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The UK Naval Nuclear Propulsion Programme and Highly Enriched Uranium

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The UK Naval Nuclear Propulsion Programme (NNPP) is highly dependent upon the United States for reactor technology and, in the past, highly enriched uranium (HEU) for its submarine reactor cores. The extent of this dependency is exemplified in the recent transfer of reactor design and technology from the US to aid development of the UK's third generation naval nuclear reactor, the PWR3, intended to power the UK's planned 'Successor' ballistic missile submarine fleet. The UK is highly unlikely to deviate from US reactor technology based on HEU fuel as a consequence of this dependency and the limited perceived benefits of moving to a reactor fuelled with low enriched uranium (LEU) following the French example. Independent exploration, development and research reactor testing of LEU fuel for next generation attack submarines (SSNs) or ballistic missile submarines (SSBNs) is therefore highly unlikely.

Nevertheless, the UK should carefully consider the consequences of being one of only two countries (with the United States) that uses weapon grade uranium for naval propulsion.[1] As one of five recognised nuclear weapon states (NWS) under the 1968 Nuclear Non-Proliferation Treaty (NPT) the UK faces no legal sanction from its continued possession, production and deployment of nuclear weapons and the weapon grade uranium and plutonium therein. Under Article III of the NPT all non-nuclear weapon states (NNWS) parties to the Treaty are required to accept safeguards to verify fulfillment of NPT obligations not to acquire or manufacture nuclear weapons or other nuclear explosive devices. A safeguards agreement is negotiated and concluded with the International Atomic Energy Agency (IAEA) in accordance with the Agency's safeguards system. The five NWS are not subject to Article III and are not required to negotiate a safeguards agreement with the IAEA. They are free to use HEU to fuel nuclear weapons and naval nuclear reactors and they are not under any legal obligation to safeguard weapon-usable fissile material declared to their military programmes, including HEU. All other NNWS parties to the NPT are legally prohibited from developing or acquiring nuclear weapons and any production of plutonium and enriched uranium for civil nuclear reactor programmes is subject to international safeguards verified by the IAEA with one exception: naval nuclear fuel.

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[1] Chunyan Ma and Frank von Hippel, 'Ending the Production of Highly Enriched Uranium for Naval Reactors,' *The Nonproliferation Review*, Spring 2001.

IAEA safeguards agreements with NNWS (INFCIRC/153 (Corrected)) permit suspension of safeguards for nuclear material for 'non-proscribed military activity'. This means that NNWS' can legally withdraw uranium of whatever level of enrichment from safeguarded facilities for use in an unsafeguarded naval nuclear reactor programme, thereby creating nuclear weapon proliferation opportunities and risks. This has been described as a major 'loophole' in the nuclear non-proliferation regime since a NNWS could choose to manufacture highly enriched uranium for a covert weapon programme under the guise of a legitimate naval nuclear reactor programme.[2]

This loophole could conceivably be closed through, *inter alia*:

- A universal legal prohibition on HEU-fuelled naval reactors requiring the development of LEU fuels and reactor cores by states that currently use HEU.
- A legal prohibition on the diversion of HEU to naval nuclear reactor programmes in NNWS only.
- Unilateral or multilateral voluntary phase out of HEU in naval nuclear reactor programmes led by the UK and US as part of a diplomatic initiative to establish an international norm against this practice comparable to US-led international efforts to convert HEU-fuelled civilian research reactors to LEU.

The political prospects for these three responses are currently slim, at best. A fourth intermediate response based on the development of a safeguards regime for HEU in naval nuclear fuel cycles is, however, perhaps a more viable proposition and one that could be taken forward by the UK. This is the focus of this paper and it is explored in four parts. The first provides an overview of the UK's NNPP and dependency on the US. The second details the UK's HEU naval nuclear fuel cycle. The third explores the possibility of a UK NNPP safeguards study. The fourth section examines the verification of a UK NNPP fuel cycle declaration. The conclusion highlights some of the challenges involved.

The purpose of the paper is to make the case that there exists a genuine and important opportunity for the UK to examine the modalities and practical impact of a transparency and safeguards regime for its naval nuclear fuel cycle. The purpose, here, would be to establish international best practice and new norms of responsible nuclear behaviour with respect to the use of HEU that can be legitimately removed from IAEA safeguards in NNWS for non-proscribed military uses, namely a naval nuclear reactor programme.

1. UK dependency on the US NNPP

The UK fuels its current Trafalgar-class and Astute-class attack submarines (SSNs) and its Vanguard-class ballistic missile submarines (SSBNs) with highly enriched uranium fuel. It is currently developing its next generation nuclear propulsion reactor to power the planned Successor submarines that will replace

[2] Greg Thielmann and Serena Kelleher-Vergantini, 'The Naval Nuclear Reactor Threat to the NPT', *Threat Assessment Brief,* Arms Control Association, Washington, D.C., 24 July 2013. Available at <https://www.armscontrol.org/files/TAB_Naval_Nuclear_Reactor_Threat_to_the_NPT_2013.pdf>

the Vanguard-class. Nuclear propulsion technology is highly classified. In the UK it is treated with even greater sensitivity than those technologies associated with the production of nuclear warheads.

The UK's Naval Nuclear Propulsion Programme is closely tied to the United States. The United States supplied the UK with its first naval nuclear reactor and has supplied fissile material for core fabrication. US assistance to the UK NNPP has been part of a wider programme of military nuclear cooperation that dates back to the 1940s Manhattan project. Cooperation abruptly ended in 1946 when the US Congress passed the Atomic Energy Act (the McMahon Act) that severely limited the transfer of restricted nuclear information and materials to any other state, causing a major rift with its wartime ally in London. Negotiations to re-establish exchange of military atomic defence information, materials and technology began after an independent UK nuclear weapons programme tested its first atom bomb in 1952 and hydrogen bomb in 1957. Britain's nuclear dependence on the United States was then cemented in the 1958 Mutual Defence Agreement (MDA) and five years later the 1963 Polaris Sales Agreement (PSA). The MDA allowed for the exchange of naval nuclear propulsion technology between the United States and UK. The UK had already initiated an indigenous NNPP in 1956 a year before the decisive H-bomb test, but by then the United States programme was already developing its fifth generation naval reactor. After a series of exchange visits in 1957-58 the United States agreed to supply the UK with one complete submarine nuclear reactor plant. This was the latest S5W pressurised water reactor (PWR) design for the US Skipjack-class submarine. The S5W went on to power a total of 98 US submarines, including different classes of SSNs and the Polaris SSBN fleet.[3]

The agreement reached under the auspices of the MDA involved the transfer of reactor technology and manufacturing expertise from Westinghouse in the United States to Rolls Royce in the UK. This enabled the UK to deploy its first nuclear-powered submarine, HMS Dreadnought, several years earlier than originally envisaged.[4] HMS Dreadnought was launched in 1960 and commissioned into service in 1963. Under the terms of the agreement cooperation on nuclear propulsion came to an end in mid-1963 exactly one year after the UK's S5W plant became operational. NNPP cooperation was terminated as a condition of the transfer in order to ensure future UK operational, design and safety independence.[5] The S5W reactor was fuelled with a core enriched in ^{235}U to between 93 and 97%.[6]

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[3] Vice Admiral Sir Robert Hill, 'Admiral Hyman G Rickover USN and the UK Nuclear Submarine Propulsion Programme', Thomas Lowe Gray Memorial Lecture presented to the Institution of Mechanical Engineers, 19 April 2005.

[4] Steve Ludlam, 'The Role of Nuclear Submarine Propulsion', in P. Cornish and J. Mackby, *U.S.-UK Nuclear Cooperation After 50 Years* (Washington, D.C.: CSIS Press, 2008), p. 255.

[5] Interview with R. Hill, former Chief Naval Engineer Officer, Royal Navy, in .P. Cornish and J. Mackby, *U.S.-UK Nuclear Cooperation After 50 Years* (Washington, D.C.: CSIS Press, 2008), p. 367.

[6] Some reports say 93%, some slightly higher. Military uranium for US naval reactors has previously been enriched to 97% ^{235}U. Testimony of Admiral McKee, Procurement and military Nuclear Systems subcommittee, House of Representatives Committee on Armed Services, Hearing on H.R.4526 Department of Energy National Security Authorizations Act FY1987-88, 20 February 1986, p. 26.

The UK's first indigenous plant and core (PWR1) based on the S5W Westinghouse design was built by Rolls Royce and deployed in the attack submarine HMS Valiant in 1966. Three sets of cores were developed for PWR1. Core 1 powered the UK's Valiant-class SSNs and Resolution-class SSBNs that carried the US Polaris strategic weapon system, core 2 powered the Churchill-class SSNs, and core 3 powered the Swiftsure and Trafalgar-class SSNs. The current PWR2 reactor was designed for the UK's Vanguard-class SSBNs that entered service in the 1990s to replace the Resolution-class and carry the US Trident strategic weapon system. Design work began in 1977 and the first PWR2 reactor was completed in 1985 with testing beginning in August 1987. The current PWR2 core design, 'Core H', has been designed to last the lifetime of the reactor (25-30 years) thereby eliminating costly mid-life reactor refuelling. Core H fuels the new Astute-class SSNs and the four Vanguard-class SSBNs were fitted with the core during their long overhaul and refuelling refits between 2002 and 2012.[7]

UK reliance on US NNPP expertise is set to deepen with the development of a new PWR3 reactor for the planned Successor SSBN announced in the coalition government's *Submarine Initial Gate Parliamentary Report* in May 2011.[8] MoD's Defence Board said the PWR3 would be 'based on a modern US plant'[9] and US support provided 'independent peer review of the UK's NNPP capability and helped to optimise its PWR3 concept design.'[10] In 2012 the US Navy said: 'Naval Reactors is providing the UK Ministry of Defence with US naval nuclear propulsion technology to facilitate development of the naval nuclear propulsion plant for the UK's next generation SUCCESSOR ballistic missile submarine'.[11] It has been suggested that MoD has been 'given visibility of the S9G reactor design that equips the US Navy's latest Virginia-Class nuclear-powered attack submarines'.[12] PWR3 will in all likelihood power the new Successor flotilla pending parliamentary approval at the 'main gate' investment decision in 2016 and possibly the next generation SSN currently dubbed Maritime Underwater Future Capability (MUFC) depending on the size of submarine.[13] The US-UK MDA

[7] The Vanguard-class is currently scheduled to be replaced by the new 'Successor' SSBN beginning 2028 when HMS Vanguard is due to retire.
[8] Ministry of Defence, The United Kingdom's Future Nuclear Deterrent: The Submarine Initial Gate Parliamentary Report (London: Ministry of Defence, 2011).
[9] Defence Board 09(62) Successor Submarine Project, Note by the Assistant Secretary, DNSR/22/11/2, 4 November 2009, http://robedwards.typepad.com/files/declassified-report-to-mod-defence-board.pdf date accessed 15 February 2015.
[10] Chris Palmer, 'Management of Key Technologies in the UK Naval Nuclear Propulsion Programme', presentation at the CSIS Project on Nuclear Issues (PONI) Capstone Conference 2011, US Strategic Command, 6 December 2011.
[11] Roland O'Rourke, *Navy Ohio Replacement (SSBN[X]) Ballistic Missile Submarine Program: Background and Issues for Congress* (Washington, D.C.: Congressional Research Service, Library of Congress, 2013), p. 8. O'Rourke's source is 'E-mail to CRS from Navy Office of Legislative Affairs, June 25, 2012.
[12] Julian Turner, 'Deep impact: inside the UK's new Successor-Class nuclear submarine', Naval-Technology.com, 30 July 2013. Available at http://www.naval-technology.com/features/feature-nuclear-submarine-successor-uk-royal-navy/
[13] Rear Admiral Andrew Mathews, 'Showing the US the way', talk at the Royal United Services Institute, London, January 17, 2008.

is renewed every 10 years. In the latest update negotiated and agreed in July 2014 Article III of the treaty was modified to authorize transfer of new reactor technology, spare parts, replacement cores and fuel elements.[14] The original text of the treaty referred to the transfer by sale of only *one* complete submarine nuclear propulsion plant (the original S5W).

The UK has also been dependent upon the United States for special nuclear materials (highly enriched uranium and plutonium) and tritium gas for its nuclear warhead and nuclear propulsion programmes. The UK initially obtained HEU for its military programme from its gas diffusion plant at Capenhurst. Capenhurst was established as the sole UK uranium enrichment site for both civil and military applications. This began in 1952, but production of HEU for military purposes ended a decade later in 1962.[15] Since then the UK has received HEU for both its warhead programme and NNPP through exchanges of special nuclear material with the US Department of Energy under the MDA. The UK imported natural uranium ore concentrate from the United States, Australia, South Africa, Namibia, Belgian Congo and Canada[16] and converted it into uranium hexafluoride (UF_6) at the UK's Springfields site in Lancashire. UK hex was then shipped to the United States for enrichment at the US Portsmouth Gaseous Diffusion Plant in Piketon, Ohio.[17] HEU enriched to between 93-97% in ^{235}U was transported back to the UK by military aircraft.

In 2000 the UK provided details of three 'barters' with the United States of special nuclear materials between 1960 and 1979. The UK supplied approximately 5.4 tonnes of plutonium and received in exchange 6.7kg of tritium and 7.5 tonnes HEU for the defence nuclear programme, including NNPP.[18] Further contracts with the US Department of Energy to supply HEU were reportedly signed in 1981 and 1987.[19] Use of US enrichment services to enrich UK-supplied uranium to the required level was reportedly formalised in the 1984 amendment to the MDA.[20] In fact, according to the International Panel on

[14] Foreign and Commonwealth Office, '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, Washington, D.C, 22 July 2014, p. 3.

[15] The Capenhurst site comprises two main facilities adjacent to each other. One is run the Nuclear Decommissioning Authority and one by URENCO. The NDA site gas diffusion plant ceased to operate in 1982 and has been decommissioned. The URENCO site produces low enriched uranium under commercial contract for nuclear fuels and is subject to Euratom and IAEA safeguards. In 2011 the NDA transferred its activities Capenhurst to Urenco. Molly Berkemeier, Wyn Q. Bowen, Christopher Hobbs and Matthew Moran, 'Governing Uranium in the United Kingdom', Danish Institute for International Studies, Copenhagen, 2014, p. 42.

[16] Since 2006 all of the uranium converted at the Springfields site comes as UO_3 from the Cameco Blind River Refinery in Ontario, Canada, to be processed into UF6 for Cameco to deliver to its utility customers, who ultimately use it for fuel in nuclear reactors after further processing. Berkemeier, *et al*, 'Governing Uranium in the United Kingdom', p. 21.

[17] Martin Bond, *Nuclear Juggernaut: The Transport of Radioactive Materials* (London: Earthscan, 1992), p. 31.

[18] Ministry of Defence, 'The United Kingdom's Defence Nuclear Weapons Programme: Plutonium and Aldermaston - An Historical Account', 2000, p. 9.

[19] Bond, *Nuclear Juggernaut*, p. 31.

[20] Peter Burt, 'Reform not Renewal: The US-UK Mutual Defence Agreement', Nuclear Information Service, Reading, June 2014, p. 10.

Fissile Materials (IPFM – a nongovernmental organisation that tracks HEU and plutonium worldwide), the UK is estimated to have received more than half of its HEU supply from the United States with an estimated transfer of at least 14 tonnes.[21]

The UK appears to have shown little interest in the development of LEU cores for submarine nuclear reactors. It remains tied to the US NNPP programme for materials, design and support under the auspices of its nuclear weapons programme, for which it also remains heavily dependent upon continued US patronage. Unless and until the US NNPP opts for an LEU propulsion plant and is prepared to share (or perhaps co-develop) such a plant with the UK, or until the UK terminates its nuclear-powered submarine programme, the UK looks set to power its submarine flotilla with current and future iterations of its HEU-fuelled PWR3.

UK nuclear weapons policy is, like many policy areas, subject to political, technical and organisational resistances to changes in policy and practice, particularly those that challenge prevailing conceptions of what constitutes an 'effective' nuclear deterrent threat in exchange for ambiguous non-proliferation benefits. The conservatism of nuclear policy communities has been well documented.[22] This applies equally to the prospect of conversion from HEU to LEU. Absent a change in nuclear mission requirements for its SSBN fleet legitimated by a shift in conceptions of what constitutes an effective UK nuclear deterrent threat and a centrally funded research, development and testing programme then non-proliferation concerns alone are unlikely to incentivise a transition in the UK NNPP programme to LEU.

2. The UK NNPP fuel cycle

In the absence of active US, US-UK, or multilateral leadership to phase out HEU-fuelled naval reactors the UK and/or US could instead develop international best practice for safeguards and transparency of HEU in naval nuclear fuel cycles, as noted in the introduction. However, given the acrimonious politics of the nuclear non-proliferation regime, it is highly unlikely that NNWS will accept additional legal safeguards to address this loophole, particularly if NWS are exempt.[23] NNWS might be willing to negotiate and apply a voluntary naval nuclear fuel cycle safeguards protocol developed by or in collaboration with NWS and

[21] The International Panel on Fissile Materials, *Global Fissile Material Report 2010*, p. 13. Available at <http://fissilematerials.org/library/gfmr10.pdf>.

[22] For example in Janne Nolan, *An Elusive Consensus: Nuclear Weapons and American Security After the Cold War* (Washington D.C.: Brookings Institution Press, 1999) and Tom Sauer, *Nuclear Inertia: US Nuclear Weapons Policy after the Cold War* (London: I.B. Taurus, 2005).

[23] Resistance to voluntary adoption of the IAEA's 1997 Additional Protocol as an additional imposition on NNWS with IAEA Comprehensive Safeguards Agreements in force highlights to difficulty of negotiating a NNWS-only naval nuclear fuel cycle safeguards protocol. Mark Hibbs, 'The Unspectacular Future of the IAEA Additional Protocol', *Proliferation Analysis*, Carnegie Endowment for International Peace, Washington, D.C., 26 April 2012. Available at <http://carnegieendowment.org/2012/04/26/unspectacular-future-of-iaea-additional-protocol>.

adopted by NWS (what Egel, Goldblum and Suzuki call a Naval-Use Safeguards Agreement, or NUSA in their working paper for this Task Force[24]).

The UK is well placed to explore the modalities and limits of applying international safeguards and additional transparency measures to its NNPP HEU for two reasons:

1) The UK NNPP is lean. It is centred on a handful of facilities and does not include an enrichment plant. This following section provides an overview of the principal facilities and processes such as is available from open sources (see the map of facilities in Appendix 2). The facilities are:
   - AWE Aldermaston, Reading (processing HEU components).
   - Rolls Royce Marine Power Operations at Raynesway, Derby (reactor design and fuel fabrication).
   - BAE Systems Maritime Devonshire Dock Complex, Barrow-in-Furness (reactor core assembly and commissioning).
   - Devonport Royal Dockyard and HMNB Devonport, Plymouth (defueling/refueling).
   - Nuclear Decommissioning Authority's Sellafield site, Cumbria (long term irradiated fuel storage).

2) The UK has in the recent past self-identified as a NWS committed to nuclear disarmament and taking an active leadership role as a 'disarmament laboratory' in developing solutions to disarmament challenges.[25] This is discussed further in the third and fourth sections of the paper.

AWE Aldermaston

The UK's Atomic Weapons Establishment (AWE) comprises AWE Aldermaston and AWE Burghfield near Reading, Berkshire. AWE is owned by MoD but since 1993 has been managed under a Government Owned Contractor Operated (GOCO) arrangement. The current operator is AWE Management Ltd, a consortium comprising Lockheed Martin Corporation, Jacobs Engineering Group Inc., and Serco Group plc. AWE Aldermaston stores and processes HEU for initial fabrication into reactor fuel for the NNPP in its aging A45 enriched uranium handling facility that can cast, machine and recycle HEU.[26] Planning for a new Enriched Uranium Facility (Project Pegasus) began in 2006 with the new complex due for completion in 2016, though this has now been extended to 2020 after several years of delay and cost overruns.[27] The Nuclear Information Service

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[24] N. Egel, B. L. Goldblum, and E. Suzuki, 'Safeguarding Nuclear Material in the Naval Sector: An Examination of Governance Frameworks', Nuclear Policy Working Group University of California, Berkeley, September 2014.
[25] Margaret Beckett (UK Foreign Secretary), 'A World Free of Nuclear Weapons?', Carnegie International Nonproliferation Conference, Keynote Address, 25 June 2007.
[26] Ministry of Defence, 'Historical Accounting'.
[27] Peter Burt, 'Project Pegasus – AWE Aldermaston's proposed Enriched Uranium Facility', *Nuclear Information Service*, November 2009. Available at <http://www.nuclearinfo.org/sites/default/files/AWE%20EUF%20briefing%20November%20 2009.pdf>. Recent reports indicate the project has been put on hold due to design and

reports that the Pegasus complex will comprise a new receipt and dispatch store, including a materials unloading and reception area and facilities for packaging materials for on and off-site transport. It will also include a 'process building and process annex with the equipment and workstations needed to manufacture enriched uranium products, including casting facilities and furnaces, electroplating baths, and equipment for rolling, heat treating, forming, shearing, and machining uranium metal', plus uranium storage vaults, a waste management and processing area including equipment for recovering enriched uranium from wastes, a Work Control Centre to control the movement of fissile materials within the facility.[28] The Ministry of Defence says AWE's enriched uranium handling facilities are 'required to maintain Trident in service, to provide successor warhead capability, submarine reactor fuel material, and to safely withdraw warheads at the end of their service life'.[29]

AWE does not enrich uranium and the UK has no plans to indigenously produce any more HEU. In 2006 MoD revealed the total audited stock of UK HEU at 21.86 tonnes as of March 2002.[30] The IPFM estimates that the UK consumed about 0.7 tonnes of its HEU stockpile during the ten-year period from 2002 to 2012. Making the conservative assumption that all of this consumption was due to fuelling of submarines, the consumption rate for the NNPP is about 0.07 tonnes annually. The IPFM also estimates that 7.2 tonnes of the UK stockpile of 21.2 tonnes as of end of 2012 is devoted to the NNPP. IPFM therefore conservatively estimates the UK has 80 or more years worth of HEU fuel for its NNPP. In addition, the IPFM estimates that the UK has about 11.7 tonnes available for weapons use and the UK has declared 1.4 tonnes for civilian purposes. Therefore, given the relatively huge stockpile of available HEU for the NNPP, the UK is not facing any shortfall pressure to switch to LEU for the foreseeable future.[31]

Research reactors

HEU has also been used in small quantities in a number of UK research reactors (about 700kg according to the International Panel on Fissile Materials), most which have been shut down or decommissioned.[32] This includes naval propulsion test reactors at the Vulcan Naval Reactor Test Establishment (NRTE), formally HMS Vulcan, at Dounreay in Scotland operated by Rolls Royce on behalf of MoD. The site was used to develop and test prototypes for the PWR1 and PWR2 naval reactor core types as well as research, manufacture, fuel examination and reprocessing of relatively small amounts of HEU test reactor

management problems. Rob Edwards, 'Pegasus grounded: vital Trident bomb project 'on hold' after problems', *Sunday Herald,* 8 March 2015.

[28] Ibid.

[29] Enriched Uranium Facility Initial Gate Business Case', DES/NW/PSO/555/35. Ministry of Defence, 3 April 2007, p. 1.

[30] Ministry of Defence, 'Historical Accounting'.

[31][31] Personal communication from Charles Ferguson, Alexander Glaser and Frank von Hippel of Princeton University, 10 March 2015; see also the 2010 and 2013 Global Fissile Reports of the International Panel on Fissile Materials, available at: http://www.fissilematerials.org.

[32] IPFM, *Global Fissile Material Report 2010*, p. 76. See also the IAEA Research Reactor Database at <http://www.iaea.org/OurWork/ST/NE/NEFW/Technical-Areas/RRS/databases.html>.

fuel.[33] The current Shore Test Facility reactor at Dounreay was commissioned in 1987 and houses the PWR2 prototype reactor that is currently proving the design of the latest submarine core.[34] The STF reactor has a short remaining life and plans are underway to remove stored fuel in the near future.[35]

Other decommissioned reactors fuelled with HEU include a small high neutron flux research reactor (VIPER) at AWE Aldermaston, a materials test reactor (HERALD) at AWE Aldermaston, and MoD's JASON research and training reactor at Greenwich.[36] The UK's remaining operational test reactors are the NEPTUNE facility at the Rolls Royce Raynesway site (see below) and Dounreay's Shore Test Facility.

Rolls Royce Marine Power Operations, Raynesway

Rolls Royce Marine Power Operations Limited (RRMPOL) operates two nuclear licensed sites at Raynesway, Derby: 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.[37]

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. The NFPP comprises 'the chemical plant, the "contact" shop (covering operations with unclad material), the "clean" shop (covering operations with clad material), the "Nuclear Materials Services" (NMS) shop (covering manufacture of stainless steel components), and the ancillaries/services facilities.'[38] HEU fuel components received from AWE are processed and the submarine nuclear reactor cores are fabricated and assembled. 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. The form and shape of HEU received from Aldermaston changes through the manufacturing process.[39] Completed fuel assemblies are

[33] Ministry of Defence, 'Historical Accounting for UK Defence Highly Enriched Uranium', March 2006, p. 4.
[34] Ministry of Defence, 'Nuclear Liabilities Management Strategy', 2011, p. 51.
[35] Defence Safety and Environment Authority, 'Japanese Earthquake and Tsunami: Implications for the UK Defence Nuclear Programme - A Regulatory Assessment by the Defence Nuclear Safety Regulator', July 2012, p. 31.
[36] Ministry of Defence, 'Historical Accounting', p. 3; Bond, *Nuclear Juggernaut*, p. 44.
[37] Health and Safety Executive, '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', May 2002.
[38] Office for Nuclear Regulation, 'Project Assessment Report', document no. ONR-RRMPOL-PAR-13-003, July 2013. Available at <http://www.onr.org.uk/pars/2013/rolls-royce-1.pdf>.
[39] Ibid.

stored at Raynesway prior to delivery.

Core production is being modernised at Raynesway and in February 2013 the final phase of a new core production facility was initiated. This is part of the UK's Core Production Capability Regeneration Project involving a comprehensive 11-year regeneration of the Raynesway site.

BAE Systems Maritime, Barrow-in-Furness

The PWRs that power the UK's attack and ballistic missile submarines are assembled and commissioned at BAE Systems Maritime's Devonshire Dock Complex at Barrow, which is the UK's only remaining submarine construction yard. 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.[40] 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 fuel remains within the RPV until it is spent and removed. The Office for Nuclear Regulation says 'The Site Safety Case allows nuclear fuel for a number of cores to be on site at any one time. Only one reactor core is permitted in any one facility on the site at any one time.'[41]

HMNB Clyde, Scotland

HM Naval Base (HMNB) Clyde, north west of Glasgow, is not part of the UK NNPP HEU fuel cycle but it does provide facilities for the operation, maintenance, and repair of all classes of UK submarine. The base is owned and operated by the MoD through the principal Clyde operating contractor, Babcock Marine Ltd. HMNB Clyde is the base port for the Vanguard-class SSBNs that deploy the US-designed and built Trident strategic nuclear weapon system. It is also the base port for the Astute-class SSNs and will be the base port for all remaining Trafalgar-class boats from 2018.[42] 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. Refueling or defueling of submarine nuclear reactor cores does *not* take place at the Clyde base.

Devonport Royal Dockyard and HMNB Devonport, Plymouth

The Devonport site in Plymouth, Devon, comprises two adjacent sites: HMNB Devonport and the Devonport Royal Dockyard. HMNB Devonport is the homeport for the Trafalgar-class attack submarines until 2018. Devonport can be

[40] Ministry of Defence, 'Local Authority and Emergency Services Information (LAESI) Edition 8', May 2011, p. 6.
[41] Submission by BAE Systems to the Office for Nuclear Regulation following the Fukushima nuclear disaster (no date provided). Available at <http://www.onr.org.uk/fukushima/bae-submission.pdf>.
[42] Ministry of Defence, 'Nuclear Liabilities', p. 46.

used by any of the Royal Navy's submarines for visits, replenishment of stores, and planned maintenance operations.[43] 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 reactor defueling and refueling. Devonport Royal Dockyard is commercially owned and Devonport Royal Dockyard Ltd (DRDL, a subsidiary of Babcock International Group plc.) is the site operator.[44]

The UK's nuclear-powered submarines are currently defueled and refuelled at the Devonport Royal Dockyard at least once during their service life. Rolls Royce's current 'Core H' is designed to last the service life of the new Astute-class SSN thereby eliminating the need for mid-life refuelling. All four Vanguard-class SSBNs were fitted with a 'Core H' as part of their planned Long Overhaul Period (Refuel) (or LOP(R)) between 2002 and 2012. However, in March 2014 MoD revealed a breach in the fuel cladding of the PWR2 prototype test reactor at Dounreay that allowed low-level radiation to leak into its sealed cooling circuit. As a result a decision was taken to replace the core in HMS Vanguard again during its next planned maintenance visit to Devonport in 2015.[45]

Attack submarines are currently de/refuelled at the dockyard's Submarine Refit Complex (SRC). The SRC, located in the northwest corner of 5 Basin, is comprised of 14 and 15 Docks, the Nuclear Support Facility (NSF) building, and the Nuclear Utilities Building (NUB).[46] A 'Future Nuclear Facilities' programme to provide a new defueling capability in the Submarine Refit Complex is nearing completion. The programme involves upgrading the dry dock and associated equipment for defueling decommissioned Swiftsure and Trafalgar-class attack submarines and, in time, the four operational Trafalgar and new Astute-class boats. 5 Basin also houses the Low Level Refuelling Facility for the temporary storage of used nuclear fuel prior to its departure off site for long-term storage, and of new fuel prior to its installation on the submarines.[47] Ballistic missile submarines are de/refuelled in 9 Dock in 5 Basin.

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. Access to the RC is gained by cutting holes in the submarine pressure hull directly above the reactor pressure vessel (RPV)…. The spent Fuel Modules (FM) and Neutron Sources (NS) are then raised from the RPV and temporarily parked in shielded storage boxes within the shielded tank. The FM/ NS is then lifted into a shielded transport container

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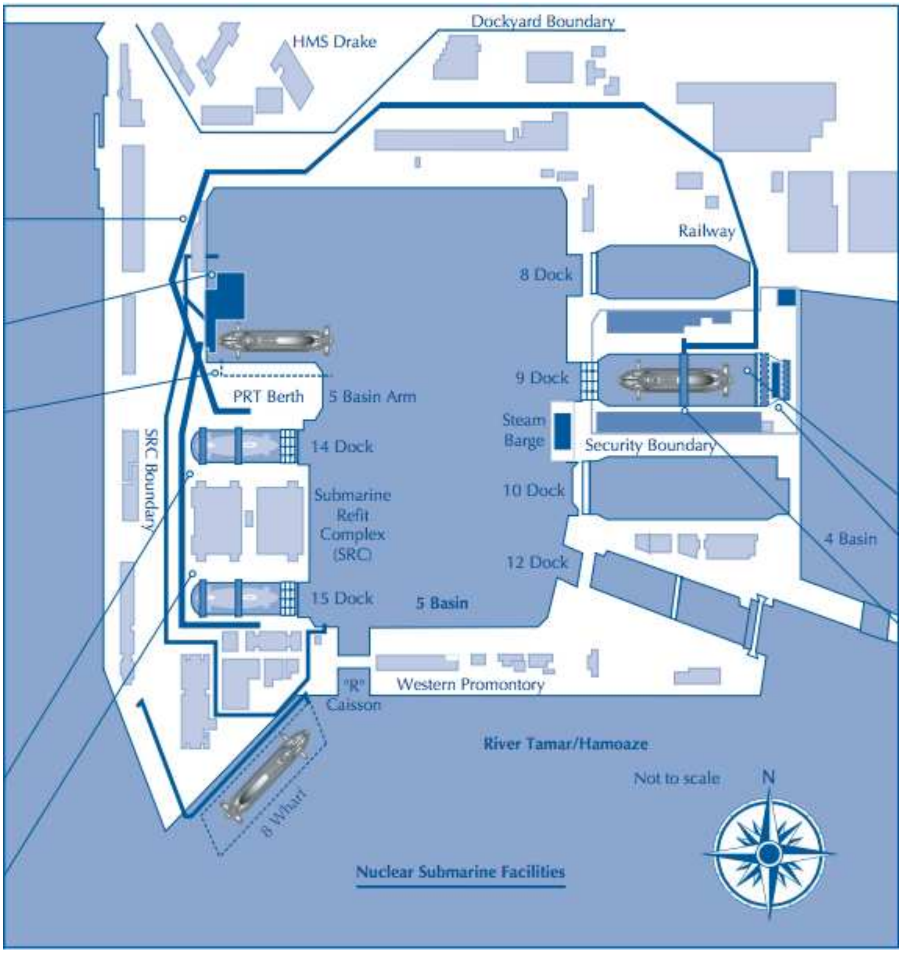
[43] Ibid., p. 47.
[44] Ibid., p. 48.
[45] Hugh Chalmers, 'The UK's Naval Nuclear Reactors: Ageing Ungracefully?', Royal United Services Institute, RUSI Analysis, 11 March 2014.
[46] Babcock, 'Decommissioning/Disposal Strategy: Submarine Dismantling – Facility Gap Analysis', p. 14. Date not given but likely 2011. Available at <https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/34127/20110815Facility_Gap_Analysis_Oct_2010U.pdf>.
[47] National Audit Office, 'The Construction of Nuclear Submarine Facilities at Devonport', HC 90 (HMSO: London, December 2002), p. 4.

before removal from the RAH to another facility within the Dockyard for onward processing.'[48] Irradiated fuel removed from submarines is moved to a storage facility for the temporary storage prior to consignment to Sellafield.[49]

Diagram of 5 Basin[50]



As of 2011 the UK had ten defueled decommissioned submarines stored afloat at Devonport, four of which have been defueled as part of the De-fuel, De-equip and Lay-up Preparation (DDLP) process. The remaining six submarines have received lay-up preparation and are stored without prior defueling whilst new defueling facilities are constructed under the Future Nuclear Facilities project.[51]

[48] Atkins, 'Future Nuclear Facilities'. Available at <http://www.atkinsglobal.co.uk/sectors-and-services/sectors/defence/documents/~/media/Files/A/Atkins-UK/Attachments/sectors/defence/library-docs/case-studies/futurenuclearfacilitiesfnf.pdf>. No date given.
[49] Ministry of Defence, 'Nuclear Liabilities', p. 48.
[50] Reproduced from National Audit Office, 'The Construction of Nuclear Submarine Facilities at Devonport', HC 90 (HMSO: London, December 2002), p. 12.
[51] Ministry of Defence, 'Nuclear Liabilities', p. 14; Office for Nuclear Regulation, 'Regulation of the Nuclear Weapon and Naval Nuclear Propulsion Progammes', Nuclear Safety Inspection Guidance Notice, NS-INSP-GD-056 Revision 2, March 2013, p. 11.

A further seven defueled submarines are currently stored afloat at the Rosyth Royal Dockyard on the Firth of Forth in Scotland.

Nuclear Decommissioning Authority's Sellafield site, Cumbria

Irradiated nuclear reactor fuel is transported once or twice a year by rail to Sellafield by Direct Rail Services (the UK's last publically-owned rail freight company) in nuclear flasks. DRS was created by British Nuclear Fuels Limited (BNFL) with ownership then transferred to the Nuclear Decommissioning Authority (NDA) in 2004.[52] Spent naval reactor fuel is placed in long-term storage in dedicated Ministry of Defence storage ponds at Sellafield (Sellafield is operated by Sellafield Ltd but owned by the Nuclear Decommissioning Authority). 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. MoD's 2001 'Nuclear Liabilities Management Strategy' states: 'The 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] that will support the continued safe and secure storage of irradiated fuel until the end of this century. Submarine cores stored in the FGOSP are being progressively transferred to the WIF. The FGOSP and WIF are safe and secure storage facilities that are maintained and safely operated by Sellafield Ltd.'[53] The WIF was available to accept irradiated fuel from December 2001. MoD had a contract with then operator BNFL to store fuel in the WIF for 40 years through to 2041.[54] In 2002 the UK Nuclear Industry Radioactive Waste Executive (NIREX, or UK Nirex Limited as it became known[55]) reported in a technical note on 'Implications of Declaring UK Uranium Stockpiles as Waste' that the UK had 51 irradiated submarine reactor cores containing HEU stored at Sellafield and that by the 2020 the number could rise to 90.[56]

3. A UK NNPP safeguards study

Having detailed the UK NNPP fuel cycle the third and fourth sections of the paper explore what a UK NNPP safeguards study and verification regime might entail. First, it is worth noting that the UK is perhaps the most politically inclined of the NWS to explore the modalities of a NNPP fuel cycle safeguards regime. Relevant precedents include:

- The UK-Norway Initiative (UKNI) on nuclear warhead dismantlement verification. In early 2007 representatives from the UK Ministry of Defence, AWE, several Norwegian laboratories and the London-based

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[52] 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.

[53] Ministry of Defence, 'Nuclear Liabilities', pp. 22-23.

[54] A. S. Daniel and R. A. Acton, 'Spent Fuel Management in the United Kingdom', in *Scientific and Technical Issues in the Management of Spent Fuel of Decommissioned Submarines*, Sarkisov, A, Tournyol du Clos, A. (eds) NATO Science Series (Springer: Netherlands, 2006), p. 62.

[55] Originally established by industry to examine options for geological disposal of radioactive waste, ownership was transferred to the Department of Trade and Industry in 2005 and then to the Nuclear Decommissioning Agency.

[56] Samantha King, 'Implications of Declaring UK Uranium Stockpiles as Waste', UK Nirex Limited, Harwell, Oxon, 26 March 2002, p. 5. Available at <http://fissilematerials.org/library/nir02.pdf>.

non-governmental organisation VERTIC (Verification Research, Training and Information Centre) began work on the technical verification of nuclear arms control leading to a series of workshops, reports and a Managed Access Exercise at AWE in 2010.[57] This was part of a wider programme to develop capabilities to verify reductions in nuclear weapons announced in the 1998 Strategic Defence Review (SDR) resulting in the Verification Research Programme at AWE.[58]

- Establishing the 'P5 process' under Secretary of State for Defence Des Browne to enable the five NWS to build mutual confidence and work collectively on difficult technical issues associated with verified nuclear disarmament. This began with the London Conference on Confidence Building Measures towards Nuclear Disarmament in September 2009 and was followed by a further five, the most recent again in London in February 2015.[59]
- Inviting a team of nuclear security experts to visit the UK in 2011 as part of the International Physical Protection Advisory Service (IPPAS) to assess the UK's nuclear security framework, compliance with the Convention on the Physical Protection of Nuclear Materials, and to see how nuclear security measures were implemented in practice at Sellafield and Barrow. The UK was the first NWS to open up its civil nuclear security regime for inspection in this way.[60]

The UK has, along with the other NWS, concluded a Voluntary Offer Agreement with the IAEA. The UK agreement, which entered into force in 1978, accepts IAEA safeguards on 'all source or special fissionable material in facilities or parts thereof within the United Kingdom, subject to exclusions for national security reasons only'.[61] Under its agreement the UK currently 'provides the IAEA with a list of its civil nuclear facilities. Nuclear materials accountancy reports and basic design information for all these facilities is supplied to the IAEA via the European Commission and the IAEA is free to designate any of them for inspection. The UK facilities currently designated and inspected by the IAEA include parts of the Sellafield facility containing separated plutonium product from the reprocessing of irradiated fuel and the gas centrifuge enrichment facility at Capenhurst.'[62]

The UK is also subject to Euratom safeguards at civil nuclear sites under the 1973 Euratom Treaty. Euratom safeguards cover natural uranium and uranium

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[57] VERTIC, 'Verifiable Multilateral Nuclear Disarmament', Fact Sheet 9, London, April 2009. Available at <http://www.vertic.org/media/assets/nim_docs/tools/NIM%20Tools%20(Factsheets)/FS9_UKNI_EN.pdf>.

[58] Ministry of Defence, *Strategic Defence Review* (HMSO: London, 1998); Atomic Weapons Establishment, *Confidence, Security and Verification: The challenge of global nuclear weapons arms control*, AWE, Reading, 2000.

[59] Nick Ritchie, 'Pathways and Purposes for P-5 Nuclear Dialogue', *European Leadership Network*, July 2013.

[60] Berkemeier *et al* 'Governing Uranium', p. 30.

[61] International Atomic Energy Agency 'INFCIRC 263', October 1978, Article 1(a), p. 2. Available at <http://www.iaea.org/Publications/Documents/Infcircs/Others/infcirc263.pdf>.

[62] Office for Nuclear Regulation, 'IAEA Safeguards in the UK'. Available at <http://www.onr.org.uk/safeguards/iaeauk.htm>.

ore concentrate. This included the Springfields uranium conversion facility until its closure in August 2014.[63] The UK has also negotiated an Additional Protocol agreement with the IAEA and Euratom that came into force in 2004.[64] Under this agreement the UK accepted additional safeguards associated with the IAEA Additional Protocol designed to detect undeclared nuclear material and activities in NNWS. The UK makes declarations to the IAEA of nuclear-related activities conducted in collaboration with NNWS to enable the IAEA to assess the completeness of declarations made by NNWS.[65] Berkemeier *et al* report that 'All the information that the United Kingdom is obliged to declare under the AP is collected by the UK Safeguards Office at the ONR and declared to the Agency via Euratom on behalf of the British government.'[66]

Voluntary adherence to INFCIRC/153 (Corrected) paragraph 14

A UK NNPP safeguards study could start by examining the implications of abiding with paragraph 14 of the IAEA safeguards agreement for *non*-NWS: 'The Structure and Content of Agreements between the Agency and States Required in Connection with the Treaty on the Non-Proliferation of Nuclear Weapons', otherwise refereed to as INFCIRC/153 (Corrected), as suggested by Sébastien Philippe.[67] Paragraph 14 concerns 'Non-Application of Safeguards to Nuclear Material to be used in Non-Peaceful Activities'. This allows states to remove nuclear material from IAEA safeguards for use in non-proscribed military activities, including a naval nuclear reactor programme.

The section states that if a NNWS intends to suspend IAEA safeguards for nuclear material intended for use in a non-proscribed military programme it must:

1. Inform the IAEA of the activity.
2. Make it clear that the material will not be used for a nuclear weapons programme.
3. Reach an agreement with the Agency to identify, to the extent possible, the period or circumstances during which safeguards will not be applied.
4. Reapply safeguards as soon as the nuclear material is reintroduced into a peaceful nuclear activity.
5. Keep the Agency informed of the total quantity and composition of unsafeguarded nuclear material in the State and of any exports of such material.

The IAEA says that such an agreement 'shall only relate to the temporal and procedural provisions, reporting arrangements, etc., but shall not involve any

[63] Berkemeier *et al* 'Governing Uranium', p. 25.
[64] Office for Nuclear Regulation, 'The UK's Additional Protocol and its implementation'. Available at <http://www.hse.gov.uk/nuclear/safeguards/protocol.htm>.
[65] Bill McCarthy (Head, Nuclear Safeguards Policy, UK Department o Energy and Climate Change), 'Nuclear Safeguards in the UK', presentation to the Nuclear Institute Congress, 14 October 2013.
[66] Berkemeier *et al* 'Governing Uranium', p. 27.
[67] Sébastien Philippe, 'Bringing Law to the Sea; Safeguarding the Naval Nuclear Fuel Cycle', *Bulletin of the Atomic Scientists*, 9 April 2014. Available at <http://thebulletin.org/bringing-law-sea-safeguarding-naval-nuclear-fuel-cycle7418>.

approval or classified knowledge of the military activity or relate to the use of the nuclear material therein.'[68]

A UK NNPP safeguards study could examine how it could fulfil these conditions that a NNWS such as Brazil would be expected to satisfy in the context of its uranium enrichment programme to provide nuclear fuel for its nuclear-powered attack submarine programme. This would be an exercise in HEU transparency building on the transparency exercise conducted in the early 2000s that resulted in MoD's 2006 report on 'Historical Accounting for UK Defence Highly Enriched Uranium'. To satisfy INFCIRC/153 (Corrected) paragraph 14 conditions the UK would need to consider the following:

1. Declare a portion of its military HEU stockpile to the NNPP programme. So far the United States is the only state that has publically declared a separate stockpile of HEU for naval reactor fuel of about 128 tons.[69]

2. Develop an independently verifiable nuclear material accountancy and control regime to demonstrate to the satisfaction of external inspectors that HEU dedicated to the NNPP was not being diverted to the nuclear weapon programme as it moved from AWE, to Raynesway, to Devonport or Barrow, and then to Sellafield.

3. Declare the quantity and provide some details on the composition of the HEU that did not release proliferative and/or military information considered classified or sensitive. This could include:
    - Declarations of all facilities regardless of operational status (operational, closed down, decommissioned) and all downstream facilities that store, process or use HEU in the NNPP including fuel fabrication facilities and reactors.
    - Declaration of quantities of HEU dedicated to the NNPP.
    - Declaration of quantities of HEU and enrichment level in specific cores.
    - Declaration of quantities of spent naval fuel at Sellafield and in decommissioned submarines at Devonport.
    - Estimates of future HEU for the current and planned Astute and Successor flotillas and additional cores for Vanguard boats if required.[70]

Managed access and proliferative information

In 2010 the UK Safeguards Office (UKSO, now part of the Office for Nuclear Regulation) published a report on best practice for international safeguards at

[68] International Atomic Energy Agency, 'The Structure and Content of Agreements between the Agency and States Required in Connection with the Treaty on the Non-Proliferation of Nuclear Weapons' (INFCIRC/153 Corrected), 1972 (Austria: IAEA), p. 5.
[69] Harold Feiveson, 'Treatment of Pre-existing Fissile Material Stocks in an FM(C)T', *UNIDIR Resources*, 2010. Available at <http://www.unidir.org/files/publications/pdfs/treatment-of-pre-existing-fissile-material-stocks-in-an-fm-c-t-392.pdf >.
[70] Adapted from Morton Bremer Maerli, 'Deep Seas and Deep-Seated Secrets: Naval Nuclear Fuel Stockpiles and the Need for Transparency', *Disarmament Diplomacy* No 49, August 2000.

UK nuclear sites. It reiterated that UK nuclear regulation and independent verification by international nuclear safeguards inspectorates rests on an effective nuclear material accountancy (NMA) and safeguards system that encompasses:

- System wide accountancy and control structures
- Calibrated measurement processes, quality control, and adherence to international standards
- Sampling and analysis
- Facility design to incorporate safeguard practices
- Identification and traceability of nuclear materials on site
- Storage controls and seals
- Off site receipt and issues of nuclear material
- Physical inventory taking (PIT) and verification (PIV)
- Nuclear material in waste monitoring and conditioning, and storage
- Commissioning and decommissioning
- Nuclear material customer contract management.[71]

MoD nuclear material is subject to a similarly strict internal materials accountancy regime to accurately account for the quantity and location of HEU.[72] The UKSO 2010 report states it is 'MOD policy to have NMA standards and management arrangements that are, so far as reasonably practicable, at least as good as those required by safeguards legislation.'[73] MoD would have to examine the extent to which its NMA system could be opened up to external verification, in particular surveillance to maintain continuity of knowledge of the status of NNPP nuclear material subject to verification; managed on site observation of on-going operational activities; and disclosure of internal NMA data, systems and processes for external audit.[74]

There are two core challenges associated with such a process: first, the essential need to prevent the release of information that could be used to develop nuclear weapons (proliferative information); second, the essential need to protect classified or sensitive military information from foreign inspectors (national security information). Under Article I of the NPT the UK is prohibited from revealing proliferation-sensitive information, including to multinational entities such as the IAEA and Euratom. During the US-Russia-IAEA 1996-2002 Trilateral Initiative to verify the disposition of US and Russian fissile material declared surplus to defence requirements, the IAEA recognised that its access to US and Russian military facilities would be restricted and that the Agency would not be permitted to take unrestricted measurements of nuclear material. Instead, the three parties developed 'information barrier' technologies to measure specific characteristics of nuclear material but only provide IAEA inspectors with a

[71] UK Safeguards Office, 'Guidance on International Safeguards and Nuclear Material Accountancy at Nuclear sites in the UK', 2010 edition, revision 1.
[72] Ministry of Defence, 'Historical Accounting', p. 6.
[73] UK Safeguards Office, 'Guidance on International Safeguards and Nuclear Material Accountancy at Nuclear sites in the UK', 2010 edition, revision 1, p. 32.
[74] Thomas Shea and Piet de Klerk, 'On the Verification of a Treaty Banning the Production of Fissile Material for use in Nuclear Weapons or other Nuclear Explosives: An IAEA Perspective', Palais des Nations, 14-15 May 2001, p. 62

binary pass/fail reading, for example that plutonium is present, that the mass is above an agreed minimum, that isotopic composition is at or below specific ratio.[75] The conflict between high-quality verification to assure inspectors that special nuclear materials are not being diverted and the risk of proliferating sensitive information through intrusive measurements has been addressed in the AWE's Verification Research Programme through the further development of information barrier technologies and managed inspector access to sensitive military nuclear facilities.[76]

A key feature of a managed access verification plan is the 'black box': a 'process or facility where inspector access is limited or entirely precluded because of the use of proprietary or classified technologies, safety, or inaccessibility'.[77] Inspectors are granted limited access to the sensitive area before and after, but not during, the sensitive operation, for example dismantling a nuclear warhead, or machining HEU fuel components. The black-boxed area is defined as a material balance area (MBA), an area within or outside of a facility in which the quantity of nuclear material transferred in and out of the area and the physical inventory of nuclear material in an area can be determined through specified procedures to establish the material balance for safeguards purposes.[78] The material balance period (MBP) would be determined by host and inspectorate, but could include a continuous inspector presence. The UKNI used the concept of an enclosed 'dismantlement cell' to which inspectors were granted managed access before and after the dismantlement of a nuclear warhead. The cell could be subject to portal perimeter continuous monitoring (PPCM) and/or closed-circuit television (CCTV) or other containment and surveillance measures to ensure all transfers of nuclear material are reflected in the NMA system, with items entering and exiting the cell subject to agreed chain-of-custody procedures.[79]

The UK can be expected to take a very cautious approach to NNPP HEU fuel cycle verification and adopt a strict interpretation of what constitutes proliferative information, as has been the case in its programme of work on the verified dismantlement of nuclear warheads.[80] Any changes to MoD operational practices to accommodate a new safeguards regime will be subject to scrutiny and approval by the safety regulators (see Appendix 1) and MoD to ensure safety and Defence Nuclear Programme requirements are met and that proliferative and classified or sensitive military information is protected. Negotiating a managed

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[75] Brian Anderson, Hugh Beach, John Finney, Nick Ritchie, Ruben Saakyan, and Christopher Watson, 'Verification of Nuclear Weapon Dismantlement: Peer Review of the UK MoD Programme', British Pugwash Group, November 2012, p. 8.

[76] United Kingdom, 'Verification of nuclear disarmament: second interim report on studies into the verification of nuclear warheads and their components', Working Paper, NPT/CONF.2005/PC.III.WP.3, NPT Preparatory Committee, New York, April 2004.

[77] H Diaz Marcano, E Miller, ET Gitau, J Wylie, and J Hockert, 'Safeguards Approaches for Black Box Processes or Facilities', Pacific Northwest National Laboratory, Richland, Washington, September 2013, p. 1.1.

[78] IAEA, 'Safeguards Glossary', 2001 edn., IAEA, Vienna, June 2002, p. 47.

[79] US Department of Energy, *Transparency and Verification Options: An Initial Analysis of Approaches for Monitoring Warhead Dismantlement*, Office of Arms Control and Nonproliferation, May 1997. Available at <http://www.fas.org/sgp/othergov/doe/dis/>.

[80] Anderson *et al* 'Verification of Nuclear Weapon Dismantlement', p. 8.

access verification plan to the satisfaction of host and inspectorate will be a challenging task and, as AWE notes, in practice 'no verification regime could possibly be devised to provide 100% confidence in its effectiveness; some residual risk must remain.'[81] Defining a material balance area can be very difficult for complex manufacturing process in large sites. The UKNI experience required establishing MBA boundaries, but negotiating and justifying specific boundaries proved contentious.

The UK will be particularly protective of information relating to reactor core mass and enrichment level, the design of the fuel and manufacturing process. This is seen as particularly sensitive as it could give operational and technological insights into the power and performance of the core, how deep and fast the submarines can operate, and core production techniques. Feiveson, however, challenges such claims:

> 'If international monitoring of naval HEU stockpiles were agreed, when HEU was required to fabricate new naval-reactor cores, a state would have to declare to the IAEA the amount of HEU that it required for the purpose. This would require states to be willing to declare to the IAEA the quantities of HEU in specific cores. Although some states currently classify this information, revealing it would not appear to reveal sensitive performance characteristics, such as the maximum power output of the core or how rapidly the power output can change or how resistant the core would be to damage resulting from the explosions of nearby torpedoes or depth charges. The verification challenge, which has not been completely worked out yet, would be to be able to determine non-intrusively that the fabricated "cores" contained the agreed amount of HEU and that the objects designated as "cores" were installed and sealed into naval reactor pressure vessels.' [82]

Philippe similarly argues:

> 'Some information crucial for uranium accounting need not be classified. For example, while the uranium inventory and the enrichment level of a fresh core can give an idea of the maximum lifetime a reactor can achieve before refueling, it gives little indication of the actual tactical performance of the submarine propulsion system.'[83]

4. Verification of a UK declaration[84]

When a safeguards agreement first enters into force the initial inventory declaration is investigated closely to assure that it is complete and accurate.[85] States are then required to carry out material balance annually and to report

[81] Atomic Weapons Establishment, *Confidence, Security and Verification*, p. 9.
[82] Harold Feiveson, 'Treatment of Pre-existing Fissile Material Stocks in an FM(C)T', *UNIDIR Resources*, 2010. Available at <http://www.unidir.org/files/publications/pdfs/treatment-of-pre-existing-fissile-material-stocks-in-an-fm-c-t-392.pdf >.
[83] Philippe, 'Bringing Law to the Sea'.
[84] This section draws heavily on Sébastien Philippe, 'Safeguarding the Military Naval Nuclear Fuel Cycle', *Journal of Nuclear Materials Management*, Vol. XLII No. 3, 2014.
[85] Tom Shea, 'Reconciling IAEA Safeguards Requirements in a Treaty Banning the Production of Fissile Material for use in Nuclear Weapons or other Nuclear Explosive Devices', in *Fissile Materials: Scope, Stocks and Verification* (Geneva: UNIDIR, 1999), p. 59.

material unaccounted for (MUF) on the basis of a measured physical inventory and measured inventory changes. Declarations are verified by the IAEA to assure they are complete and accurate.

Aldermaston

HEU declared to the UK NNPP would have to be stored in a secure storage area separate to HEU for the nuclear weapon programme, if it isn't done so already. Inspectors would be provided inventory data to verify that a certain amount of uranium enriched to above a specific minimum had left the country's military uranium NNPP stockpile to be processed into fuel components. Portal perimeter continuous monitoring could be established and applied to the UK NNPP fissile material stockpile. The UK uses portal monitors to aid the control of the flow of fissile materials into and out of specified areas, including at AWE, to detect any unauthorised movement of such materials. The UK states 'it is possible, provided that any security concerns are managed, that their outputs could be relayed to an central verification centre external to the establishment'.[86]

It is likely that fuel component manufacturing activities would need to be black boxed within the current A45 and new Pegasus EU Facility. Sébastien Philippe outlines the use of 'black box areas' to protect classified and sensitive fuel characteristics and manufacturing processes. It would only be accessible to inspectors when no production was occurring and HEU material and components were absent. HEU components would be monitored when they entered and exited the black box area in sealed containers. Inspectors could conduct a physical inventory take of the agreed material balance area within the site to satisfy nuclear material balance accounting.[87]

Inspectors would not be permitted to make unrestricted measurements of military nuclear materials, as noted above. HEU material could potentially be verified through use of passive and active non-destructive assay techniques involving gamma spectroscopy and neutron counting to verify the presence of highly enriched uranium but also the mass, isotopic content and geometry of the fissile material.[88] This would be dependent upon development of appropriate information barrier technologies to prevent release of proliferative information whilst allowing inspectors access to sufficient information for verification purposes. However, assuming the same machining tools and areas are used for manufacturing HEU components as well as NNPP fuel and warhead components, it cannot be excluded that inspections and measurements could find traces of weapon materials, even if their source had been removed prior to the start of inspections.[89]

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[86] United Kingdom, 'Verification of nuclear disarmament', p. 5.

[87] Philippe, 'Bringing Law to the Sea'. See also David Cliff, Hassan Elbahtimy, and Andreas Persbo, 'Verifying Warhead Dismantlement: Past, Present and Future', VERTIC, London, September 2010, pp. 78-9.

[88] Anderson *et al*, 'Verification of Nuclear Weapon Dismantlement', pp. 15-18.

[89] Annette Schaper, 'Verification of a Fissile Material Cut-off Treaty', *Disarmament Forum*, No. 4, 2010 (Geneva: UNIDIR), p. 52.

Rolls Royce

Tags and seals would be used on transport containers to enable inspectors to trace HEU fuel components transported from AWE to Raynesway and then to trace individual batches of fuel from Raynesway to Barrow and Devonport to verify receipt and dispatch of HEU between facilities in the UK NNPP HEU fuel cycle. The UK uses tags and seals throughout its nuclear weapon programme to track warheads. It has also conducted studies of tags and seals to ensure chain-of-custody maintenance for inspectors during transport, storage and dismantlement of warheads.[90]

Manufacturing of naval fuel elements would also have to be black boxed within the NFPP at Raynesway. Philippe suggests that a black box area for fuel fabrication would be connected to the facility's fresh fuel storage area with a single point of access monitored by cameras and that fuel assemblies would exit the black box area in sealed containers for storage or transport. Inspectors could verify ^{235}U content of containers, apply seals, and verify the nuclear material balance of the declared facility or specific material balance area(s). [91]

Barrow and Devonport

Inspectors would need to be able to verify receipt of fresh fuel assemblies from Raynesway to Barrow and Devonport and monitor fuel elements placed in storage pending the loading of fuel into a reactor. Philippe suggests 'the guarantee of non-diversion of fissile materials would mostly rely on cask sealing and tagging as well as random assaying of stored casks. Cameras could record the activity within the building as a complementary measure.'[92] Inspectors would then need to verify the assembly of the reactor core and the installation of the core into the submarine's reactor pressure vessel. Inspectors would, however, undoubtedly be prohibited from seeing into the submarine and would have very limited access to the naval base to prevent acquisition of sensitive operational information relating to internal ship design, ship movements, weaponry, military personnel, and so on. Once fuel has been loaded the HEU is beyond the reach of inspectors. Nevertheless, Shea and de Klerk suggest that periodic measurement of radiation within or external to docked naval vessels as reactor power levels are varied would provide further assurance that the HEU remains committed to the declared NNPP.[93]

When the submarines are defueled at Devonport the spent fuel will need to be accounted for. Philippe suggests that the reactor hatch (or in the UK's case the area of the hull to be cut to access the reactor pressure vessel) would first be presented to inspectors before being opened and inspectors could verify that any hatch seals in place had not been broken. The pressure vessel would then be opened and fuel module and neutron sources removed in the absence of inspectors. Individual fuel elements would be transferred to shielded transport containers that could be tagged and sealed before transfer to a monitored spent

[90] United Kingdom, 'Verification of nuclear disarmament', p. 4.
[91] Philippe, 'Safeguarding the Military Naval Nuclear Fuel Cycle', p. 47.
[92] Ibid., p. 48.
[93] Shea and de Klerk, 'On the Verification a Treaty', p. 62

fuel area within the Dockyard before being transported to Sellafield. Philippe suggests 'the inspectors seal every spent fuel cask. Before doing so a neutron and/or gamma profiling of randomly selected fuel elements could be made using a cask radiation profiling system. This would allow re-verifying the content of the casks at a later stage by comparing new radiation profiles to the baseline fingerprints.'[94] Inspectors could then externally verify the absence of irradiated fuel within the submarine's pressure vessel with gamma detectors.[95]

Sellafield

Inspectors would conduct inventory checks of receipt and storage of irradiated fuel casks from Devonport in MoD's dedicated Wet Inlet Facility fuel storage pond at Sellafield. The inspection regime would involve off-site monitoring and routine testing of decommissioned cores, including thermal imaging.[96]

5. Resource challenges

Accommodating external verification into the NNPP HEU fuel cycle would present a series of challenges for MoD. The first is a set of challenges associated with negotiating a managed access verification system with external inspectorates, as noted above.

The second involves facility design. Older facilities are likely to prove more resistant to any changes required to facilitate external verification of NNPP fuel cycle activities, and changes in physical organisation of sites and machinery as well as design and implementation of externally-verifiable safeguards will require additional resource. Nevertheless, construction of the new Enriched Uranium Facility (Project Pegasus) at AWE Aldermaston, the new Core Production Capability at Rolls Royce's Raynesway site, continued investment in new facilities at the Devonport Royal Dockyard, and the new Wet Inlet Facility irradiated fuel storage site at Sellafield will incorporate current best practice for internal nuclear materials accountancy. This could potentially make external verification of an NNPP HEU safeguards regime a moderately less onerous task.

Finally, third, the NNPP is currently under strain. It is producing the PWR2 H-core for the Astute-class SSN fleet, designing and validating the new PWR3 reactor for the planned Successor SSBN, and now it also has to manufacture a new unplanned replacement core for HMS Vanguard, plus an MoD option on a further core,[97] all alongside the challenges of the system-wide recapitalisation programme at Aldermaston, Raynesway and Devonport. An additional project to develop and test a verification system for the NNPP fuel cycle would at this time be resisted.

Nevertheless, an in-coming government after the election in May 2015 could take the opportunity to develop international best practice for safeguards and

[94] Philippe, 'Safeguarding the Military Naval Nuclear Fuel Cycle', p. 48.
[95] Ibid., p. 49.
[96] Ibid., p. 49.
[97] National Audit Office, 'Ministry of Defence: Major Projects Report 2014 and the Equipment Plan 2014 to 2024', HC 941-I (London: NAO, January 2015), p. 59.

transparency of HEU for naval nuclear fuel cycles. VERTIC reports that studies by the US Department of Energy, the Trilateral Initiative and the UKNI all reach the same conclusion: 'it is possible to give inspectors access while at the same time protecting the inspected party from inadvertent loss of classified information. This conclusion is underpinned by the UK verification research programme.'[98] The UK could now extend this process to its NNPP fuel cycle beginning with an exploratory study as it did in 2000 on verified warhead dismantlement following the policy decision set out in the 1998 SDR.[99] This could be an important signal of its intention to contribute positively to the nuclear non-proliferation regime at a time when the regime is likely to be under significant pressure, particularly if there is no agreement on a final document and work plan after the forthcoming NPT Review Conference, also in May.

Finally, the UK has an opportunity to work with the United States in the upcoming 2016 Nuclear Security Summit to be convened in the United States. The UK and US could declare their intention to move forward with investigation of the feasibility of a transparency and safeguards programme for their NNPPs as well as consideration of a near-term research and development programme to explore the potential conversion of naval reactors from HEU to LEU fuel for subsequent generations of nuclear-powered warships yet to be designed.

[98] Cliff *et al*, 'Verifying Warhead Dismantlement', p. 89.
[99] Atomic Weapons Establishment, *Confidence, Security and Verification*.

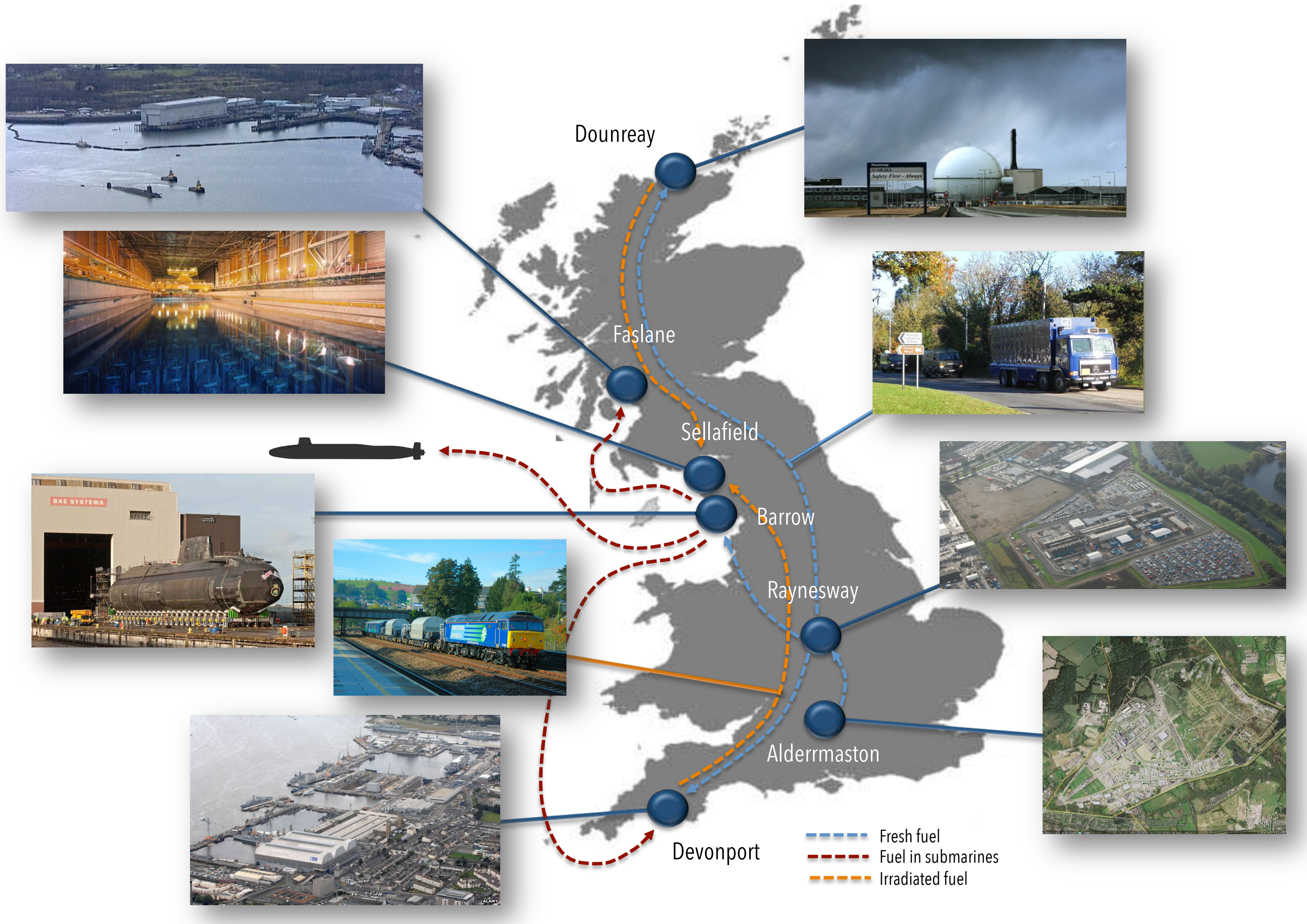
Appendix 1: Nuclear regulation in the UK

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).[100] DNSR directly regulates the design and approval of UK nuclear warheads and naval reactor plants.[101] 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. PUS requires the Director, Defence Safety and Environment Authority (D DSEA) to appoint and manage the Regulator. Authority is delegated to DNSR-Hd to require Defence Nuclear Programme (DNP) operations to cease in extremis.[102] The DNP encompasses the Nuclear Weapons Programme (NWP) and Naval Nuclear Propulsion Programme (NNPP). DNSR sets regulatory policy for the DNP and provides assurance to the defence secretary via DSEA and PUS. 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.

Raynesway is a licensed nuclear site solely regulated by the ONR. AWE Aldermaston and its sister site AWE 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 handing. 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.[103]

[100] Ministry of Defence, 'Nuclear Liabilities', p. 15.
[101] Defence Safety and Environment Authority, 'Japanese Earthquake and Tsunami: Implications for the UK Defence Nuclear Programme - A Regulatory Assessment by the Defence Nuclear Safety Regulator', July 2012, p. 15.
[102] Ministry of Defence, 'JSP 518: Regulation of the Naval Nuclear Propulsion Programme', Part 1: Directive, July 2014, p. 4.
[103] Ministry of Defence, 'Nuclear Liabilities', p. 44-46; 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

Appendix 2: UK NNPP HEU fuel cycle



Acronyms

AWE	Atomic Weapons Establishment
DNP	Defence Nuclear Programme
DRDL	Devonport Royal Dockyard Limited
EA	Environment Agency
EUF	Enriched uranium facility
HMNB	Her Majesty's Naval Base
HEU	Highly enriched uranium
IPFM	International Panel on Fissile Materials
LEU	Low enriched uranium
LOP(R)	Long Overhaul Period (Refuel)
MBA	Material balance area
MBP	Material balance period
MDA	Mutual Defence Agreement
MDP SEG	Ministry of Defence Police Special Escort Group
MUFC	Maritime Underwater Future Capability
NDA	Nuclear Decommissioning Authority
NFPP	Nuclear fuel production plant
NMA	Nuclear material accountancy
NNPP	Naval Nuclear Propulsion Programme
NNWS	Non-nuclear weapon state
NPT	Non-Proliferation Treaty
NRTE	Naval Reactor Test Establishment
NSRP	Nuclear steam raising plant
NWP	Nuclear weapon programme
NWS	Nuclear weapon state
ONR	Office for Nuclear Regulation
PPCM	Portal perimeter continuous monitoring
PSA	Polaris Sales Agreement
PWR	Pressurised water reactor
RPV	Reactor pressure vessel
RRMPOL	Rolls Royce Marine Power Operations Limited
SDR	Strategic Defence Review
SEPA	Scottish Environment Protection Agency
SRF	Submarine Refit Complex
STF	Shore Test Facility
UKNI	United Kingdom-Norway Initiative
UKSO	UK Safeguards Office
WIF	Wet Inlet Facility
VERTIC	Verification Research, Training and Information Centre