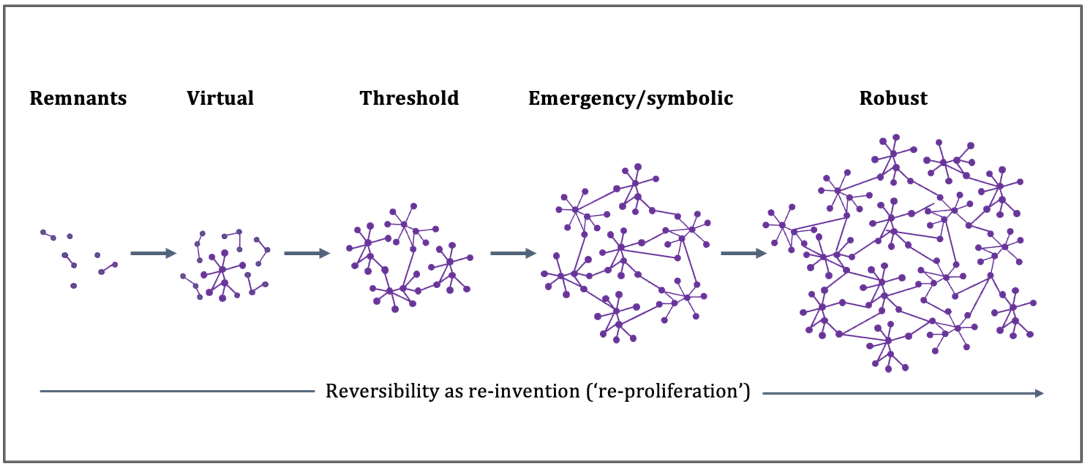


Figure 6: A spectrum of 're-proliferation' and re-invention

In sum, there are some useful terms for organising how we differentiate, develop and engage with a nuclear weapons complex as a system of systems:

1. **System components**: materials, meanings, competencies, institutions and money flows.
2. **Nuclear weapons complex subsystems:** Fissile material, warhead, delivery system, reactor, policy, meaning, operations and legacy.
3. **Nested systems:** nuclear complex, military complex, scientific-industrial base, US-Europe security, national identity.
4. **Process drivers**: time, cost, difficulty, urgency (driving a process of 'unmaking' or 'remaking' a nuclear weapons complex)
5. **Stages of re-proliferation and disarmament reversal:** remnants, virtual, threshold, emergency, and robust, emergency.
6. **System builders:** Ministry of Defence, BAE & submarine-building industry, AWE, Treasury, US nuclear weapons complex, UK nuclear workforce.

Hierarchy of nuclear weapons complex components

Given the scope of the UK nuclear weapons complex, workshop participants were asked to identify what they considered the **most important aspects** of the complex that enable it to function over time (which could be whole subsystems, specific components or particular relationships) and then to organise these hierarchically.

Interestingly, given the consistent focus on *materials* (warheads, fissile material, sites and so on) in discussions of nuclear disarmament and especially nuclear disarmament verification, it was surprising that a set of issues captured under the 'meanings' and 'political support' were deemed the most important, with some of the major material components (submarine, missile, reactor) assigned comparatively *less* importance.[7]

This reinforces recent work that the core 'system' of a nuclear weapons complex is not *material*, but a shared *system of meaning* in which nuclear weapons are understood to make sense. An exclusive focus on material capabilities misses this.[8]

Most important	**Meanings** National identities and meanings associated with nuclear weapons in the UK. In particular, dominant understandings about defence**,** beliefs in the global power of deterrence as central to the idea of Britishness, rhetorical commitments to 'the nuclear deterrent] as the 'ultimate guarantor of our security' and 'MoD's number one priority' **Political support** The political priority given to nuclear weapons at Prime Ministerial and Cabinet level.

[7] This could be because these aspects are embedded in wider systems that go beyond the nuclear weapons complex (the wider US and NATO relationship, the wider UK submarine-building industry and the military-civil nuclear infrastructure

[8] Ritchie N. (2023). Irreversibility and Nuclear Disarmament: Unmaking Nuclear Weapon Complexes. *Journal for Peace and Nuclear Disarmament*, 6(2), 218–243.

	The decision-making institutions, structures and institutional political pressure and momentum to sustain the UK's nuclear weapons complex.
Important	**Knowledge and expertise** Tacit knowledge and relevant scientific and technical expertise, training and education across the disciplines necessary for designing, manufacturing and maintaining nuclear weapons. **Relationships** Forging and sustaining relationships between operational capabilities and components across the system of systems. International relationships for strategic and technical support and cooperation (US, France, Australia) **Fissile material** Possession (or production) of sufficient military fissile materials to sustain the warhead programme. **Political support** Treasury support and sustainable funding. Policy and institutional coherence across the defence nuclear enterprise (government departments, workforce, industry, Treasury, Navy and so on). **Warhead production infrastructure** The full suite of appropriate facilities and materials for an operational nuclear weapons capability, notably warhead manufacturing and assembly/warhead assembly facilities. Nuclear warhead design capability (depending on requirement). **Deterrence** Collective belief in the necessity and efficacy of nuclear deterrence for national security. The demands and expectations of UK allies/NATO for the UK to contribute to nuclear deterrence.
Less important	**Delivery system** Supply of missile technology from the US Nuclear reactor production capability Submarine manufacturing capability

Priorities and difficulties maximising irreversibility

The workshop also asked participants to identify those sub-systems or key components that would need to be the focus of deliberate top-down irreversibility steps and then to organise these in terms of importance, difficulty and urgency. Importance referred to the significance of a step for maximising irreversibility. Difficulty included cost as well as technical and political challenges. Urgency referred to the timescale of irreversibility steps on a scale from immediate priority to medium priority to less urgent, i.e. actions that need to be undertaken but can or will have to come later in a disarmament process. The exercise resulted in the following outcomes. These were *not* agreed by consensus, but reflect a breadth of ideas in response to the question of importance, urgency and irreversibility:

Most important and most difficult areas:	**Meanings** 1. Changing meanings ascribed to nuclear weapons in terms of the legitimacy and value of nuclear weapons and nuclear deterrence in UK security narratives. This was less about making nuclear disarmament irreversible than making nuclear weapons undesirable. **Fissile material** 2. Fissile materials, notably significantly reducing or ending availability of separated plutonium and HEU (including downblending most/all HEU). **Warhead production infrastructure** **5.** Starting the process of dismantling warheads and destroying, converting and recycling materials and components as soon as possible subject to sufficient external verification.
Long-term, important but difficult steps:	**Civil nuclear programme phase out** 1. Rethinking the commitment of nuclear power as a technology that is being superseded and would no longer be tied into a military nuclear programme. **Nuclear complex repurposing and phase out** 2. Defence diversification of nuclear weapons complex sites and regions. 3. Converting ballistic missile submarines (SSBNs) to multi-role conventional cruise missile and special forces submarines (SSGNs) following the US example with four of its Ohio-class submarines. 4. Mothballing, dismantling, decontaminating, converting and destroying facilities and wider infrastructure. **Fissile material production phase out** 5. Ending URENCO enrichment at the Capenhurst site. 6. Safely decommissioning reprocessing at Sellafield as soon as possible.

	7. Converting Tritium to heavy water and dispensing into the ocean. **Knowledge** 8. Destruction of data and records in a 'believable' way. 9. Retaining the necessary expertise and facilities to accomplish nuclear disarmament over many years, since parts of AWE materials and facilities will be required until all defence nuclear material is eliminated.
Important but more straight-forward immediate and longer-term steps:	**Operational changes** 1. Ending SSBN patrols, removing missiles from submarines, disbanding SSBN crews, and starting the process of de-fueling SSBNs 2. Backfilling Trident missile magazines at RNAD Coulport once missiles have been returned to the US Naval Submarine Base at King's Bay. 3. Decommissioning or demolishing equipment at Coulport for loading missiles and warheads on submarines. **Political changes** 4. A major public relations and diplomatic campaign to amplify the disarmament message. 5. Introducing national implementing legislation making it illegal for the UK to be a nuclear-armed state, e.g. an equivalent to the 1996 Chemical Weapons Act for UK compliance with the 1993 Chemical Weapons Convention. 6. Withdrawing from the US Mutual Defense Agreement and Polaris Sales Agreement. **Fissile materials and safeguards** 7. Inviting international observation and verification of an initial set of changes. 8. Declaring some portion of fissile material stockpiles as excess to military requirements and placing them under international safeguards. 9. Placing fissile material production facilities under international safeguards. 10. Investing in a low-enriched uranium nuclear propulsion plant design to allow phaseout of HEU.

The meanings ascribed to the UK nuclear weapons were again one of the most important factors, but also one of the most difficult, along with the minimisation and disposal of fissile material stockpiles and getting a verified warhead dismantlement process underway.

This exercise also usefully identified steps that would demonstrate a commitment to irreversibility in a nuclear disarmament process that could fall under 'Phase 1' in Figure 3

Part two: The UK nuclear weapons complex

The second part of this report maps the nine subsystems of the UK nuclear weapons complex identified above. The purpose of the exercise is to demonstrate the complexity of the UK nuclear weapons complex as a system of systems and the scope of the actors, processes, sites, materials, policies and meanings needed to sustain it.

1. Fissile material production and management system (Fissile Material)

The ‘fissile material production and management system’ captures the infrastructure necessary to manufacture and manage fissile materials for use in nuclear weapons and submarine reactors. The core materials are weapon-grade Pu-239; highly-enriched U-235, U-238, and tritium. Its three sub-systems are:

1. Fissile material production
2. Fissile material component fabrication
3. Fissile material control and accounting

The UK no longer produces fissile material for use in nuclear weapons. Highly-enriched uranium was manufactured at the Capenhurst Gaseous Diffusion Plant from 1952-62, after which it produced low-enriched uranium for nuclear power reactors until 1982. Decommissioning of the plant was completed in 1997. The UK also received around 13 tons of HEU from the US in a series of barter agreements. A separate set of commercial gaseous centrifuge uranium enrichment plants were also built at the Capenhurst and are operated by the URENCO consortium for production of nuclear reactor fuel.

Plutonium for the UK military programme was produced in six nuclear reactors at the Sellafield site (Windscale Piles 1 and 2 followed by four Magnox reactors comprising the Calder Hall nuclear power station on the Sellafield site) as well as four reactors at the

Chapelcross power station. In addition, it is suspected that some plutonium for the military programme came from spent fuel from civil Magnox reactors prior to 1969. By 2004, all of these reactors had been shut down.[9] Chapel Cross reactors were also used to produce tritium for the weapons programme.

The UK also exchanged some plutonium with the US. In addition, the UK has a large stockpile of separated reactor-grade plutonium produced in commercial power plants and dual-use reactors. This was estimated at 116.5 tonnes in December 2021, which included 4.4 tonnes of military-origin plutonium declared excess and moved to the civilian stockpile. The UK operated two reprocessing plants at Sellafield that were shut down in 2018 and 2022. The UK does not therefore manufacture fissile material for its military programme, but it has a large stockpile of HEU and weapon-grade plutonium that is subject to a national fissile material control and accounting system.

Nuclear licensed sites in the UK used solely for military purposes are not subject to safeguards requirements. Nevertheless, it is UK policy to have nuclear materials accountancy standards and management arrangements that are at least as good as those required by nuclear safeguards legislation for all other nuclear licensed sites for which IAEA safeguards are in place under the UK's Voluntary Offer Agreement (VOA).[10]

Under the VOA, the UK has a responsibility to establish, implement and maintain a State System of Accounting for and Control (SSAC) of civil nuclear material subject, a domestic framework for the regulation of nuclear safeguards, and comprehensive reporting of Nuclear Material Accountancy, Control and Safeguards (NMACS) declarations to the IAEA.[11] Within MOD, the application of the materials accountancy regime is the responsibility of the Strategic Weapons Project Team (SWPT).[12] AWE documents also refer to a AWE Nuclear Material Accountancy and Control (NMA&C) manual and requirements for contractors to maintain material accountancy standards and put in place a Materials Accountancy Plan for 'accountable nuclear materials' (ANM).[13]

Uranium and plutonium components for nuclear weapons are manufactured and tested at AWE Aldermaston. Plutonium pits are manufactured at the A90 Plutonium Technology Centre which is being replaced by the Aurora facility. Enriched uranium components are stored and manufactured at the A45 plant to be replaced by the much-delayed Pegasus facility by 2030.[14] Tritium is purified and reservoirs filled at the Tritium Handling Facility.

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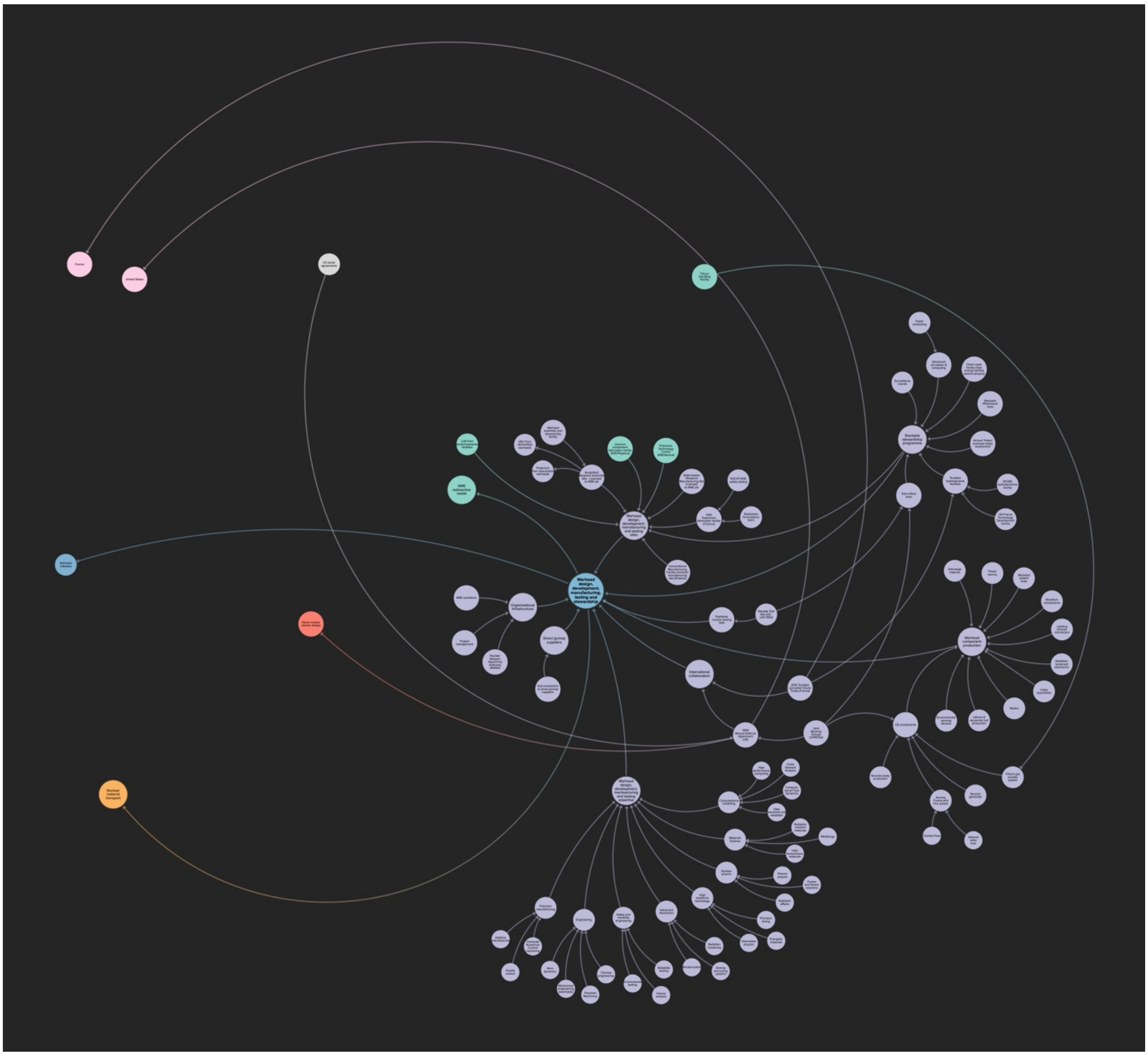
[9] Albright D., Berkhout F. & Walker W. (1997). Plutonium and Highly Enriched Uranium 1996 World Inventories, Capabilities and Policies. Oxford University Press for SIPRI, Stockholm. Barnham K., Nelson, J. & Stevens, R.(2000). Did Civil Reactors Supply Plutonium for Weapons? Nature 407, 833–834.
[10] Department for Business, Energy and Industrial Strategy (BEIS) and the Nuclear Decommissioning Authority (NDA) (2022). 2022 UK Radioactive Waste and Material Inventory. Available at <https://assets.publishing.service.gov.uk/media/63e24c2e8fa8f50e805a3e66/2022_Materials_Report_-_010223.pdf>
[11] Office for Nuclear Regulation (ONR) (2022). ONR Nuclear Material Accountancy, Control, and Safeguards Assessment Principles (ONMACS). ONR-CNSS-MAN-001. Available at <https://www.onr.org.uk/operational/other/onr-cnss-man-001.pdf>.
[12] Hansard (2010). House of Commons. 29 January. Column 1121W. Available at <https://publications.parliament.uk/pa/cm200910/cmhansrd/cm100129/text/100129w0005.htm>.
[13] Atomics Weapons Establishment (AWE) Aldermaston (2015). Standard Terms and Conditions, p. 50. Available at <https://www.awe.co.uk/wp-content/uploads/2015/08/AWE-Standard-Terms-and-Conditions-PDF-August-5.pdf>.
[14] Hansard (2022). House of Commons Written Questions. 'AWE Aldermaston and WE Burghfield'. UIN 45, tabled on 10 May 2022. Available at <https://questions-statements.parliament.uk/written-questions/detail/2022-05-10/45>.

2. Warhead design, development, production, and stewardship system (Warhead)



The 'Warhead design, development, production, and stewardship system (Warhead)' comprises four sub-systems:

1. Warhead design, development, manufacturing, and testing
2. Production of non-nuclear warhead components
3. Warhead manufacturing expertise
4. Stockpile through-life management programme

Warhead design, development, manufacturing, assembly and testing sites are based at AWE Aldermaston and Burghfield. Warhead testing and certification facilities and expertise are needed for fundamental research, development of technology, design, prototype development, environmental testing of engineered products, and materials research on and manufacturing of plutonium, uranium, beryllium, insensitive high explosives and lenses, lithium-6 deuteride, tritium, and a wide range of inorganic and organic materials. This is necessary to provide assurance of warhead safety and reliability without full-scale testing, to investigate age-related changes and implications understood, to develop and test computer simulations used to predict the effect of future warhead changes. The Ministry of Defence highlighted three areas as particularly important for assurance of the safety and effectiveness of UK warheads: high performance computer simulation, hydrodynamics and high energy density physics.[15]

The UK has invested in new facilities to sustain warhead design, diagnostic and manufacturing capabilities without explosive nuclear testing under the Nuclear Weapons Capability Sustainment Programme initiated in 2005. The Ministry of Defence says that the Nuclear Weapons Capability Sustainment Programme is designed “To deliver and sustain the capability (skills, technology, science, personnel, production and support) to underwrite the UK nuclear warhead stockpile now and in the future”.[16] Key facilities include:

- Orion Laser facility that began operations in 2012 to investigate how nuclear materials respond under intense temperatures and pressures (now in a mid-life upgrade).
- Teutates facilities - a joint UK-France Technology Development Centre at Aldermaston to support hydrodynamic research to study the effects of ageing and manufacturing processes on nuclear warheads without nuclear explosive testing and the main UK-France Teutates-Epure hydrodynamics facility in Valduc, France.
- Vulcan 7.42 PetaFLOPs supercomputer installed in 2020 for executing complex simulations to certify nuclear warheads.
- Circinus High Explosives fabrication facility.
- Phoenix Conventional Manufacturing Facility precision manufacturing site.

AWE Burghfield is responsible for the assembly, disassembly and refurbishment of the warheads. Warhead assembly and disassembly currently takes place in facilities known as ‘Gravel Gerties’, which are designed to collapse inwards in the event of an explosion. These are being replaced by the new Mensa facility for the assembly and disassembly of current and future nuclear warheads.

This includes extensive stockpile surveillance involving surveillance rounds, destructive and non-destructive Stockpile Withdrawal Tests, high-fidelity computer modelling, and hydrodynamic experiments in order to provide an annual safety assessment for the Trident warhead stockpile.

Design, testing and manufacture of non-nuclear warhead components is a core part of AWE’s programme. The US provides substantial support in warhead design, integration and non-nuclear components under the 1958 Mutual Defence Agreement (MDA). The UK warhead is believed to be closely based on the US W76 Trident warhead. The US is thought to have supplied the Mk4 re-entry bodies for the UK warheads, as well as the Arming Fusing and Firing system, neutron generator, and the tritium gas transfer system. The UK has benefitted from the US W76 Life Extension Program (LEP) that involved design and production in the US of a new Arming, Fusing and Firing system (AF&F) for the Mk4a re-entry body, a new tritium Gas Transfer System, a new the MC 4700 Arming, Fusing, and Firing System (AF&F), and new neutron generator designed by the Sandia National

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[15] Ministry of Defence (2006). Memorandum submitted by the Ministry of Defence, Annex C (Investment at the Atomic Weapons Establishment), 19 January, paras 7-8. Submitted to the House of Commons Defence Committee, HCP835.
[16] Ministry of Defence, Major Projects Portfolio, March 2021. Available at <https://www.gov.uk/government/publications/mod-government-major-projects-portfolio-data-2021>.

Laboratory. In addition, the US and UK have conducted joint hydrodynamic experiments under the auspices of the MDA at AWE and the Nevada Test Site.[17] The UK has also conducted joint subcritical nuclear tests at the Nevada Test Site to support US and UK warhead certification efforts.[18]

The warhead programme requires design, development, manufacturing and testing expertise in a host of niche and state-of-the-art scientific and technological areas, including precision manufacturing, safety and reliability engineering, thermal and aerodynamic engineering, advanced electronics, high explosive technology and modelling, nuclear physics, materials science and computer modelling.

3. Submarine platform and missile delivery infrastructure (Delivery)

The 'Submarine platform and missile delivery infrastructure (Delivery)' encompasses two subsystems:

1. A submarine manufacturing capability system.
2. A SLBM leasing and support system.

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[17] Hansard (2009). House of Commons. 27 February. Column 1151W; Onions, K., Pitman, R. & Marsh, C. (2002). Science of nuclear warheads. *Nature* 415, p. 856.
[18] O'Nions, K., Anderson R., & Pitman, R. (2008). Reflections on the Strength of the 1958 Agreement. In Mackby, J. and Cornish, P. (eds.) *U.S.-UK Nuclear Cooperation After 50 Years* (CSIS Press: Washington, D.C.), p. 182.

These encompass further systems of ‘SSBN crew training’, ‘US SSBN support’, ‘Decommissioning’, and ‘Competencies (skills, knowledge, expertise, experience)’ for SSBN design and construction. The UK’s nuclear arsenal and submarine industry have undergone steady consolidation, reducing to one nuclear warhead (Holbrook), one nuclear missile system (US Trident II D5 SLBM), one delivery vehicle (Vanguard-class SSBN) designed and built by one supplier (BAE Systems) at one submarine yard (Barrow-in-Furness) for one customer (MOD). Maintaining a nuclear-powered submarine-building industry and the sovereign capability and skills to design, development, build, support, operation and decommissioning submarines and their Nuclear Steam Raising Plant (NSRP) is a strategic priority for MoD.[19]

Retention of key skills and experience has been a major challenge throughout the submarine manufacturing supply chain, which had experienced real difficulties in retaining specialist workforces during periods of inactivity in the submarine programme.[20] A number of initiative have been developed to address this including the 200 Submarine Enterprise Collaborative Agreement (SECA), the 2010 Submarine Enterprise Performance Programme initiative through which the three Tier 1 industrial suppliers (BAE Systems, Rolls Royce, and Babcock Marine) work collaboratively with MoD, the standing up of the Submarine Delivery Agency (SDA) in 2018 as an Executive Agency of MOD, and the Dreadnought Alliance between the SDA, BAE Systems and Rolls Royce to deliver the Dreadnought-class SSBN fleet.

1958 MDA and 1963 PSA (amended for Trident) provide for extensive cooperation with the US on SSBN design and support.[21] The UK is working with the US on the next generation SSBN (the Dreadnought-class in the UK and Colombia-class in the US). The main focus of current collaborative work is the development of a Common Missile Compartment run through the Naval Sea Systems Command in Washington.[22]

The UK has a substantial submarine training and assessment programme and facilities including HMS Raleigh Royal Naval Submarine School in Cornwall, in the Trident Training Facility at Faslane that houses a full size Trident II (D5) Active Inert Missile (AIM) in its launch tube and associated control system, and the Vanguard simulator that replicates the machinery control room system in the Vanguard submarines.[23] The UK submarine service suffers perennial recruitment and retention problems. The 2002 Submarine Manning and Retention Review recommended a range of remuneration measures to address the problem.[24] By 2008 these measures were having only limited impact with the Armed Services Pay Review Body reporting widespread shortfalls in the Submarine Service.

The UK is entirely dependent upon the US for the SLBM delivery system for its nuclear warheads. The 1963 Polaris Sales Agreement (PSA) was negotiated to permit the UK to

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[19] Ministry of Defence (2005) *Defence Industrial Strategy*, Cm 6697 (London: HMSO), pp. 22 & 70.
[20] Ibid., p. 18.
[21] Chamberlain N., Butler N., & Andrews, D. (2004). US-UK Nuclear Weapons Collaboration Under the Mutual Defence Agreement. *BASIC*. Special Report 2004.3.
[22] (2008) CMC Contract to Define Future SSBN Launchers for UK, USA. *Defense Industry Daily.* December 26.
[23] Funnell F. (2008). Training and Simulation Systems. *Janes Underwater Warfare Systems 2008-2009* (Surrey: Janes Information Group, 2008), pp. 616-617.
[24] Armed Services Pay Review Body (2004). Thirty Third Report 2004, Cm 6113 (London: HMSO), p. 13.

acquire, support and operate the US Polaris and later the Trident II (D5) ballistic missile systems. The UK purchased 58 Trident II (D5) missiles as part of a larger collective pool maintained at the United States Strategic Weapons Facility Atlantic, King's Bay, Georgia. The UK is therefore dependent upon the US for supply, refurbishment and test firing of its Trident missiles and the software used for missile targeting and firing.[25]

4. Naval Nuclear Propulsion Plant (Reactor)

The 'Naval Nuclear Propulsion Plant (Reactor)' system has three subsystems:

1. Naval nuclear fuel production plant.
2. Naval reactor training
3. Naval reactor decommissioning

Current UK submarines are powered by Rolls Royce's Pressurised Water Reactor-2 (PWR2) nuclear reactor. The UK has prioritised the capability to manufacture a naval nuclear power plant (NNPP) and Rolls Royce is currently developing a new PWR3 reactor for the Dreadnought-class SSBN. The 1958 MDA provides for extensive cooperation with the US on naval nuclear reactor technologies and the PWR3 is based on a modern US reactor plant.[26]

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[25] Ainslie J. (2005). The Future of the British Bomb. *Scottish CND*, pp. 12, 67.

[26] Ministry of Defence (2011). The United Kingdom's Future Nuclear Deterrent: The Submarine Initial Gate Parliamentary Report (London: Ministry of Defence). Defence Board (2009). 09(62) Successor Submarine Project, Note by the Assistant Secretary, DNSR/22/11/2, 4 November. Available at <http://robedwards.typepad.com/files/declassified-report-to-mod-defence-board.pdf>.

The US-UK MDA is renewed every 10 years. In the July 2014 update Article III of the treaty was modified to authorise transfer of new reactor technology, spare parts, replacement cores and fuel elements.[27]

The UK NNPP system is lean and centred on a handful of facilities: AWE Aldermaston for processing HEU components; Rolls Royce Marine Power Operations at Raynesway, Derby for naval reactor design, testing and fuel fabrication; BAE Systems Maritime Devonshire Dock Complex, Barrow-in-Furness, for reactor core assembly and commissioning; Devonport Royal Dockyard and HMNB Devonport, Plymouth, for reactor defueling and refuelling); Nuclear Decommissioning Authority's Sellafield site, Cumbria, for long term irradiated fuel storage).

Rolls Royce Marine Power Operations Limited (RRMPOL) operates two nuclear licensed sites at Raynesway, Derby, for naval reactor design, testing and fuel fabrication: a manufacturing site and the Neptune site. The Neptune site comprises a reactor hall with adjoining fuel storage facilities, radiation laboratories and radioactive waste management facilities and a separate radioactive components handling facility. The low energy reactor is used to develop and prove submarine reactor designs.[28] Raynesway is a commercially owned nuclear licensed site. Processed HEU for the NNPP is transported by road in a fleet of High Security Vehicles (HSVs) escorted by the Ministry of Defence Police (MDP) Special Escort Group (SEG) from AWE Aldermaston to the Nuclear Fuel Production Plant (NFPP, also known as the Core Design and Manufacturing Site) at Raynesway. Core manufacture requires manufacturing fuel assembly and control rod modules based on high burn up fuels such as uranium-zirconium, uranium-aluminium, and metal ceramic fuels. Much of the work involves conventional manufacturing processes common to other engineering industries. At the end of this process, all the components are brought together and the finished reactor core is trial assembled. Completed fuel assemblies are stored at Raynesway prior to delivery.

New fuel assemblies are transported by road from Raynesway to Barrow in the form of separate modular units that are individually packaged into protective containers called New Module Containers (NMC) designed in accordance with IAEA standards. NMCs are loaded onto standard road transport vehicles and escorted by the MDP SEG.[29] New fuel received from Raynesway is stored and then assembled into a reactor core. The cores are installed into the submarine reactor pressure vessel (RPV), and the finished reactor is then tested and commissioned.

The Devonport site in Plymouth comprises two adjacent sites: HMNB Devonport and the Devonport Royal Dockyard. HMNB Devonport is the homeport for the Trafalgar-class attack submarines until 2018. The Naval Base is owned and operated by MoD and is supported by Babcock International Group Marine & Technology Division. The Devonport Royal Dockyard provides the Royal Navy's repair and refitting facilities for the UK's submarines, including

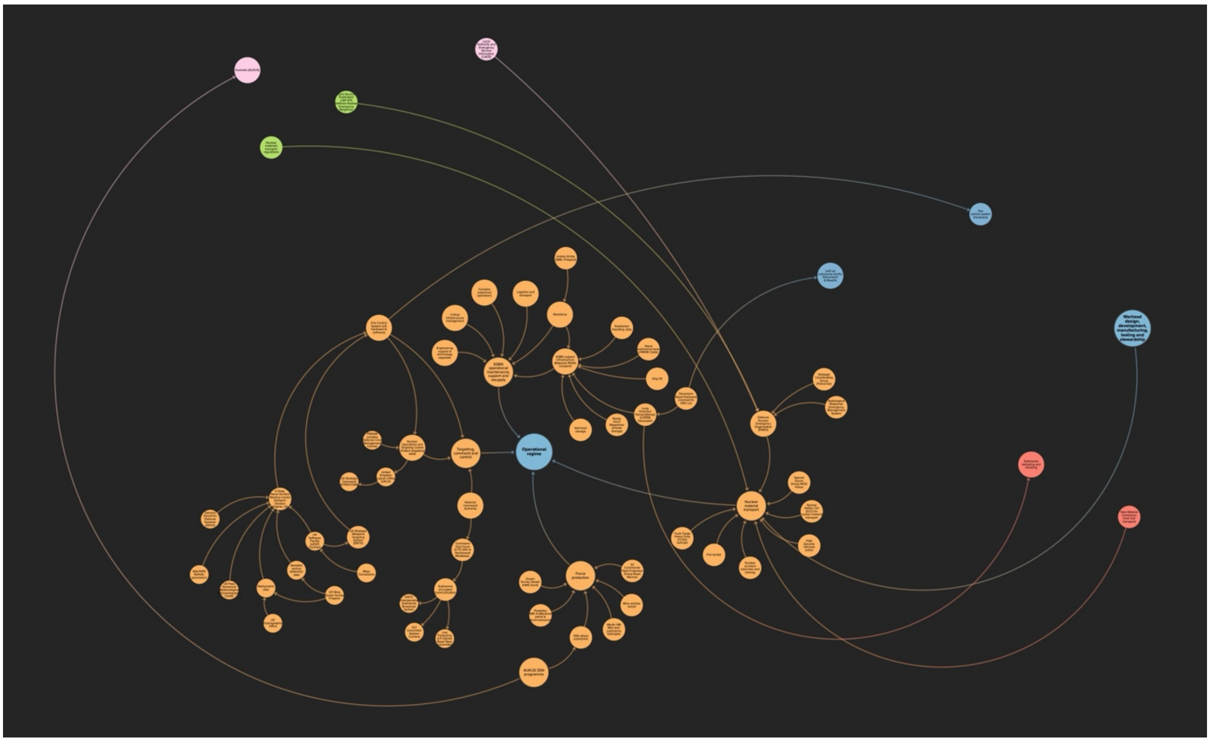
[27] Foreign and Commonwealth Office (2014). Amendment to the Agreement between the Government of the United Kingdom of Great Britain and Northern Ireland and the Government of the United States of America for Cooperation on the Uses of Atomic Energy for Mutual Defense Purposes. CM 8996. 22 July, p. 3.
[28] Health and Safety Executive (2002). A review by the Health and Safety Executive's Nuclear Installations Inspectorate of the strategy of Rolls-Royce Marine Power Operations Ltd for the decommissioning of its nuclear sites.
[29] Ministry of Defence (2011). Local Authority and Emergency Services Information (LAESI) Edition 8, p. 6.

reactor defueling and refuelling. Devonport Royal Dockyard is commercially owned and Devonport Royal Dockyard Ltd (DRDL, a subsidiary of Babcock International Group plc.) is the site operator. Vanguard-class SSBNs are defueled and refuelled at the Devonport Royal Dockyard as part of their planned Long Overhaul Period (Refuel) (LOP(R)).

Defueling of submarines is currently carried out from a mobile Reactor Access House (RAH) which traverses the dry dock and is positioned above the reactor compartment (RC) of the submarine. Irradiated fuel removed from submarines is moved to a storage facility for the temporary storage prior to consignment to Sellafield. Defueled decommissioned submarines are stored afloat at Devonport and Rosyth Royal Dockyard on the Firth of Forth in Scotland through a De-fuel, De-equip and Lay-up Preparation (DDLP) process.

Irradiated nuclear reactor fuel is transported by rail in nuclear flasks to Sellafield by Direct Rail Services operated by the Nuclear Decommissioning Authority (NDA).[30] Spent naval reactor fuel is placed in long-term storage in dedicated Ministry of Defence storage ponds at Sellafield. Ultimately, the spent fuel must either be reprocessed to recover unused ^{235}U or sent for permanent disposal, most likely in a future geological repository. The UK's first submarine cores were placed in Sellafield's First Generation Oxide Storage Pond. In 2003, MoD commissioned a dedicated fuel storage pond at Sellafield called the WIF (Wet Inlet Facility).

5. Operational regime (Operations)



The 'Operational regime (Operations)' system comprises subsystems:

[30] The NDA is a non-departmental public body set up in April 2005 under the Energy Act 2004 to take strategic responsibility for the UK's civil nuclear legacy and transfer long-term British Nuclear Fuels Ltd (BNFL) and UK Atomic Energy Agency (UKAEA) nuclear decommissioning and clean-up liabilities to the public sector.

1. Targeting, command and control.
2. Nuclear material transport.
3. SSBN operational maintenance, support and resupply.
4. Force protection.
5. Operational workforce

SSBN operational maintenance, support and resupply centres on HM Naval Base (HMNB) Clyde. The base is owned and operated by the MOD through the main Clyde operating contractor, Babcock Marine Ltd. The Naval Base comprises separate sites at Faslane and Coulport. The Faslane site provides a range of nuclear submarine support capabilities including facilities for the maintenance and repair of submarines. The Coulport site undertakes the storage, processing, maintenance and issue of the Trident weapon system and conventional weapons for all submarines. The large shiplift building at Faslane can raise a fully-armed Vanguard-class submarine out of the water for maintenance in a covered hall. There is also a dedicated finger jetty for the Vanguard submarines. Berths are equipped with backed-up power supplies to maintain and monitor nuclear submarine systems and much of the site is hardened to withstand earthquake, fire, explosion or tidal surges. There are also berths used by visiting warships and the Sandown class minehunters based in Faslane. The site also includes large engineering workshops and storage areas.

The heart of the Coulport site is the Trident Storage Area with three compounds: 16 Ready Issue Magazine underground bunkers with air-locked doors each able to store a single Trident missile, a nuclear-warhead storage site and a nuclear-warhead processing building. The bunkers are well separated and able to withstand explosions of rocket fuel or the very remote possibility of an earthquake. Trident missiles are loaded into submarines at the Explosives Handling Jetty (EHJ), which is a specially constructed covered floating dock. The submarine enters and the missiles are loaded vertically into the missile tubes by overhead crane. There is also a separate jetty for loading torpedoes which are stored on the site.[31]

Conventional force protection involves 'committed' forces whose primary role is SSBN force protection and constitutes a single mine warfare vessel, a single survey vessel and 43 Commando Fleet Protection Group Royal Marines (a 550-strong Unit based at HMNB Clyde). 'Contingent' forces are not planned routinely to deploy to support SSBN operations, but can be. These include two attack submarines, a single destroyer or frigate, three additional mine warfare vessels, a single Royal fleet auxiliary vessel, Merlin anti-submarine warfare helicopters, and maritime reconnaissance aircraft.

The workforce for the UK nuclear weapons system is based around five key centres: the Barrow shipyard, the Devonport naval base in Plymouth, Babcock Naval Services at Faslane, the Rolls Royce Raynesway site, and the nuclear weapons production complex at Aldermaston. In 2007, the Barrow shipyard employed approximately 3,500 people, Devonport Management Limited employed 5,200 staff, 4,700 of whom were permanent employees, and Babcock Naval Services that operates Faslane and Coulport employed

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[31] Ainslie J. (2010) Trident: Nowhere to Go. Scottish CND. https://www.banthebomb.org/wp-content/uploads/2021/07/2012-Trident-Nowhere-To-Go-report.pdf>.

approximately 1,400, with an additional 1,000 MoD civilian staff, at Faslane and 670 at Coulport and a further 2,500 workers employed through external contractors. AWE employed 4,230 staff at Aldermaston and 340 at Burghfield. The workforce is closer to 6,000 now.[32] A further 2,000 staff were employed by contractors at the two sites. Rolls Royce employed 930 on the submarine programme. Amicus, the UK's second largest trade union, stated in 2006 that a further 13,500 jobs were dependent on the Barrow yard, with a further 6,000 jobs supported by Faslane and 1,200 more dependent on Coulport.[33]

Road transport of UK nuclear weapons, Special Nuclear Materials and reactor fuel is the responsibility of the Defence Nuclear Organisation Warhead (WHD) Transport Organisation. The Special Escort Group of the Ministry of Defence Police, SEG (MDP), escort the nuclear materials and remain on standby during their transit. Immediate Response Forces (IRF) are embedded within the road and rail transport. Trident warheads are contained within PD AWG 516 packages. These are kept on Load Transfer Platform Trolleys (LTPT) until moved by crane or put onto Truck Cargo Heavy Duty (TCHD) vehicles for road transport.

The UK nuclear targeting and command and control system is centred on an order from the Prime Minister to authorise the firing of UK nuclear weapons. The authenticated order is communicated to SSBN on patrol via the Nuclear Operations and Targeting Centre (NOTC) located within PINDAR bunker under MOD Main Building in Whitehall. Ainslie reports that UK targeting data is created in the Nuclear Operations and Targeting Centre in London which relies on US software. The Nuclear Firing Control Message is communicated using Very Low Frequency (VLF) through VLF transmitters. UK nuclear targeting is integrated into US nuclear targeting plans. The United Kingdom Liaison Office (UKLO) is within the United States Strategic Command (USSTRATCOM) headquarters at Offutt Air Force Base, Nebraska. It provides an interface between the UK and US nuclear targeting systems.[34]

The Fire Control System (FCS) on the submarine processes targeting information and sends instructions to Trident D5 missiles and their nuclear warheads. The FCS handles information on targets and the submarine's location as well as bathymetric, gravity and meteorological data. Ainslie reports that the UK Fire Control System uses software produced in the US by K Department of the Naval Surface Warfare Center Dahlgren Division (NSWCDD) in Virginia. K40 branch at NSWCDD is responsible for Trident SLBM research and analysis. K50 develops SLBM software. These branches carry out work for both the US and UK Trident programmes.[35] Both UK and US Trident submarines use the Mk 98 Fire Control System hardware produced by General Dynamics Defense System (GDDS).[36]

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[32] Private information

[33] Hansard (2010). House of Commons. Column 621W. 9 September; Scottish Trades Union Council (2007). Cancelling Trident: The Economic and Employment Consequences for Scotland. Glasgow, p. 12.

[34] House of Commons Defence Committee (1993). Progress of the Trident Programme. HC 549, p. 9; Interview with Frank Miller by Jessica Yeats (2008). Center for Strategic and International Studies (CSIS), January 28. Audio files available at https://www.csis.org/programs/international-security-program/project-nuclear-issues/us-uk-nuclear-cooperation-after-50#:~:text=As%20Britain%20and%20the%20United,collaborated%20to%20examine%20that%20history>.

[35] Ainslie J. (2005). *Future of the British Bomb* (Clydeside Press, Glasgow), p. 70.

[36] Ibid., p. 67.

Ainslie reports that air density and wind data that can affect the warhead in the final stages of the trajectory is produced for the US Navy by the US Fleet Numerical Meteorological and Oceanography Center (FNMOC), compressed into Ballistic Parameters (BALPARs) and sent to UK SSBNs by radio every 12 hours from the US or through Northwood. Bathymetric data provides gravity data and a bathymetric fix of the vessel's position. The UK MOD's hydrographic survey office produces special detailed material to support nuclear submarine operations. The survey ship, HMS Scott, has equipment designed to produce data in a format compatible with US systems.[37]

Computer models are used for shore-based targeting, performance assessment and fire control software. The United Kingdom Software Facility (UKSF) is located in an underground bunker at Corsham, Wiltshire. UKSF is run by the MOD Strategic Weapons Integrated Project Team (SWPT) with support from Mass Consultants. The UK software facility maintains, updates and modifies US codes and models for the UK Trident system.[38] Ainslie reports that UKSF tests the US-supplied software for the Fire Control System and issues it to UK submarines. UKSF has a Mk98 Fire Control System that is identical to that on a UK Trident submarine. When the Navy is introducing a hardware upgrade, UKSF operates both the old and the new modifications of the system. Personnel at UKSF who work on the Fire Control System software visit the US Navy site at Dahlgren, Virginia, where this software is produced. US technicians from Dahlgren are seconded to UKSF when required.

Trident missiles are test fired from British submarines near Cape Canaveral under US supervision. The evaluation of missile tests has been almost entirely carried out by US laboratories. The Applied Physics Laboratory (APL) of John Hopkins University in Maryland evaluates UK Trident missile system operations and tests along with Charles Stark Draper Laboratories that make the missile guidance system.

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[37] Plesch D. & Ainslie J. (2016). Trident: Strategic Dependence & Sovereignty. Scottish CND and School of Oriental and African Studies.
[38] Ibid.

6. Safety and security regulatory regime (Regulation)

The 'safety and security regulatory regime (Regulation)' comprises three subsystems:

1. Office for Nuclear Regulation system.
2. Defense Nuclear Safety Regulator system.
3. Legal framework (legislation).

Defence nuclear activities in the UK are regulated by the Office for Nuclear Regulation (ONR) (previously the Health and Safety Executive Nuclear Installations Inspectorate), the Environment Agency (EA) and the Scottish Environment Protection Agency (SEPA). Exemptions are made for the Defence Nuclear Programme. Exempted activities are regulated by MoD's internal nuclear safety regulator, the Defence Nuclear Safety Regulator (DNSR).[39] The ONR licences defence sites operated by third parties, whilst the DNSR oversees sites owned and operated by the Ministry of Defence.

DNSR directly regulates the design and approval of UK nuclear warheads and naval reactor plants and its activities cover all nuclear safety related elements of the Concept, Assessment, Demonstration, Manufacture, In-service and Disposal cycle (CADMID) cycle

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[39] Defence Nuclear Organisation (2022) Nuclear Liabilities Management Strategy. Ministry of Defence. Available at <https://assets.publishing.service.gov.uk/media/628e3534d3bf7f1f433ae20d/Nuclear_Liabilities_Management_Strategy.pdf>.

applied to defence procurement. The Head of the Nuclear Propulsion Project Team (NP Hd) and Director Warhead (Dir Whd) are the formal Authorisees with Design Authority responsibilities for the naval nuclear propulsion plant and Trident nuclear weapon, respectively with responsibility for maintaining appropriate safety cases. Under DNSR nuclear weapon regulation is managed by the Nuclear Weapon Regulator and Deputy Head (DNSR-NWR) and nuclear propulsion regulation by the Nuclear Propulsion Regulator (DNSR-NPR). The Secretary of State (SoS) for Defence formally delegates via the Permanent Under Secretary (PUS) responsibility for safe conduct of defence activities. DNSR regulates the transport of Defence nuclear material. Security arrangements across the Defence Nuclear Enterprise are under the responsibility of the Security Policy and Operations, Defence Nuclear Security Regulator (SPO-DefNucSyR).

In MOD's Defence Equipment and Support (DE&S) organisation the Nuclear Propulsion Project Team (NP-PT) provides in-service support relating to reactor plant readiness for operation. It controls associated work undertaken by the Nuclear Steam Raising Plant (NSRP) Technical Authority (Rolls Royce Submarines) and is the formal DNSR authorisee for operation of the Naval Reactor Propulsion Plant at sea and operational berths.

Rolls Royce's' Raynesway plant is a licensed nuclear site solely regulated by the ONR. AWE Aldermaston and Burghfield are licensed by the ONR. DNSR authorises and regulates specific nuclear activities, primarily those exempt from the licensing requirement of the Nuclear Installations Act. The ONR regulates HMNB Clyde, HMNB Devonport, and Vulcan Nuclear Test Reactor Establishment (NRTE) in accordance with applicable legislation, but all nuclear activities at the sites are authorised and regulated by DNSR. The Barrow site is licensed by the ONR for nuclear fuel storage and handling. DNSR authorises and regulates specific exempted nuclear activities, including initial testing of the nuclear reactor. In practice, Barrow has regulated areas split between ONR and DNSR with much joint regulation and coordination.[40] The regulatory framework also requires Authorisees to have adequate arrangements for the safe decommissioning of nuclear weapons, naval reactor plant, components or relevant support equipment.

MOD also has General Agreements with the Health and Safety Executive (HSE), ONR and the Scottish Environment Protection Agency (SEPA). DNSR has signed Memoranda of Understanding with the Environment Agency (EA) and a Standard Operating Procedure with the Autorité de Sûreté Nucléaire et à la radioprotection pour les activités et installations intéressant la Défense (ASND). Letters of Understanding have been signed between DNSR and ONR, the Defence Ordnance Munitions and Explosives Safety Regulator (DOSR) and the Defence Nuclear Security Regulator (DefNucSyR).

The nuclear regulatory framework is derived from legislation including the Nuclear Installations Act (1965), Health and Safety at Work Act (1974), Radiation (Emergency Preparedness and Public Information) Regulations (REPPIR, 2001) and Ionising Radiations Regulations (1999). It is developed in detail through a set of regulatory policy documents,

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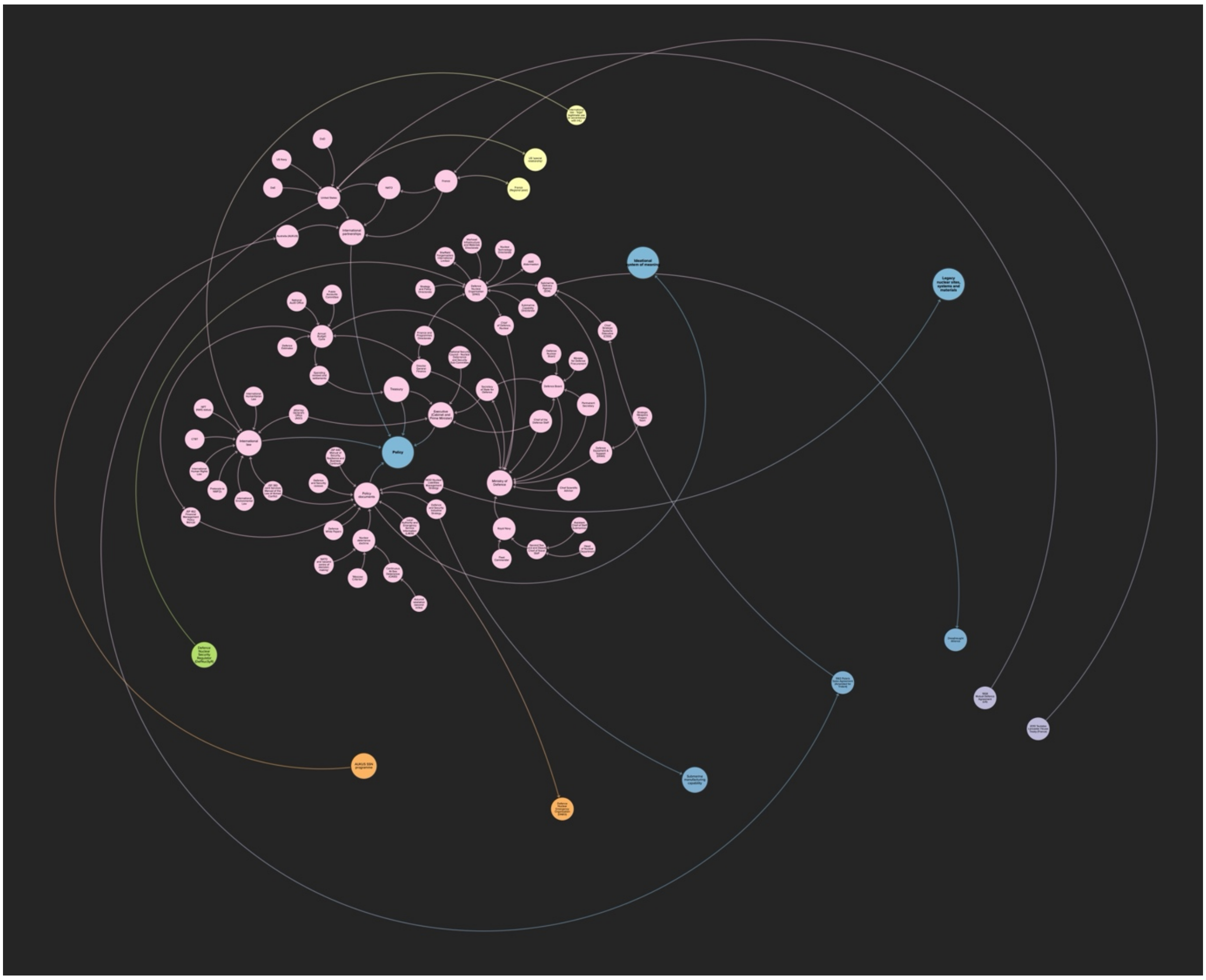
[40] Ibid,; Office for Nuclear Regulation, 'Regulation of the Nuclear Weapon and Naval Nuclear Propulsion Programmes', Nuclear Safety Inspection Guidance Notice, NS-INSP-GD-056 Revision 2, March 2013, p. 10

including: DSA02–DNSR for the Regulation of the Defence Nuclear Enterprise, which contains the overarching regulations and requirements applicable across Authorised Sites and regulated nuclear activities within the Defence Nuclear Enterprise; DSA03–DNSR provides additional regulatory advice and guidance to Inspectors, Authorisees and duty holders in support of Defence Nuclear Enterprise activities; DSA01.1 - Defence Policy for Health, Safety, and Environmental Protection; Joint Service Publication (JSP 471), Defence Nuclear Emergency Response; Joint Service Publication (JSP 628) Security Regulation of the Defence Nuclear Enterprise. DNSR generally uses the Office for Nuclear Regulation (ONR) Safety Assessment Principles (SAPs), Technical Assessment Guides (TAGs) and Technical Inspection Guides (TIGs). Where further specific guidance is required DNSR has produced its own TAGs.

A fundamental feature of UK law (as required by the Health and Safety at Work Act 1974 (HSWA)) is that the risk to the workforce and the public is to be reduced so far as is reasonably practicable (SFAIRP). The legal term SFAIRP is also expressed as “As Low As Reasonably Practicable” (ALARP) in day-to-day usage.

Nuclear Authorisees are required to maintain a comprehensive capability to respond to nuclear emergencies. Joint Service Publication (JSP 471), Defence Nuclear Emergency Response, provides nuclear emergency planning policy requirements. Declaration of a nuclear emergency activates MOD’s Defence Nuclear Emergency Organisation (HQ DNEO) in the Defence Crisis Management Centre (DCMC) as part of the Defence Crisis Management Organisation (DCMO). DNEO maintains a range of contingency plans involving the emergency services and Local and Health Authorities, Fire and Rescue Service Mass Decontamination procedures, the Centre for Radiation, Chemical and Environmental Hazards (CRCE), and the UK Health Security Agency (UKHSA). The Radiological Response Emergency Management System (RREMS) is the dedicated nuclear emergency response information management system used by MOD, industry partners and DSTL as the primary information tool to aid decision makers and responders in the event of a Defence nuclear incident or emergency. RREMS is a part of the joint BEIS/MOD Nuclear Emergency Radiological Information and Monitoring Network (NERIMNET). MOD and industry partners are required to maintain an adequate number of RREMS trained personnel to support the nuclear emergency response.

7. Policy and doctrine infrastructure (Policy)



The 'Policy and doctrine infrastructure (Policy)' system comprises four subsystems:

1. Ministry of Defence (esp. Defence Nuclear Organisation)
2. Executive (Cabinet and Prime Minister).
3. Nuclear deterrence doctrine.
4. International law.

Nuclear weapons policy is ultimately the responsibility of the Prime Minister advised by the Chief of the Defence Staff and National Security Council. Significant nuclear weapons policy decisions have always been taken by the prime minister, with input from a few close Cabinet colleagues and advisers.

Defence nuclear policy is run through the Ministry of Defence and its Defence Nuclear Organisation. DNO is led by the Chief of Defence Nuclear who is accountable to the MOD Permanent Secretary. DNO is responsible for all nuclear submarine programmes, nuclear warhead programmes and defence nuclear relationship with the US, France and Australia. It is split into six directorates and one group: Strategy and Policy Directorate; Submarine Capability Directorate; Corporate Finance Directorate; Security and Safety Directorate; SSN-AUKUS Directorate; Enterprise Portfolio Directorate; and Warhead Group. DNO is also responsible for the Submarine Delivery Agency, AWE, and Sheffield Forgemasters

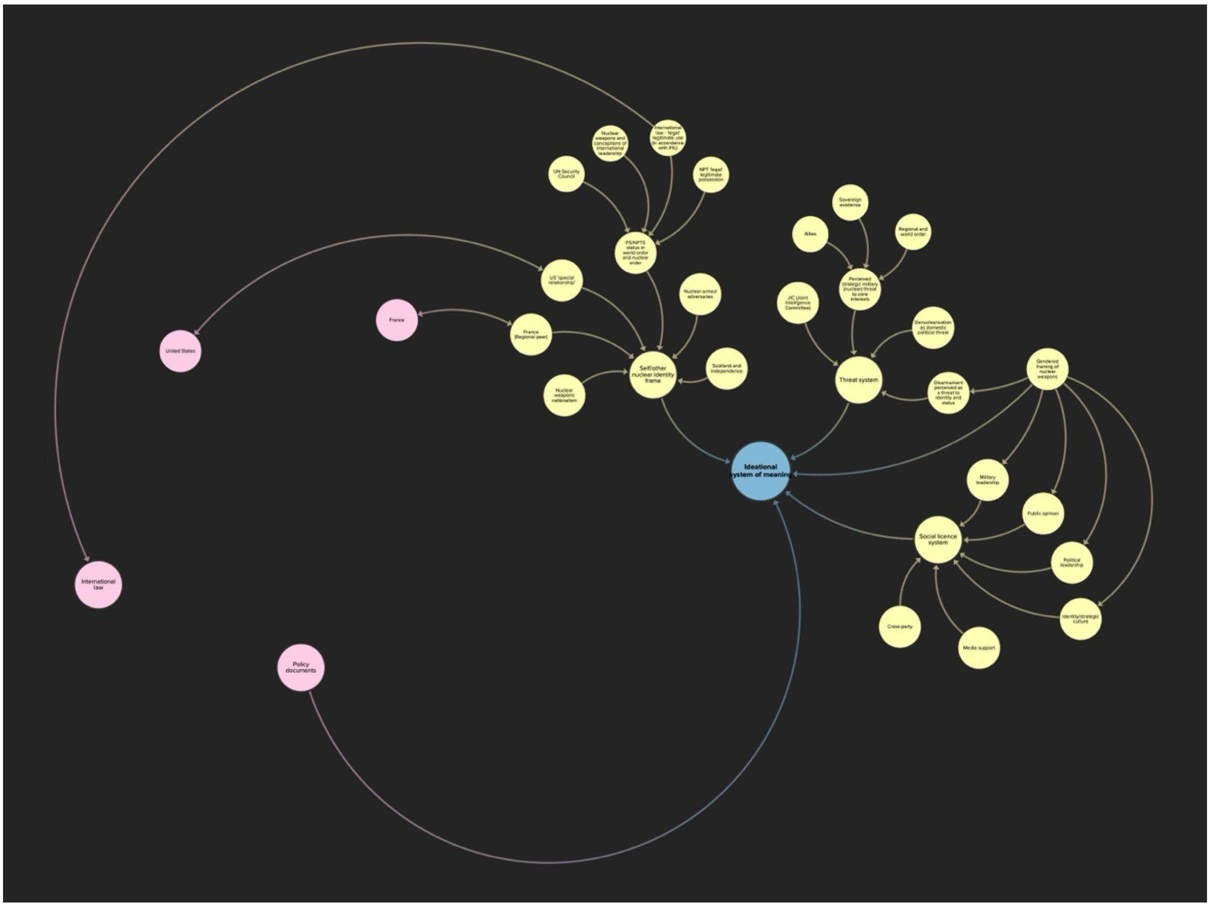
International Limited which produces large scale steel components for submarine programmes and was nationalised in 2021.

The Defence Nuclear Enterprise is overseen by the Defence Nuclear Board - a sub-committee of the Defence Board. It is the most senior board within MOD that deals exclusively with nuclear-related matters and is chaired by the Minister for Defence Procurement. Treasury funding of the Defence Nuclear Enterprise is done through the MOD Annual Budget Cycle directed by Director General Finance as the principal financial advisor for defence responsible for all aspects of financial management and control, including the overall defence budget.

Long-standing UK nuclear deterrence policy rooted in concepts of minimum deterrence, holding Soviet and then Russian centres of power at risk (the so-called 'Moscow Criterion'), the UK constituting a 'second centre' of nuclear weapon decision-making in NATO, and a force posture of continuous at-sea deterrence (CASD) form part of UK government and MOD strategic culture, operating assumptions, defence objectives and is embedded in defence and security policy documents.

UK nuclear weapons policy is also constrained by international legal obligations including customary international law. This includes international humanitarian, environmental and human rights law, the Comprehensive Test Ban Treaty, protocols to regional nuclear weapon-free zones, and commitments under the NPT. The NPT identifies the UK as one of five 'nuclear weapon states', defined as those that had manufactured and exploded a nuclear weapon or other nuclear explosive device prior to January 1, 1967. In so doing, it formally divides NPT States Parties into nuclear and non-nuclear weapon states. This has been interpreted in NWS, including the UK as constituting a legal and therefore legitimate 'right' to possess nuclear weapons.

8. Ideational system of meaning that makes sense of nuclear weapons (Meaning)



The 'Ideational system of meaning that makes sense of nuclear weapons (Meaning)' comprises three subsystems:

1. A self/other nuclear identity frame.
2. A threat system (requiring nuclear weapons) .
3. A social licence system.

There has long been an elite discourse in the UK that associates nuclear weapons with core national identity conceptions. These include an identity as a 'pivotal power' and 'force for good' with responsibilities for international security and an obligation, willingness and capability to intervene actively in international conflicts. Nuclear weapons are judged to provide an 'insurance' against a military intervention going awry. Possession of nuclear weapons therefore reaffirms and in part constitutes a shared UK national identity as an interventionist, pivotal world power.

This extends to self/other identity relationships with the US and the role of nuclear weapons in the 'special relationship' and an 'Atlanticist' identity of being the closest ally of the US. This 'special relationship' identity has several core components that produce particular kinds of national interest and policy outcomes: ensuring that the US remains engaged in the world; a commitment to US values and national security objectives; the capability and willingness to fight alongside the United States with interoperable forces. Nuclear weapons serve two important functions in this context. First, they are perceived to enhance the UK's political and military credibility in Washington by providing a significant power projection capability that is fully interoperable with US forces. Second, by sharing the 'burden' of the nuclear defence of NATO and extension of a nuclear deterrent commitment to Europe. Anchoring itself to the US is therefore a fundamental part of the UK’s security strategy and identity, and nuclear weapons are seen as both an important part of the anchor and a symbol of its strength. Actions that could conceivably have a negative effect on the relationship with the US and thereby undermine the UK’s security must be avoided.

UK nuclear weapons also depend on a shared conception of threat to the UK, allies and core values. The social construction of enemy images is a political process based on prevailing interpretive frameworks for understanding and explaining international security dynamics. UK identity as a nuclear-armed state is asserted through a national security discourse that constructs Russia, China, Iran and other ‘rogue’ states as core nuclear threats to the UK and the wider international order that *require* a UK nuclear capability. This is informed by a discourse of nuclear exceptionalism that often frames nuclear weapons in the hands of the West and its allies as legitimate because Western actions (including the possession and possible use of nuclear weapons) are rooted in a set of values that are universal, irreducible, just, and authoritative whereas nuclear weapons deployed by authoritarian states are illegitimate and undermine the Western idea of international order. Nuclear protection of the liberal international order against non-liberal, non-democratic nuclear-armed ‘other’ is a necessary, global public good.

Nuclear identities pervade popular culture, public opinion, the mainstream media and political parties in ways that generate a ‘social licence’ that supports and legitimises the deployment of UK nuclear weapons. In the Labour Party, for example, the difficult history of its nuclear weapons policy decisions during the Polaris and Trident debates in the 1960s and 1980s threatened to rupture the party leading a long process of transforming the party's foreign policy and defence identity to one in which it was seen as strong on defence and unequivocally supportive of Trident and Britain's status as a nuclear weapon state.

9. Legacy nuclear sites, materials and systems (Legacy)

The ‘Legacy nuclear sites, materials and systems (Legacy)’ subsystem comprises five subsystems:

1. Warhead material production and testing sites.
2. Nuclear weapons design, development, manufacturing and testing sites.
3. Excess fissile materials.
4. RAF bases for nuclear-armed aircraft.
5. Decommissioned UK nuclear weapons.

The purpose of including the Legacy subsystem is 1) to demonstrate extent to which the UK nuclear weapons complex has reduced over time, and 2) to integrate decommissioning and long-term nuclear waste and fissile material management into the map of the current complex.

As noted above, the UK has ceased production of uranium and plutonium for its military programmes and has decommissioned or is in the process of decommissioning military fissile material production sites and other sites associated with the nuclear weapons complex. MOD’s 2022 Nuclear Liabilities Management Strategy sets out policy and processes for managing five categories of liability: submarines, irradiated nuclear fuel, nuclear materials, sites and facilities. and radioactive waste. Submarines encompasses the UK’s 21 decommissioned nuclear-powered submarines that require dismantling, only seven of which have been defueled. Irradiated fuel refers to spent submarine nuclear reactor fuel, this includes fuel that has been removed from submarines and transferred to Sellafield as noted above, fuel that is still in decommissioned submarines, and prototype and test fuel, such as reactor cores that have been tested at the Vulcan Naval Reactor Test Establishment at Dounreay, Scotland. Nuclear materials covers uranium and plutonium that is no longer required for defence purposes, some of which has been placed under IAEA safeguards. The rest is referred to as a strategic reserve for military purposes. Some military uranium and plutonium could be transferred to the Nuclear Decommissioning Authority (NDA) that manages civil nuclear liabilities to immobilise and store pending final disposal. Sites and facilities refers to defence nuclear facilities. The first two sites that will require full decommissioning are the Vulcan site and Rosyth Royal Dockyard. Radioactive waste overs the management of Very Low-Level Waste, Low-Level Waste and Intermediate Level Waste (MOD has no High-Level Waste liabilities).[41]

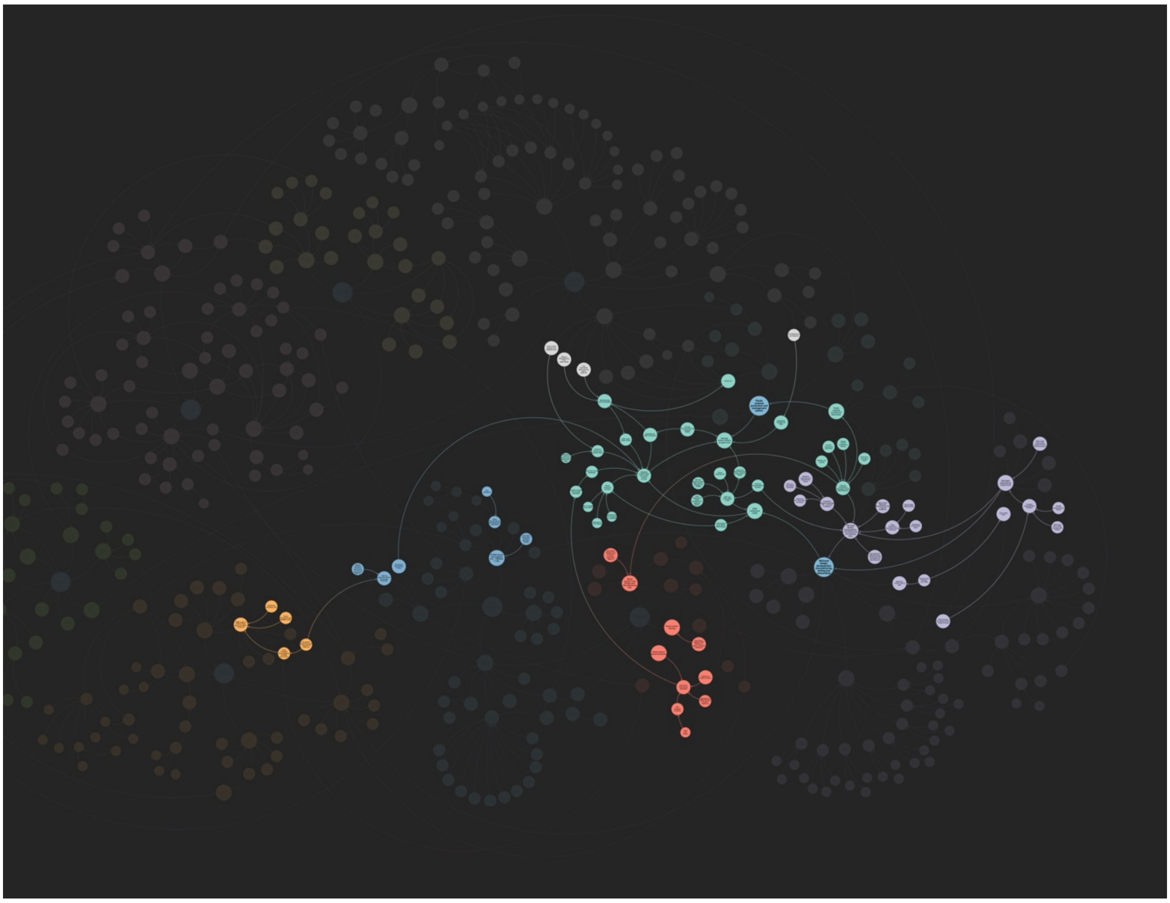
Most of the UK's decommissioned UK nuclear weapon programmes and delivery platform sites were RAF bases in the UK, Germany, Singapore and Cyprus and a series of nuclear bombs developed first independently and then with US support and tested in Australia and the Pacific. For completeness, this subsystem also includes US nuclear cruise missile sites in the UK and US nuclear weapons made available to UK armed forces through a set of agreements called 'Project E'. This included warheads for the short-lived THOR IRBM, depth-bombs for Nimrod aircraft, and nuclear rockets, artillery and atomic demolition munitions for the British Army of the Rhine (BAOR) during the Cold War RAF bases for nuclear-armed aircraft. A separate report for this project has explored the process of denuclearising the RAF in the 1990s following the withdrawal of the WE177 bomb in 1998.

[41] Defence Nuclear Organisation (2022) Nuclear Liabilities Management Strategy,

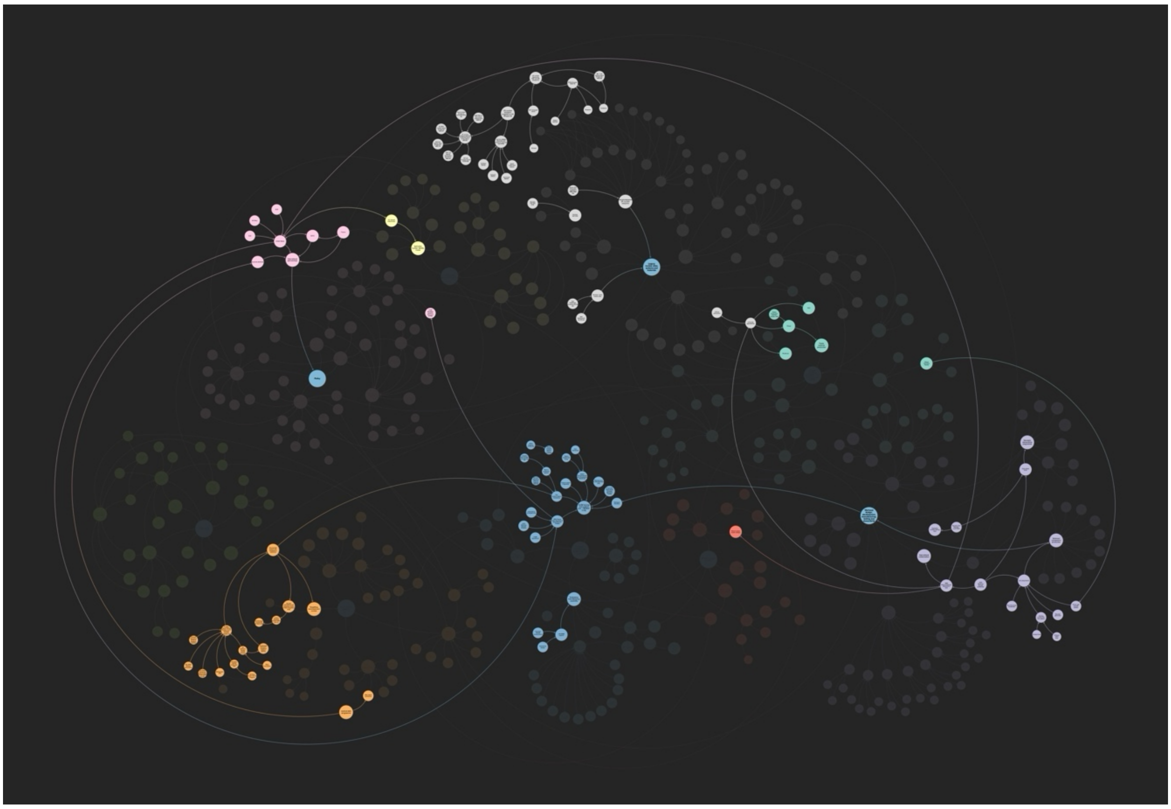
Appendix

The map can also be used to highlight other important components of the UK nuclear weapons complex across the nine subsystems, for example the extent of US support, international agreements, key organisations, nuclear sites and a nuclear waste system.

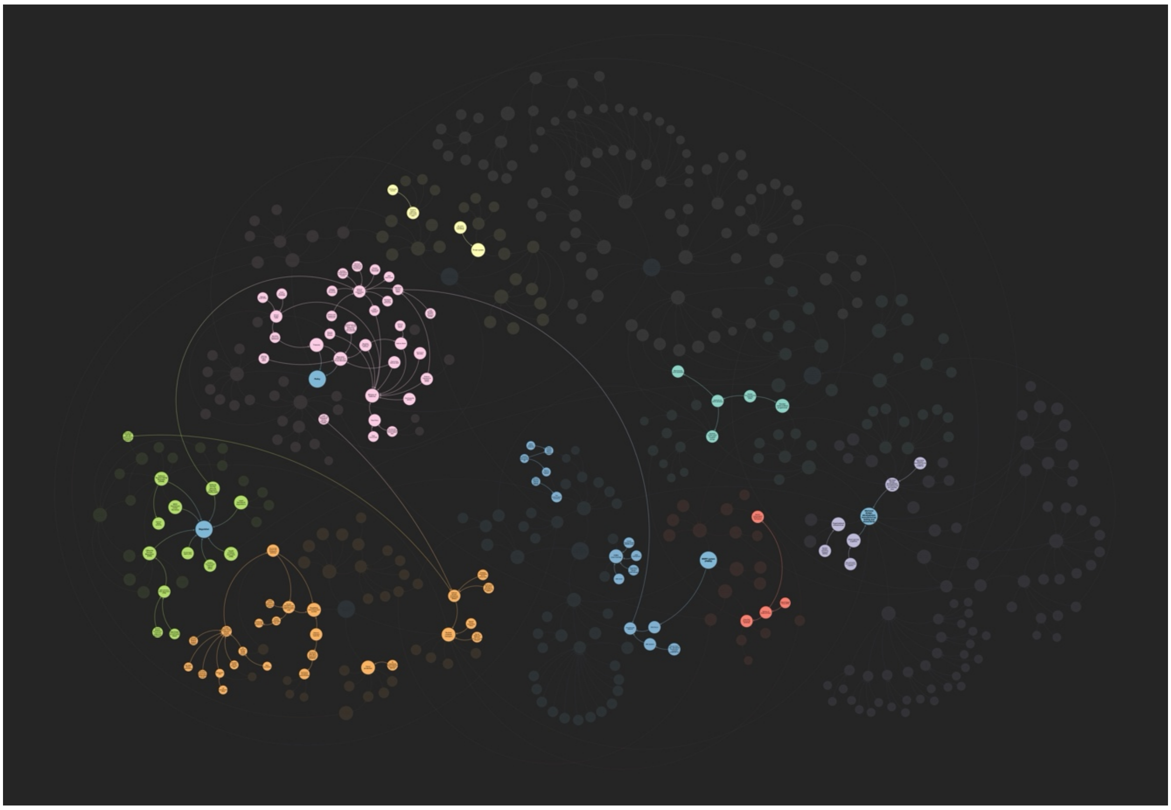
Nuclear sites



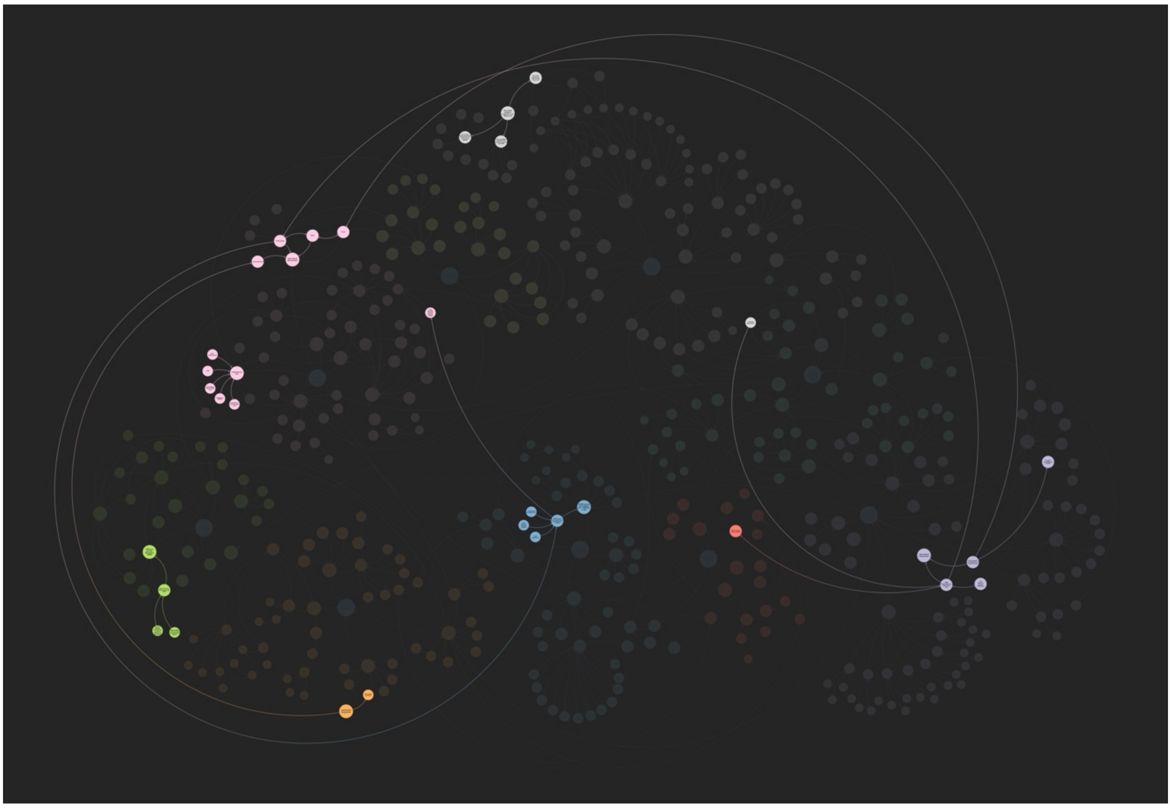
US support



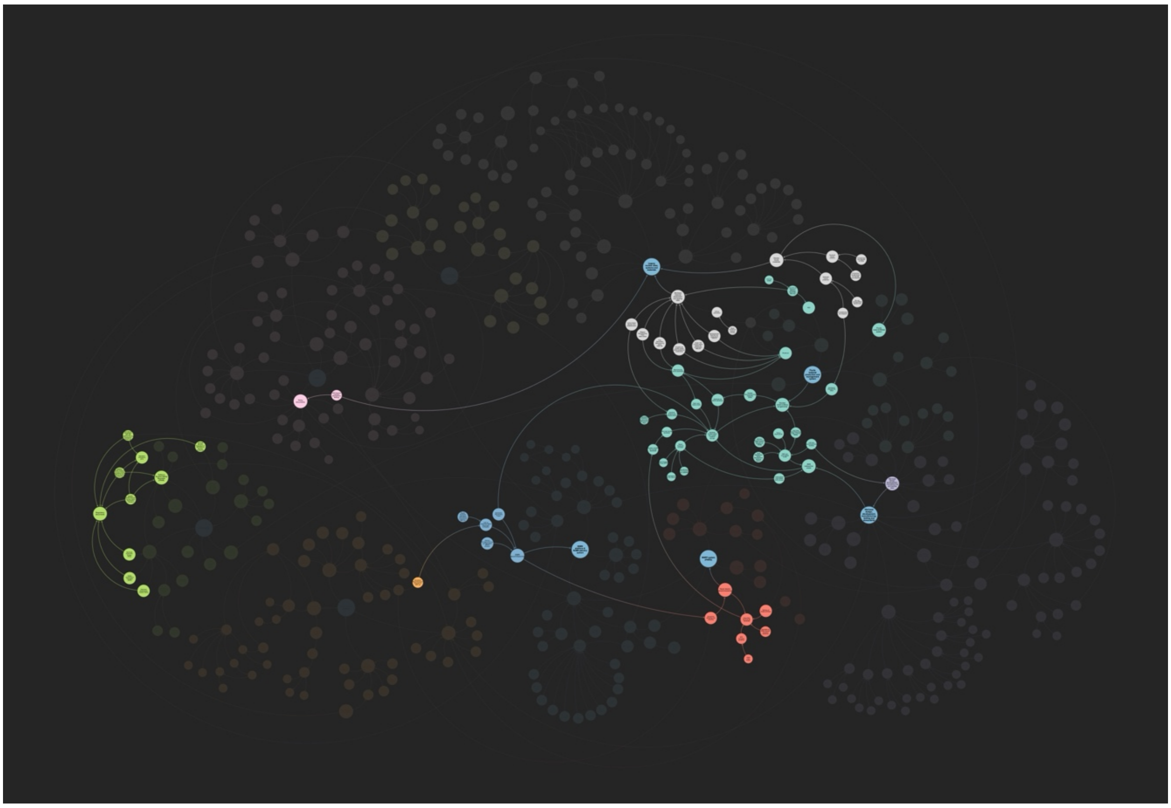
Organisations



International agreements



Nuclear waste and decommissioning



PROJECT ON IRREVERSIBLE NUCLEAR DISARMAMENT

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