

# United Kingdom

John Ainslie<sup>1</sup>

## Status of the United Kingdom's nuclear forces

In September 2010, the UK government announced that it had “not more than 225” Trident nuclear warheads and that this would be reduced to “not more than 180” by the mid 2020s.<sup>2</sup> 120 of these warheads were “operationally available” as of January 2015.<sup>3</sup>

The UK Trident warhead contains a mixture of UK and US elements. The high explosive in the warhead is British.<sup>4</sup> Three key components are supplied from the US.<sup>5</sup> They are parts of the US W76 warhead. In 1978 and 1979 the UK conducted nuclear tests to develop a small high-yield warhead design.<sup>6</sup> The UK then received information on the W76 design from the US in August 1980.<sup>7</sup> The final design probably combines US and UK features. The yield is likely to be similar to the W76, i.e. around 100 kilotons. A lower-yield variant of this warhead has also been produced.<sup>8</sup> The number of lower-yield warheads is not known, but these are likely to constitute only a small proportion of the stockpile

## Delivery systems

The UK's only delivery system is the US-built Trident D5 missile. There are four Vanguard class submarines. Normally three of these are armed with Trident missiles and the fourth is in refit.<sup>9</sup> Each armed submarine carries 40 nuclear warheads.<sup>10</sup> These are deployed on eight missiles.

## Fissile materials

Calder Hall and Chapelcross power stations produced over 1 tonne of weapons grade plutonium for the Trident programme between 1985 and 1995.<sup>11</sup> When the UK ceased production in 1995, the stockpile of military plutonium was 3.5 tonnes. In 1999 the MoD placed 0.3 tonnes of weapons grade plutonium under international safeguards, leaving 3.2 tonnes not subject to these safeguards.<sup>12</sup>

In 2002 the UK had a stockpile of 21.64 tonnes of highly enriched uranium (HEU).<sup>13</sup> Some of this has come from the US. The UK produced between four and five tonnes of HEU at Capenhurst between 1954 and 1962.<sup>14</sup> This implies that the UK procured an additional 21–22 tonnes of HEU from the US between 1964 and 2002.<sup>15</sup> A large proportion of the HEU stock will be in the form of submarine reactor fuel.

## Infrastructure

Nuclear warheads are developed and manufactured at the Atomic Weapons Establishment (AWE) sites of Aldermaston and Burghfield in Berkshire. The work at Aldermaston includes the production of plutonium, HEU, and Beryllium components and research into warhead design. Warheads are assembled and disassembled at Burghfield.

Vanguard class submarines operate from HM Clyde Naval Base, 25 miles from Glasgow, Scotland's largest city. The base includes a submarine facility, Faslane, and a nuclear weapons depot, Coulport. Submarines are built at Barrow in Furness. The fuel cores for naval reactors are manufactured by Rolls Royce in Derby. There is normally one Vanguard class submarine in refit at Devonport dockyard.

Rolls Royce operates a prototype submarine reactor at HMS Vulcan, Dounreay. It is planning to close down this reactor in 2015.<sup>16</sup> In 2012 a fuel core problem was identified in the prototype reactor.

The nuclear firing chain is a substantial element of the infrastructure for Trident.<sup>17</sup> The key facilities are: (1) the Nuclear Operations and Targeting Centre, underneath the MoD Main Building in Whitehall, London; (2) Commander Task Force 345, at the Permanent Joint Headquarters, Northwood, Middlesex; and (3) Corsham Computer Centre, a deep underground bunker in Wiltshire that processes the UK's fire control and targeting software. The primary way to send launch instructions to submarines is through two Very Low Frequency transmitters at Skelton and Anthorn in Cumbria.

The Strategic Weapons System Integrated Project Team (SWS IPT) at Abbey Wood in Bristol manages the Trident programme and the projects to modernise UK nuclear forces.

## Modernisation

In December 2006 President Bush wrote to Prime Minister Blair, agreeing to support the British nuclear weapon programme. Bush referred to “the steps outlined in your letter to maintain and modernize the U.K.'s capability in this area for the longer term.”<sup>18</sup>

## Warhead Modification Program (Mk4A)

A significant program is underway to modify the Trident warhead that is currently in service. In 2006 the UK Government said “the existing nuclear warhead design will last into the 2020s.”<sup>19</sup> The December 2014 update to parliament on the future of the nuclear deterrent said “the current warhead ... is planned to remain in service into the 2040s.”<sup>20</sup> This indicates that the UK has decided to extend the life of the current warhead by around 20 years. This will require a significant refurbishment project.

The government has been reticent about the existence of the warhead modification programme and has told Members of Parliament that it is not possible to identify how much it costs.<sup>21</sup> However, there are several references to the project in official documents. Annual reports from the Defence Nuclear Environmental and Safety Board in 2006–2008 referred to a “Warhead Modification” program.<sup>22</sup> In 2007 a lists of MOD projects included “Mk4A refurbishment programme”. This was later renamed “Nuclear Weapons Mk4A”.<sup>23</sup>

The work is being carried out under the wider “Nuclear Warhead Capability Sustainment Programme”. The aims of this programme include delivering and sustaining “the capability to underwrite the UK stockpile now and in the future including *transition to Mk4A*” and developing and delivering “the UK stockpile to the Mk4A warhead (production, skills, science) approved design.”<sup>24</sup>

The Safety Review of the Atomic Weapons Establishment for 2013 refers to “Mk4A assessment” and “Mk4A operations” as key future activities.<sup>25</sup> A 2014 report from the Office of Nuclear Regulation (ONR) said, “The United Kingdom (UK) Ministry of Defence (MoD) and AWE plc have decided to implement the *existing warhead service life modifications*.”<sup>26</sup> The first phase of this programme involves adapting warhead surveillance systems at the Burghfield assembly facility. Changes will be made to “procedures, tooling, equipment, commissioning and operator training”.<sup>27</sup>

The UK warhead modification project is similar to the US Mk4A / W76-1 upgrade. A senior staff engineer at Lockheed Martin in California is responsible for planning, coordinating, and executing the development and production of “UK Trident Mk4A Reentry Systems as part of the UK Trident Weapon System Life Extension program.”<sup>28</sup> A common component of the US and UK programmes is a new Mk4A Arming, Fuzing, and Firing (AF&F) system which is manufactured in the US.

The original US W76-0/Mk4 warhead was designed for deployment on the relatively inaccurate C4 missile against a limited range of types of targets.<sup>29</sup> The Mk4A AF&F was developed so that warheads on D5 missiles would be effective against hardened targets.<sup>30</sup> The draft military characteristics for Mk4A include “near surface burst,” which was not an option for Mk4.<sup>31</sup> A 1994 report indicated that the proposed D5/Mk4A combination would be effective against a wide range of targets, including SS-11 missile silos.<sup>32</sup>

The UK Trident warhead includes a Gas Transfer System (GTS). The GTS stores tritium and injects it into the plutonium pit. The GTS in UK warheads are manufactured in the US. The UK modification programme will almost certainly include replacing the GTS with a new design, Acorn II, which is part of the US W76-1 upgrade. The new GTS is likely to improve the performance of the warhead.<sup>33</sup>

A significant component of the US W76-1 upgrade is the refurbishment of the fusion part of the nuclear warhead, the secondary. A declassified Sandia National Laboratory report, written in 2001, shows that there are several problems, including corrosion, with the W76 secondary.<sup>34</sup> Aldermaston has worked closely with the US laboratories on research into Uranium corrosion, the problem which lies behind the upgrade to the secondary. It is likely that the secondary and radiation case of the UK warhead will be refurbished in order to extend their life into the 2040s.

In March 2011 Sandia National Laboratory announced that it had conducted “the first W76-1 United Kingdom trials test” at their Weapons Evaluation and Test Laboratory (WETL) and that this had “provided qualification data critical to the UK implementation of the W76-1.”<sup>35</sup> One of the centrifuges in WETL simulates the ballistic trajectory of the W76/Mk4 submarine-launched reentry-vehicle.<sup>36</sup>

## New warhead

The modified warhead would only be in service for the initial part of the projected life of the new successor submarine. On 29 June 2007 David Gould, the senior official responsible for defence procurement, told an Industry Day meeting that their plan was “to replace the entire Vanguard Class submarine system. *Including the warhead and missile*.”<sup>37</sup>

The 2014 update to parliament on the future nuclear deterrent said “a decision on whether to replace the existing warhead will not be required until the next Parliament.”<sup>38</sup> This places the decision between 2015 and 2020. A more precise date was given in 2010 by the Defence Minister Liam Fox, who said “We don’t have to think about new warheads until 2019.”<sup>39</sup> The 2014 update says that it would take 17 years to develop a new warhead. This suggests that a new warhead could be in service in 2036.

The Nuclear Warhead Capability Sustainment Programme provides the extensive range of facilities which would be required to design and build a new warhead. One of the aims of the programme is “to have the capability required for a future warhead if required.”<sup>40</sup> It also sustains the expertise needed. In 2006 Clive Marsh, Chief Scientist at AWE, said that most of their research and development work at the establishment focused on design capabilities, including the potential to develop a successor, as distinct from supporting the current warhead.<sup>41</sup>

There are a number of signs which indicate that AWE is not just sustaining generic capabilities for warhead development, but that it is developing designs as options for a successor warhead. The MoD set up a Warhead Pre-Concepts Working Group.<sup>42</sup> AWE is the Coordinating Design Organisation for “potential successor warhead candidates”.<sup>43</sup> There is a directorate within AWE responsible for work on the Successor, separate from other directorates which deal with Trident and Capability.<sup>44</sup>

Owen Price, a senior official at AWE, said the Establishment has been increasing the range of tasks that it can carry out, in order to improve its ability to design and build a new warhead.<sup>45</sup> He highlighted systems engineering and warhead integration as two critical capabilities AWE will need to develop for a successor warhead programme.<sup>46</sup>

Three areas where AWE is working on new designs are AF&F, Gas Transfer Systems, and Neutron Generators.

The UK is developing an AF&F for a successor warhead. This is a joint AWE, US Air Force, and US Navy initiative. The goal is “the development of a joint arming, fuzing, and firing system for application to the Air Force Mk12A, the Navy Mk5 and a UK re-entry system.”<sup>47</sup> This is related to UK successor warhead designs of a specific size.<sup>48</sup> A joint working group of US Navy, US Air Force, and British engineers leads the work.<sup>49</sup> AWE is producing Demonstrators to test new AF&F concepts in laboratory conditions and in a relevant environment.<sup>50</sup> They are developing electronics,<sup>51</sup> circuit boards,<sup>52</sup> High Integrity Software and Hardware,<sup>53</sup> firing sets,<sup>54</sup> and capacitors<sup>55</sup> for AF&Fs. The engineers designing these components are expected to spend some of their time working in the US.<sup>56</sup> Likewise, their American counterparts at Sandia National Laboratory have been told they will be collaborating with AWE.<sup>57</sup>

AWE is developing new GTS for a successor warhead. They are working on “designs of hydrogen storage and delivery systems for possible future warheads”.<sup>58</sup> The establishment has recruited staff to design new GTS and to test the new models in the UK and US.<sup>59</sup> Researchers are developing new pressure vessels and joining technologies.<sup>60</sup> AWE is working with two American laboratories, Sandia and Los Alamos, to design “long-life GTS”.<sup>61</sup> The laboratories have shared their advanced designs for GTS valves.

AWE recruited engineers and scientists, between 2006 and 2011, to develop new neutron generators and their components.<sup>62</sup> In 2008 the Establishment was developing “novel neutron tube” designs for neutron generators in collaboration with the US.<sup>63</sup>

## Missile system life extension

The US Strategic Systems Program (SSP) is extending the life of the D5 Trident weapon system. They are updating all the Trident subsystems: launcher, navigation, fire control, guidance, missile, and re-entry.<sup>64</sup> All of these modernization measures apply to the system deployed on British submarines. In December 2006, US President Bush wrote to Prime Minister Blair, saying, “We will work to ensure that the necessary components of the overall system are made available to the United Kingdom to support life-extended D5 missiles.”<sup>65</sup> One US contract in November 2014 refers to the “UK VANGUARD Class SSBN Work Planning Document for Trident II SWS Modernization”.<sup>66</sup>

The US Navy plans to carry out the first operational test of the Life Extended missile (D5 LE) in October 2018.<sup>67</sup> A graph in the 2006 report on the future of the UK nuclear deterrent suggests that the Trident D5 LE missile will enter service with the Royal Navy around 2020.

A key part of the D5LE program is the development, by Charles Stark Draper Laboratory, of a new guidance system, Mk6LE.<sup>68</sup> Draper is replacing the gyroscope, accelerometer, and stellar camera in the guidance module.<sup>69</sup> Mk6LE will be more flexible and easier to upgrade than the current Mk6 unit.<sup>70</sup> The new guidance system will be able to “support new missions”.<sup>71</sup> It will “allow for mission adaptability”.<sup>72</sup> Draper has, over several decades, improved the performance of missile guidance systems. The effect has been to make each new generation of ballistic missiles more accurate than the last. Its development of the Mk6LE is a continuation of this trend.<sup>73</sup> The combination of new hardware and software in this advanced guidance system will improve the capability of the D5 missile.

The Mk98 Fire Control System (FCS) controls the launch of Trident missiles. In 2002/03 the US supplied an upgraded Mod 5 FCS to the UK Trident fleet.<sup>74</sup> This meant that the missiles could be more rapidly retargeted.<sup>75</sup> The FCS was further modified to Mod 7 in 2011.<sup>76</sup> General Dynamics Advanced Information Systems (GDAIS) are now designing the next upgrade, Mod 9.<sup>77</sup> This will operate alongside the new Mk6LE missile guidance system.<sup>78</sup>

The navigation system provides information on the exact position of the submarine and is critical for the performance of Trident. The US Strategic Systems Program is upgrading the Electro Static Gyro Navigation (ESGN) system on British and American Trident submarines.<sup>79</sup>

The Reentry Bodies on a Trident missile are spun off the Post Boost Control Vehicle by a Release Assembly. Lockheed Martin has developed a new Alternate Release Assembly (ARA). Tests on the ARA were carried out in 2011 and 2012. A 2014 contract for components of the Trident missile system includes the provision of “hardware to support the United Kingdom’s ARA system”.<sup>80</sup> This indicates that the new ARA will be introduced onto Trident missiles in service with the Royal Navy over the next few years.

## New missile

The intention is that the UK successor submarine will remain in service until the 2060s and the US Ohio replacement will be operational until the 2080s. The Life Extension programme for D5 will only sustain this missile until the early 2040s. D5 will not be available for most of the intended lives of the new submarines. The UK government has acknowledged that “investment in a replacement ballistic missile would eventually be needed.”<sup>81</sup> Rear Admiral Benedict, head of the US Strategic Systems Program, has said “This is not a decision we can postpone

through 2020-2030 – this is a near-term decision that will affect sustainment and recapitalization.”<sup>82</sup>

## Successor submarine

Approval for initial work on a new nuclear-armed submarine was given in 2007. The “Main Gate” decision, to proceed further with the project and to place the main construction contracts, is due to be made in early 2016.

£4,181 million is being spent on the new submarines prior to the Main Gate decision. This initial expenditure is on design work, development of a new reactor, and the purchase of “long lead” items for the first two submarines.

The successor submarine will be powered by a new reactor, PWR3. The design of the new plant is heavily dependent on “a high level of technology transfer from the US”.<sup>83</sup> A review of the PWR3 design was due at the end of 2014. This was expected to mark the design freeze of the reactor plant.<sup>84</sup> The first PWR3 reactor is due to be built by Rolls Royce by 2023.<sup>85</sup> The design has a passive cooling system. This is the most significant change in reactor design that the MOD has ever made. The MOD failed to anticipate how difficult it would be to recruit a sufficient number of qualified engineers to design and produce the new reactor. As a result, the estimated cost of developing the new reactor increased by £151 million in 2014.<sup>86</sup> A contract has been placed for the design and production of a new fuel core, core J, for the reactor in the first successor submarine.

The US Navy was working with the Royal Navy in a joint research programme, from FY2010 to FY2014, to reduce the electromagnetic signatures of the UK Successor and US Ohio Replacement submarines.<sup>87</sup> This, along with the reduced noise-signature of the PWR3 reactor, will mean that the new submarines will be more difficult to detect than current vessels. This is an enhancement of capability.

In October 2014 General Dynamics Electric Boat was awarded a contract for \$59 million to build 12 missile tubes for the first successor class submarine. Until then the UK government had stressed that its intention was to reduce the number of operational missiles carried on each submarine to eight. It had not always made it clear that the new submarines might have an additional four empty missile tubes. For example on 19 October 2010 John Duncan, the British ambassador for multilateral arms control and disarmament, told the UN General Assembly's First Committee that Britain would “configure the next generation of submarines with only eight operational missile tubes.”<sup>88</sup>

By building the submarines with four extra missile tubes, the UK is leaving open the possibility that a future government could increase the firepower of the nuclear fleet by 50%. The approach taken today may echo that adopted in the 1980s, when the government decided that

Trident submarines would only need to carry 12 missiles when they entered service but ordered that Vanguard class submarines should be built with 16 launch tubes in case a future government wanted to add more missiles later.<sup>89</sup>

The missile tubes are part of the Common Missile Compartment (CMC), which is being developed in the US for both US and UK submarines. Some of the work in the US on CMC is specifically for the UK successor submarine.<sup>90</sup>

The decision on whether three or four submarines will be built will be taken in 2016. The government's planning assumption is that there will be four.<sup>91</sup> This is reflected in the missile tube order. The US Navy issued a press release indicating that General Dynamics expect to build a total of 48 missile tubes for 4 UK submarines.<sup>92</sup> Tubes for the later submarines may be included as options in the contract.

The first successor submarine is due to enter service in 2028. The Audit Office report says that the new submarines are expected to have a 25 year life with the option of at least a five year extension. However this probably understates the projected life of the new vessels. One advantage of the PWR3 reactor is that it would enable the successor submarine to remain in service for longer than the current Vanguard class. A presentation from Babcock Marine says that the new submarines will be in service until 2067.<sup>93</sup>

## Infrastructure

### Atomic Weapons Establishment

The Atomic Weapons Establishment (AWE) designs and manufactures the UK's nuclear weapons at Aldermaston and Burghfield in Berkshire. The government has a large programme to rebuild or refurbish most of the facilities at these sites. This work is part of the Nuclear Warhead Capability Sustainment Program which began in 2005 and is due to continue until 2025. The budget for this program is £21,884 million.<sup>94</sup> Over 40 % of the expenditure is for capital projects.<sup>95</sup> In 2007 Nick Bennet, Director of Strategic Technologies in the MoD, said that the NWCSPP included “some 100 facility schemes focused at AWE over the next 20 years.”<sup>96</sup>

The UK government has tried to separate this project from the Trident replacement programme. For example, in November 2005 the MoD told the House of Commons Defence Committee, “This additional investment at AWE is required to sustain the existing warhead stockpile in-service irrespective of decisions on any successor warhead.”<sup>97</sup>

Owen Price of AWE has questioned whether the rebuilding work can really be separated from the design and production of a new warhead. He noted that “in the absence of this funding, it might be reasonable to assume that intellectual and infrastructure capabilities future options would have been more limited or less credible.”<sup>98</sup>

In 2002 AWE was considering whether to build a new warhead assembly/disassembly facility at Aldermaston rather than Burghfield. One reason it did not locate the building at Aldermaston was that “there might not be sufficient room at Aldermaston to accommodate facilities for a successor programme as well as Trident.”<sup>99</sup> This suggests that at least some of the new facilities are specifically required for a new warhead.

The plutonium pits for warheads are manufactured in building A90 at Aldermaston. This is being refurbished at a cost of £272 million. A90 is a replica of facility PF-4 at Los Alamos Nuclear Laboratory in the United States. There is close liaison with the US site over manufacturing techniques and upgrading work.

Highly enriched uranium (HEU) components are currently produced in building A45. In 2011 AWE were planning to spend £32 million on an upgrade to this facility. In August 2012 corrosion was found in structural steelwork in the building and it was closed pending repairs which are due to be completed in May 2015.<sup>100</sup>

A new Enriched Uranium Facility (EUF) is under construction. The new complex, Project Pegasus, will manufacture, process, and store HEU components for warheads. It is critical for the UK’s capacity to build new warheads. One of its aims is to “undertake the specialised chemical and metallurgical operations needed to manufacture enriched uranium components for successor warheads to Trident, should they be built.”<sup>101</sup>

AWE has liaised with its US counterparts over the development of the equivalent American plant, the Uranium Processing Facility. The US plant will manufacture and assemble the fusion stage and the radiation case of warheads. The EUF will probably produce the same components. It will also carry out the initial fabrication of fuel rods for nuclear-powered submarines.<sup>102</sup>

The EUF was due to be completed in 2018. The start of the project was delayed due to concerns from the Office of Nuclear Regulation. In 2014 the MOD was reviewing the project after concerns that the cost, thought to be around £634 million, was spiralling out of control.<sup>103</sup>

Trident nuclear warheads are currently assembled and disassembled in a complex at AWE Burghfield which has four “Gravel Gertie” assembly bays. A new facility, with a similar production capacity, is under construction at a cost of around £700 million. This has four assembly chambers each of which is surrounded by double walls. The new building, Project Mensa, is due to be completed in 2015. A High Explosives Fabrication Facility (Circinus) and a substantial office complex (Gemini) have also been completed at Aldermaston. One new component manufacturing facility (Leo) at Burghfield became operational in 2011 and a second (Phoenix) was due to be completed in 2014.

A new laser facility, Orion, became fully operational in April 2013. Although the Orion laser is available for academic research, 85% of the facilities’ time is allocated to support for the nuclear weapons’ programme.<sup>104</sup> The laser conducts high energy density physics experiments to support AWE’s warhead certification programme.<sup>105</sup> High Energy Density Physics research at Aldermaston is “typically in support of secondary physics”.<sup>106</sup> Orion will be able to simulate, for a fraction of a second, the intense heat and extreme pressures that are experienced during the fusion stage of a thermonuclear explosion.<sup>107</sup> Under an agreement signed in 2014 the UK and France will share use of Orion and the new French Megajoule laser which is under construction.<sup>108</sup>

A Technology Development Centre is under construction, adjacent to the existing hydrodynamic test facilities at Aldermaston. The new centre will provide “a capability for undertaking research and development into x-ray and other diagnostic techniques in support of future hydrodynamic experiments to be undertaken within the Epuré facility located in Valduc.”<sup>109</sup> The key equipment in the centre will be an Inductive Voltage Adder (IVA) x-ray machine. Components of the IVA have been built in the US and will be assembled in the new centre at Aldermaston.<sup>110</sup> Epuré is due to be operational for British purposes in 2016, using a French x-ray machine. Aldermaston will develop a second x-ray machine for Epuré by 2019 and a third by 2022.

AWE operates several of the most powerful supercomputers in the UK. In 2010 AWE ordered Blackthorn and Willow computers which have a combined performance of 721 Teraflops (trillion calculations per second).<sup>111</sup> There was a further jump in AWE’s computing power in January 2014 when three SGI ICE X computers were installed. These will have a combined performance of 1.8 Petaflops (thousand trillion calculations per second).<sup>112</sup> AWE’s supercomputers are used to “simulate and understand the science of nuclear explosions.”<sup>113</sup> The move to Petaflop computing will enhance the UK’s ability to modernise existing warheads and to design new ones.

## Other infrastructure

The 2006 White Paper said that the government expected to spend £2–3 billion, at 2006 prices, on infrastructure over the life of the successor submarine.<sup>114</sup> The 2010 defence review indicated that the government “agreed to defer and potentially to remove over £1 billion of future spending on infrastructure over the next 10 years.”<sup>115</sup> The postponement was for a period of ten years.<sup>116</sup> The submarine infrastructure facilities at Faslane, Coulport, and Devonport each have a projected lifespan of 40 years. The MoD plans to extend the life of these facilities to keep them operational until 2040.<sup>117</sup> Its plans for the sustaining this infrastructure until the 2060s are not clear.

The construction of new facilities at Barrow, where the successor submarine will be built, was brought forward in 2014. This has increased by around £300 million, the

amount which is due to be spent before the Main Gate decision.

The UK government is spending £1,255 million on the Core Production Capability project.<sup>118</sup> Rolls Royce is building a new facility to develop and build the fuel cores for submarine reactors at Raynesway in Derby. The project is to be completed by 2022. This project is critical for the successor submarine programme. Core J1, the fuel core for the first successor submarine, is also funded under this project.

There were initial proposals to modernize the Nuclear Command and Control system or “Nuclear Firing Chain”. In November 2010 the Defence Minister announced that these plans had been postponed for ten years and might be cancelled.<sup>119</sup>

## Timelines

Upgrade of nuclear warhead to Mk4A – 2015-2025  
Decision on new warhead – 2019  
New warhead in service – 2036  
D5 LE missile in service with Royal Navy – 2020  
New missile in service – 2040  
Main gate decision on successor submarine – 2016  
First successor submarine in service – 2028  
End of life of successor submarine – 2067  
Completion of Nuclear Warhead Capability Sustainment Program at AWE – 2025  
Completion of Core Production Capability – 2022  
Faslane shiplift, Coulport Explosive Handling Jetty and Devonport Dry Dock – Life extended until 2040

## Economics

Production of the successor submarine is estimated to cost around £25 billion.<sup>120</sup> In 2007 the running costs of the new system were projected to be £1.5 billion.<sup>121</sup> On this basis, the total operating costs for the planned 39-year lifespan would be £59 billion. A large part of the £21 billion Nuclear Warhead Capability Sustainment Program should also be considered as part of the true costs of Trident replacement. The total through-life costs of Trident replacement are likely to be in the region of £100 billion. Former Defence Minister, Nick Harvey, suggested that this was a minimum amount, saying, “I would have thought that £100 billion is the very least it would cost. I would take a private guess that the quantum would in fact be well in excess of that figure.”<sup>122</sup>

There have been substantial reductions in some areas of the UK’s defence budget, including army personnel. In December 2013 the Chief of Defence Staff, General Nick Houghton, argued that the MoD would have to live with future cuts. He said it should move away from spending huge amounts on “exquisite technology” for large-scale conflict and focus instead on maintaining adequate levels

of personnel and developing new equipment that is appropriate to current and future threats.<sup>123</sup>

A further round of budget cuts is expected between 2015 and 2020. In December 2014 the Institute of Fiscal Studies (IFS) argued that cuts of 22% overall might be required. Some areas of funding (health, education, and overseas aid) are protected. As a result the IFS calculated that 41% cuts might be required in non-protected departments, such as defence.<sup>124</sup> There is serious concern within the UK military about the impact of further cuts in personnel, which may be introduced in order to pay for the equipment budget, including nuclear procurement.<sup>125</sup> Labour MP Roger Godsiff has argued against Trident replacement on these grounds. In January 2015 he told the House of Commons, “In a choice between spending money on conventional weapons and improving our internal security or committing £100 billion to a mythical so-called independent deterrent, I know which I would choose.”<sup>126</sup>

The key UK-based companies in the Trident programme include BAE Systems, Babcock Marine, Rolls Royce, and Serco. BAE Systems operates the submarine construction yard at Barrow in Furness. Babcock Marine runs Devonport dockyard, which refits nuclear submarines, and support facilities at the Clyde Naval Base. Rolls Royce designs, manufactures, and supports the nuclear reactors on British submarines. Serco has a one-third share in AWE Management Limited (AWEML), which operates the UK nuclear warhead development and manufacturing facilities. BAE Systems, Babcock Marine, and Rolls Royce are the three main contractors for the successor submarine. They are also the three Tier 1 suppliers in the wider Submarine Enterprise Performance Program (SEPP).<sup>127</sup>

US arms giant Lockheed Martin plays a leading role in the UK nuclear weapons’ programme. It is the lead contractor for the Trident missile system. The company also has a one-third share in AWEML. Lockheed Martin UK maintains components of the Trident missile system at the Clyde Naval Base. AWEML, Lockheed Martin UK, and Babcock Marine are partners in ABL Alliance, a joint venture that is responsible for nuclear warhead and Strategic Weapon System activities at the Clyde Naval Base. Lockheed Martin manages Sandia National Laboratory, the US facility which designs and produces non-nuclear components of the UK Trident warhead. The Managing Director and the Production Director at AWEML are both US citizens and former employees of Lockheed Martin.

Other US-based companies involved in the UK Trident programme include Jacob’s Engineering, General Dynamics, and Electric Boat. Jacob’s Engineering has a one-third share in AWEML. General Dynamics produces support systems for Trident, including the Fire Control System. Electric Boat is assisting BAE Systems with the successor submarine.

## International law and doctrine

In his submission to the 2012 nuclear Non-Proliferation Treaty (NPT) Preparatory Committee Peter Duncan, the UK ambassador said that the UK did not support a treaty banning nuclear weapons. He said that the recent focus on the humanitarian impact of nuclear weapons stemmed from frustration with the pace of disarmament and he added “we share that frustration”.<sup>128</sup> However, in setting out the case for Trident replacement, the previous UK government argued that the NPT does not set a timetable for nuclear disarmament and does not specifically prohibit the updating of nuclear capabilities.<sup>129</sup> By pursuing an extensive program of modernisation the UK is obstructing progress towards disarmament. It can hardly claim that it truly shares the exasperation of states which do not possess nuclear weapons.

The UK’s modernisation plans are closely bound up with its special nuclear relationship with the US.<sup>130</sup> The transfer of nuclear weapon design information, warhead components, and fissile material from the US to the UK is contrary to the spirit of the NPT and sets an example that is inconsistent with the purpose of the Treaty.

In 2010 H.E. Judge Mohammed Bedjaoui, former President of the International Court of Justice, was asked for his view on the legality of a nuclear weapon system that deploys over 100 warheads, each with a yield of 100 kilotons (like the UK Trident force). He concluded:

Even in an extreme circumstance of self-defence, in which the very survival of a State would be at stake, the use of a 100 kt nuclear warhead (regardless of whether it was targeted to land accurately on or above a military target) would always fail the tests of controllability, discrimination, civilian immunity, and neutral rights and would thus be unlawful...

The modernization, updating or renewal of such a nuclear weapon system would also be a material breach of the NPT obligations, particularly the unequivocal undertaking by the nuclear-weapon states to ‘accomplish the total elimination of their nuclear arsenals leading to nuclear disarmament’ and the fundamental Article VI obligation to negotiate in good faith on cessation of the arms race and on nuclear disarmament, with the understanding that these negotiations must be pursued in good faith and brought to conclusion in a timely manner.<sup>131</sup>

In November 2006 Phillipe Sands QC and Helen Law gave advice on the legality of the maintenance and replacement of the UK Trident system. They said:

If the position of the UK is that a nuclear deterrent remains necessary whilst there is the unascertainable risk of a future threat developing, this amounts to a de facto acceptance that the UK will never fully disarm. In our opinion, this can only

negate the good faith with which the UK is required to negotiate [to achieve nuclear disarmament under Article VI of the NPT].<sup>132</sup>

The Mk4A warhead modification program and the upgrade of all elements of the Trident system are likely to enhance the targeting capability of Trident. Sands and Law argue that upgrades of this nature would be likely to increase the circumstances in which the UK’s nuclear weapons would be used and that this would be contrary to the UK’s obligation to pursue a diminishing role for nuclear weapons, as set out at the 2000 NPT Review Conference and reaffirmed at the 2010 NPT Review Conference. Lord Murray, formerly the senior government law officer in Scotland, has said that the deployment of Trident on continuous patrol, in the absence of an imminent danger to Britain, could be seen as “a continuing threat of unrestricted use against others” and therefore contrary to international law.<sup>133</sup> He also has questioned whether the upgrading of Trident can be reconciled with the UK’s obligation to pursue negotiations on disarmament in good faith.

Dependence on American support is a significant driver for Britain’s modernisation efforts. The Royal Navy is determined to buy the latest American equipment, so it is not left with the costs and problems of sustaining an obsolete system. One of the main goals of AWE’s research programme is to retain Britain’s unique access to the closely guarded secrets of the US nuclear laboratories. In return for this assistance, the United States expects that the UK would join any nuclear coalition of the willing.<sup>134</sup> The US-UK nuclear exchange is based on the Mutual Defence Agreement, which was renewed for a further ten years in 2014.

The UK’s nuclear targeting policy during the Cold War was designed to destroy 50% of the buildings in Moscow and other Soviet cities. The decision to acquire Trident, in 1980, enabled targeting to be more precise, but the focus remained on facilities in and around Moscow.<sup>135</sup> In 2012 the Deputy Prime Minister Nick Clegg implied that UK targeting policy was still focused on the Russian capital.<sup>136</sup> A study by Scottish CND, published for the 2013 Oslo Conference on the Humanitarian Impact of Nuclear Weapons, found that an attack with 40 Trident nuclear warheads on targets in and around Moscow would result in 5.4 million short-term fatalities.<sup>137</sup>

## Public discourse

The Conservative Party supports replacing Trident with a new fleet of nuclear submarines armed with ballistic missiles. It argues that Trident and its replacement should be kept on continuous patrol. While the decision on three or four submarines will not be taken until 2016, the planning assumption is that four vessels will be built. Some Conservative MPs argue that the UK should keep nuclear weapons in order to retain its status in the world. Oliver Colville MP said, “I can confirm my commitment to

our retaining our nuclear arsenal because, in my opinion, it is the cornerstone of our membership of NATO and of our seat on the UN Security Council.”<sup>138</sup> The senior Conservative MP Michael Heseltine gave a further reason for keeping Trident, saying in a BBC debate, “to leave France as the only nuclear power in Europe would be a reckless piece of irresponsibility.”<sup>139</sup>

The Labour Party conducted an extensive review of policies in 2014. Several submissions to the review argued that Trident should be scrapped, but this option was rejected. Others proposed that Trident replacement should be considered in the 2015 Defence Review and this has become party policy. Apart from this, the Labour party position is the same as that of the Conservative party. When the idea of taking Trident off patrol was raised in 2013 it was rejected by Labour’s defence spokesperson. The party’s position is that it supports continuous patrols unless there is convincing new evidence for abandoning this posture. Vernon Coaker, Labour Defence spokesperson, told the House of Commons on 20 January 2015, “We want a minimum independent credible deterrent, based on continuous-at-sea deterrence.”<sup>140</sup>

As part of the Coalition government, the Liberal Democrats initiated a review of alternatives to a Trident-type system.<sup>141</sup> The study was conducted by the Cabinet Office. It reviewed a range of alternative nuclear weapon systems, including submarine-launched cruise missiles and air-launched missiles. It presented a complex range of alternative levels of alert. The review argued that developing anything other than a Trident-type system would take longer and cost more. The report was flawed in a number of ways: it did not consider nuclear disarmament as an option; it assumed that any future force must be armed with weapons with a similar yield to Trident; and in its unclassified form the report failed to define the level of damage that a UK nuclear force would be required to inflict.

Liberal Democrats have changed their policy as a result of this study. The party has joined the Conservatives and Labour in recommending a replacement similar to Trident. The Liberal Democrat MP Alan Reid told the House of Commons, “A submarine system with ballistic missiles remains the most effective and least vulnerable form of deterrent.”<sup>142</sup>

In February 2015, Centre Forum, a Liberal Democrat think tank, suggested that the UK could acquire 100 UK versions of the US B61-12 bomb and deploy them both on land-based aircraft and on the UK’s new aircraft carriers.<sup>143</sup> However, in the light of the Cabinet Office report, this proposal is unlikely to receive much support.

The Liberal Democrats depart from their Conservative and Labour colleagues in arguing that the submarines do not need to maintain a continuous patrol. They also say that fewer than four submarines should be built. Liberal Democrat minister Danny Alexander said that these changes would save £4 billion in the through-life costs of

the system. This implies a total cost of £96 billion rather than £100 billion.

The Liberal Democrat policy of opposing continuous patrols has been attacked by their political opponents. For example, Bob Stewart MP said, “We cannot have a part-time deterrent.”<sup>144</sup> All UK operational nuclear weapons are based in Scotland. The Scottish National Party (SNP), which has formed the Scottish Government since May 2007, is strongly opposed to Trident. On 6 August 2014 the Scottish Parliament passed a resolution calling for the “speediest safe withdrawal of nuclear weapons from Scotland” and supporting a global ban on nuclear weapons.



Photo: Pond5/Pzaxe

A referendum on Scottish independence was held in September 2014. The future of Trident was a key issue in the referendum campaign. Prior to the vote the Scottish Government said that an independent Scotland would demand that all nuclear weapons were removed within four years and it would introduce a constitutional ban on nuclear weapons. Removing Trident from Scotland would be likely to leave the UK without any nuclear weapons, because of the severe difficulties of relocating Trident.<sup>145</sup> In 2012 a report by the Scottish Campaign for Nuclear



Disarmament argued that it would be practically possible to remove all nuclear warheads from Scotland in two years and to dismantled them all within four years.<sup>146</sup> 45% of the population voted for independence. While this means that Scotland remains within the United Kingdom, the issue is likely to re-emerge in future years.

In December 2014 the SNP joined with Plaid Cymru (the National Party of Wales) and the Green Party in a joint statement which said that, if there was a hung parliament after the May 2015 election, they would only support a UK government that is committed to abandoning the plans for Trident replacement.

UK government's decisions to build or upgrade nuclear weapons have, since the 1960s, have been based on the argument that "now is not the time to disarm". Sir Michael Quinlan, former permanent secretary at the MoD, said that each set of decision-makers, over several decades, produced "a set of rationales to clothe that gut decision."<sup>147</sup> Former Prime Minister Tony Blair wrote in his biography, "Imagine standing up in the House of Commons and saying I've decided to scrap it. We're not going to say that, are we?"<sup>148</sup>

Supporters of the UK nuclear force argue that even if the UK abandoned nuclear weapons, this would have no effect on other nuclear armed states.<sup>149</sup> Professor Michael Clarke, Director General of the Royal United Services Institute, disagrees. He argues that if Britain were to scrap Trident this would be the most significant nuclear decision the world has ever seen.<sup>150</sup> Professor William Walker points out that such a move would be unique because of Britain's role in the early development of nuclear weapons and its position as one of the three custodians of the NPT.<sup>151</sup> Walker adds that if Britain disarmed this would be far more dramatic than the examples of disarmament we have seen so far. These have been in the peculiar situations of the disintegration of the Soviet Union and the end of apartheid in South Africa. Clarke adds that, even if others don't follow and we end up in an unstable scenario with more nuclear-armed states, Britain would still be better off by not being one of them.

# Notes:

1. Thanks are noted to Peter Burt of the Nuclear Information Service (<http://www.nuclearinfo.org/>) and Veronika Tudhope of Scottish CND for their assistance with research.
2. Strategic Defence and Security Review 2010, para 3.11, [http://www.direct.gov.uk/prod\\_consum\\_dg/groups/dg\\_digitalassets/@dg/@en/documents/digitalasset/dg\\_191634.pdf](http://www.direct.gov.uk/prod_consum_dg/groups/dg_digitalassets/@dg/@en/documents/digitalasset/dg_191634.pdf).
3. Statement by Defence Minister Michael Fallon, Hansard, 20 January 2015, <http://www.publications.parliament.uk/pa/cm201415/cmhansrd/cm150120/debtext/150120-0002.htm>.
4. The UK Trident warhead contains EDC37, a British explosive, rather than the American equivalent, PBX9501.
5. The UK has purchased three W76 components—the Arming, Fuzing and Firing System, Gas Transfer System and Neutron Generator—from the US. Hansard, 4 December 2009.
6. John Ainslie, “UK nuclear tests 1974-1991,” November 2011, <http://banthebomb.org/ne/images/stories/pdfs/uktests.pdf>
7. “Minutes of the MoD Trident Group,” The National Archives (TNA) DEFE 24-2125 e79, 7 August 1980.
8. The White Paper on Trident replacement in December 2006 referred to “the continuing availability of a lower yield from our warhead”. The Future of the United Kingdom’s Nuclear Deterrent, December 2006, Cm 6994, paras 4-9.
9. There are periods, following the end of a long refit, when only two submarines are armed.
10. Statement by Defence Minister Michael Fallon, Hansard, 20 January 2015, <http://www.publications.parliament.uk/pa/cm201415/cmhansrd/cm150120/debtext/150120-0002.htm>.
11. John Ainslie, “Special Nuclear Materials for the UK Trident Programme,” <http://banthebomb.org/ne/images/stories/pdfs/tridentsnm.pdf>. This includes an analysis of the figures published in “Plutonium and Aldermaston: a historical account,” MoD, 2000.
12. “Plutonium and Aldermaston: a historical account,” MoD, 2000.
13. “Historical accounting for UK defence Highly Enriched Uranium,” MoD, March 2006.
14. In February 1957 the plan was to produce 4910 kg of HEU at Capenhurst between 1958/9 and 1961/2, Cost estimates for plutonium and uranium 235 for the years 1958-63—see “Note by the Technical Policy Branch,” Risley, February 1957, TNA AB16-3878 e12. There was a requirement for 3463 kg of HEU for Green Grass and Red Snow warheads between 1957/8 and 1961/2, TNA AB43-92 e46, 4 May 1964. In 1996 the Stockholm International Peace Research Institute (SIPRI) estimated that Capenhurst had produced 3.8–4.9 tonnes of HEU, almost all of this between 1959 and 1961. Available at <http://nuclearweaponarchive.org/UK/UKFacility.html>.
15. The official account of the HEU stockpile says that the two sources of HEU for the UK military programme were the Capenhurst plant (until 1962) and the United States. Historical accounting for UK defence Highly Enriched Uranium, MOD, March 2006. 7.5 tonnes were obtained from the US between 1964 and 1969 in exchange for plutonium. See “Plutonium and Aldermaston: a historical account,” MoD, 2000. This implies that the UK procured the remaining 14-15 tonnes of HEU from the US between 1970 and 2002.
16. The MoD said that Vulcan would be scaled down or closed after 2015. See BBC, 2 November 2011. Rolls Royce told John Thurso MP that it would retain a workforce of around the current size beyond 2030. See- John O’Groat Journal, 16 November 2011.
17. Trident Value for Money – C4 Infrastructure, obtained under the Freedom of Information Act by Greenpeace.
18. Letter from George W Bush to Tony Blair, 7 December 2006.
19. 2006 White Paper on Trident replacement.
20. 2014 update to parliament.
21. Hansard House of Commons, 26 October 2011, Column 203W,
22. Defence Nuclear Environment and Safety Board Assurance reports for 2006, 2007, and 2008.
23. MoD project P00221E. Excel spreadsheet accessed on the MOD website in 2007 but no longer online.
24. Government Major Projects Portfolio data MoD, 2013, <https://www.gov.uk/government/collections/major-projects-data#2014-data>.
25. Environment, safety, health and quality function, Annual review on safety to the regulatory community (CY 13), AWE, 31 July 2013.
26. Government Major Projects Portfolio data, MoD, 2013, <https://www.gov.uk/government/collections/major-projects-data#2014-data>.
27. Ibid.
28. <https://www.linkedin.com/pub/paul-tom/b/b09/672>
29. A key Measure of Effectiveness for C4/Mk4, when it was originally developed, was a target with a vulnerability number (VNTK) of 27P0. A target of this type would be destroyed by blast overpressure of around 150 psi, which is far less than required to destroy a hardened target. C4 achieved sufficient accuracy to be effective against 27P0. This Measure of Effectiveness for C4/Mk4 was used again in 1994. Joint DoD/DoE Trident Mk4/Mk5 Reentry Body Alternate Warhead Phase 2 Feasibility Study Report, January 1994, p9-14.
30. Joint DoD/DoE Trident Mk4/Mk5 Reentry Body Alternate Warhead Phase 2 Feasibility Study Report, January 1994; Sharpening Trident, John Ainslie, 2009, <http://www.swordofdamocles.org/pdf/sharpeningtrident.doc>
31. Joint DoD/DoE Trident Mk4/Mk5 Reentry Body Alternate Warhead Phase 2 Feasibility Study Report, January 1994, Appendix B p 8. A near-surface burst detonates the warhead before it reaches the ground, but at a height where the fireball will touch the surface.
32. A redacted chart shows the effectiveness of D5/Mk4A against a range of targets up to VNTK 46L8 (SS-11) with a comment “This represents a set of targets likely to be eligible for the Mk4A”, Alternate Warhead Study pp. 9–17.
33. “The tritium GTS can be the easiest way to improve the performance margin of an existing weapon without extensive rebuilding of the weapon or its nuclear components. Changes to the tritium GTS can sometimes compensate for the potential loss of performance margin due to aging or other phenomena” Independent Analysis Tritium R&D Facility Consolidation, October 2008, available at [http://www.complexttransformationspeis.com/RM\\_508%20-%20Tech-Source%202008g.pdf](http://www.complexttransformationspeis.com/RM_508%20-%20Tech-Source%202008g.pdf).
34. <http://www.trivalleycares.org/new/govdocs/SecondaryLifetimeAssessment01-part1.pdf>
35. Sandia Lab Accomplishments, March 2011, [http://www.sandia.gov/Lab-News/labs-accomplish/2011/lab\\_accomp-2011.pdf](http://www.sandia.gov/Lab-News/labs-accomplish/2011/lab_accomp-2011.pdf); reported by Hans Kristensen in the Federation of American Scientist Blog on 1 April, <http://www.fas.org/blog/ssp/2011/04/britishw76-1.php>.
36. Justification for Critical Decision 1, SNL Weapons Evaluation Test Laboratory at Pantex, Amarillo, Texas, [http://www.arclanning.com/projects/archive/screen-pdf/19712.801\\_wetl.pdf](http://www.arclanning.com/projects/archive/screen-pdf/19712.801_wetl.pdf).
37. Speech by David Gould, Chief Operating Officer, Defence Equipment and Support, to the Future Deterrent Industry Day at Abbey Wood, Bristol on 29 June 2007.
38. December 2014 update
39. <http://www.unian.info/world/420345-uk-and-france-agree-to-joint-nuclear-testing-treaty.html>
40. Government Major Projects Portfolio data MOD 2013 <https://www.gov.uk/government/collections/major-projects-data#2014-data>
41. “Our research and development work splits into two main but inter-related areas. The first is the requirement to maintain the current Trident stockpile. The second is to develop our overall warhead design and assurance capabilities, including the ability to provide a new warhead lest our government should ever need it as a successor to Trident. Most of our research is conducted into this capability area”. Clive Marsh, Chief Scientist AWE, <http://www.youtube.com/watch?v=gT8qCFkblv4>.
42. Future Nuclear Deterrent Industry Day, Nuclear Warhead Context, Nick Bennet – DG Strat Tech, 29 June 2007. Reply by Des Browne to question from Nick Harvey, Hansard, 28 November 2007.
43. How Much Science Is Enough? Nicola S Cox and Duncan R Farr, A collection of papers from the 2009 PONI Conference Series, Center for Strategic and International Studies, 2010, p. 52.
44. “At AWE, this portfolio of experience is spread across the Trident, Capability and Successor Directorates”. How Much Science Is Enough? p. 53.
45. AWE’s capacity to carry out certain tasks was at a low ebb in the late 1990s. In some areas they retained the ability to specify work, but not to carry it out themselves - Must Life Extension Compromise Responsiveness? Owen Price, AWE, A collection of papers from the 2005 PONI conference series, Center for Strategic and International Studies, 2006, p. 113f.
46. Must Life Extension Compromise Responsiveness? p. 120. A key aim of the Technology Division at AWE is to improve systems engineering and warhead integration skills—How Much Science is Enough? p. 51.
47. US Air Force Research, Development Test and Evaluation FY2012 BA 5, PE 060422F Nuclear Weapon Support
48. One task in the AF&F project, to be carried out in FY2011, was to “document enveloping requirements to support Navy, Air Force and UK applications”, US Navy Research, Development, Test & Evaluation budget FY2012, BA7 PE 0101221N Strategic Sub & Wpn Supt, February 2011. The UK successor warhead will probably be designed to fit into the US Mk5 Re-entry Vehicle.
49. US Navy Research Development Test and Evaluation budget FY2010, BA-7, PE 0101221N Strategic Sub & Weapons System Support, May 2009.
50. “Development of the Integrated AF&F demonstrators ... to TRL4 and TRL5” Vacancy for Arms Fusing and Firing (AF&F) Mechanical Design Engineer, accessed 25 April 2011. Technical Readiness Level 4 (TRL 4) is testing in a laboratory and TRL 5 is testing in a relevant environment.

# Notes:

51. Vacancy for Electrical/Electronic Design Engineer, accessed 25 April 2011.
52. Vacancy for Senior Digital Electronics Research and Development Engineer, accessed 25 April 2011.
53. Vacancy for Formal Methods and Software Engineer, accessed 15 May 2008.
54. Vacancies for Firing Unit Mechanical Designer and Electronics Engineer, accessed 25 April 2011.
55. Vacancy for Pulsed Energy Component Scientist, accessed 31 October 2010.
56. "Liaise with overseas colleagues ... longer-term secondment overseas may be required to support collaborative activities" Vacancy for Senior Digital Electronics Research and Development Engineer, accessed 25 April 2011.
57. SNL vacancy for Weapons Systems Engineer, accessed 10 July 2011. The scope of this post includes "support arming, fusing, and firing (AF&F) architecture development". The employee is expected to "participate in advanced architecture studies in collaboration with the Department of Defence and the United Kingdom Atomic Weapons Establishment".
58. AWE vacancy for Design Engineer - Gas Transfer, accessed 12 November 2007.
59. AWE vacancy for Hydrogen Storage Engineer - Gas Transfer, accessed 11 July 2008.
60. AWE vacancies for Pressure Vessel Engineer - Gas Transfer (12 November 2007), Joining Engineer—Gas Transfer (12 November 2007), Senior Pressure Vessel Engineer—Gas Transfer (12 November 2007).
61. Fiscal Year 2009 Program Implementation Plan, Directed Stockpile Work, Research and Development Program, National Nuclear Security Administration (NNSA), Revision 3, 26 August 2009, p. 26.
62. AWE vacancies for Mechanical - Design Engineer (25 April 2011), High Voltage Test Equipment Engineer (13 June 2006), Electro-Explosives Specialist (21 October 2006), Neutron Tube Design Team Leader (22 July 2006), Thin Film Specialist (22 July 2006).
63. AWE vacancy for vacuum tube materials scientist, accessed 8 May 2008.
64. Statement of Rear Admiral Terry Benedict, Director Strategic Systems Programs, Subcommittee on Strategic Forces of the Senate Armed Services Committee, 6 April 2011, available at <http://armed-services.senate.gov/statemnt/2011/04%20April/Benedict%2004-06-11.pdf>.
65. Letter from George W Bush to Tony Blair, 7 December 2006.
66. [https://www.fbo.gov/?s=opportunity&mode=form&id=-171065ca74b831af3215017eddbbeefdc&tab=core&\\_cview=0](https://www.fbo.gov/?s=opportunity&mode=form&id=-171065ca74b831af3215017eddbbeefdc&tab=core&_cview=0)
67. [http://www.dod.mil/pubs/foi/Logistics\\_material\\_readiness/acq\\_bud\\_fin/SARs/14-F-0402\\_DOC\\_73\\_Trident\\_II\\_MissileDecember2013SAR.PDF](http://www.dod.mil/pubs/foi/Logistics_material_readiness/acq_bud_fin/SARs/14-F-0402_DOC_73_Trident_II_MissileDecember2013SAR.PDF)
68. [http://www.draper.com/profile\\_boost\\_guidance.html](http://www.draper.com/profile_boost_guidance.html).
69. A solid-state Interferometric Fiber Optic Gyroscope (IFOG) will replace the current mechanical gyro, an Alternate Pendulous Integrating Gyroscopic Assembly (Alt PIGA) that will replace the current PIGA accelerometer. Charles Stark Draper Laboratory and the E2V Corporation have designed a new stellar camera. [http://www.akama.com/company/The\\_Charles\\_Stark\\_Draper\\_Laboratory\\_Inc\\_a27463334185.html](http://www.akama.com/company/The_Charles_Stark_Draper_Laboratory_Inc_a27463334185.html); A simulation-based Integration Approach for the First Trident Mk6 Life Extension Guidance System, presentation to the AIAA Missile Sciences Conference, Monterey, 18-20 November 2008.
70. Explorations, Spring 2006, Draper Laboratory,
71. Explorations, Spring 2006, Draper Laboratory,
72. A simulation-based Integration Approach for the First Trident Mk6 Life Extension Guidance System, presentation to the AIAA Missile Sciences Conference, Monterey, 18-20 November 2008,
73. "Since the development of MK1, Draper has significantly improved the reliability and accuracy of the follow-on systems, continuing today with the development of the MARK 6 MOD 1 system" Mk6 Mod 1 is an alternative name for Mk6LE, available at [http://www.draper.com/Documents/Flier\\_Strategic.pdf](http://www.draper.com/Documents/Flier_Strategic.pdf).
74. Written answer by Adam Ingram to question from Angus Robertson, Hansard, 18 June 2004.
75. Admiral JT Mitchell, SSPO, testimony to Senate Committee on Armed Services, 11 May 1993, quoted in Proliferation of WMD and US Nuclear Strategy, Hans Kristensen, BASIC, 1998.
76. Statement of Rear Admiral Terry Benedict, Director Strategic Systems Programs, Subcommittee on Strategic Forces of the Senate Armed Services Committee, 6 April 2011, available at <http://armed-services.senate.gov/statemnt/2011/04%20April/Benedict%2004-06-11.pdf>.
77. Solicitation N0003005G0068N09 Mk98 Mod 8/9 Concept Exploration, 26 July 2006, [www.fbodaily.com](http://www.fbodaily.com).
78. Solicitation N00030-07-G-0044X793, Mk6 LE 344 update 26 August 2009, [www.fbodaily.com](http://www.fbodaily.com); Mk98 Mod 9 is part of the SSP Shipboard Integration (SSI) increment 4.
79. Draft request for proposal (DRFP) N00030-10-R-0018, SSP, 24 June 2009, [www.fbodaily.com](http://www.fbodaily.com); The first navigation upgrade is SSI increment 4.
80. <https://www.fbo.gov/index?s=opportunity&mode=form&tab=core&id=2c06b9957b49029b70e2cfbe4cc3f137>
81. The United Kingdom's Future Nuclear Deterrent: The Submarine Initial Gate Parliamentary Report, May 2011.
82. A joint Navy-Air Force ballistic missile. DoDBuzz, 21 October 2011, available at <http://www.dodbuzz.com/2011/10/21/a-joint-navy-air-force-ballistic-missile/>.
83. Major Projects Report, MOD, National Audit Office, January 2015 <http://www.nao.org.uk/wp-content/uploads/2015/01/Major-projects-report-2014-appendices-and-project-summary-sheets.pdf>
84. 2014 update to parliament
85. 'Nuclear submarines' Parliamentary written answer by Peter Luff. Official Report (Hansard), 2 July 2012, Column 470W: <http://www.publications.parliament.uk/pa/cm201213/cmhansrd/cm120702/text/120702w0003.htm#12070253000285>
86. Major Projects Report, MOD, National Audit Office, January 2015 <http://www.nao.org.uk/wp-content/uploads/2015/01/Major-projects-report-2014-appendices-and-project-summary-sheets.pdf>
87. FY2012 budget, Navy RDT&E, BA 4 Advanced Component Development and Prototypes, PE 0603561N, Advanced Submarine System Development.
88. [http://www.nti.org/media/pdfs/60\\_3.pdf?\\_=1316627912](http://www.nti.org/media/pdfs/60_3.pdf?_=1316627912)
89. United Kingdom Strategic Deterrent. Note by the Secretary of State for Defence for MISC 7 cabinet subcommittee, 2 November 1981. The National Archives, AIR 8-2846 e70i
90. Part of one order requires the contractor to "perform systems engineering Analysis and modelling efforts related to launch Probability of Success (POS), model development, shock analysis, on/offload analysis, stowage vibration, etc. In support of the UK Unique CMC and UK Successor Programs" between April 2015 and March 2017. [https://www.fbo.gov/index?s=opportunity&mode=form&id=5cfe9616f97f74f2c-193c2c4a9a3e027&tab=core&\\_cview=1](https://www.fbo.gov/index?s=opportunity&mode=form&id=5cfe9616f97f74f2c-193c2c4a9a3e027&tab=core&_cview=1)
91. 2014 update
92. [http://www.navy.mil/submit/display.asp?story\\_id=84166](http://www.navy.mil/submit/display.asp?story_id=84166)
93. <http://www.theeci.org/Documents/community/NUCSIG/Public%20downloads/Bootle%202011/5%20CQINucSIG%20presentation%20Jan%2011%20at%20Bootle%20Website%20version.ppt>
94. Government Major Projects Portfolio data MOD 2013 <https://www.gov.uk/government/collections/major-projects-data#2014-data>
95. MOD response to Freedom of Information request from Nuclear Information Service.
96. Future Nuclear Deterrent Industry Day, Nuclear Warhead Context, Nick Bennet -DG Strat Tech, 29 June 2007.
97. The future of the UK's Strategic Nuclear Deterrent: Written evidence from the Ministry of Defence, HC 835 2005/06 Ev 5.
98. Must Life Extension Compromise Responsiveness? Owen Price, AWE, A collection of papers from the 2005 PONI conference series, Center for Strategic and International Studies, 2005, p. 116. [http://csis.org/images/stories/poni/090108\\_2005\\_conference\\_series\\_text.pdf](http://csis.org/images/stories/poni/090108_2005_conference_series_text.pdf)
99. Recommendation for the AWE Burghfield Site, AWE, 3 December 2002. This also said, "There is insufficient space at Aldermaston alone to accommodate the new operational facilities in the Company's Major Investment Schemes and those that would be required for any Successor Programme." A list of requirements for the Aldermaston site in this report included "future facilities for a successor system".
100. <http://news.onr.org.uk/2013/12/onr-extend-terms-of-awe-improvement-notice/>
101. Enriched Uranium Facility Initial Gate Business Case, paragraph 1. Reference DES/NW/PSO/555/35. Ministry of Defence, 3 April 2007, quoted in Project Pegasus—AWE Aldermaston's proposed Enriched Uranium Facility, Nuclear Information Service, 2010.
102. Enriched Uranium Facility Initial Gate Business Case, paragraph 1. Reference DES/NW/PSO/555/35. Ministry of Defence, 3 April 2007, quoted in Project Pegasus—AWE Aldermaston's proposed Enriched Uranium Facility, Nuclear Information Service, 2010.
103. <http://www.independent.co.uk/news/uk/politics/mod-orders-review-into-spiralling-cost-of-project-pegasus-nuclear-plant-9893206.html>
104. <http://www.awe.co.uk/app/uploads/2014/10/Treadwell-et-al-Orion-a-commissioned-user-facility-2013.pdf>
105. <http://www.awe.co.uk/app/uploads/2014/09/Discovery24September2013.pdf>
106. High Energy Density Physics, NNSA, April 2001, Appendix G - UK Statement on High Energy Density Physics.

107. Warhead assurance under CTBT constraints, Dr Daryl Lanberg, Chief Scientist AWE, PONI Fall Conference, 21 September 2010.
108. [https://www.gov.uk/government/uploads/system/uploads/attachment\\_data/file/277167/France-UK\\_Summit-Declaration\\_on\\_Security\\_and\\_Defence.pdf](https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/277167/France-UK_Summit-Declaration_on_Security_and_Defence.pdf)
109. <http://planning.westberks.gov.uk/rpp/index.asp?caseref=11/02557/COM-IND>
110. "Initial Tests of the AWE Hydrus IVA Marx" and "Status of the AWE Hydrus Fabrication". 18<sup>th</sup> IEEE Pulsed Power Conference 2011, p 96 & 113. <http://ppc.missouri.edu/abstract.pdf>
111. <http://www.top500.org/site/47363>
112. [http://www.sgi.com/company\\_info/newsroom/press\\_releases/2013/november/awe.html](http://www.sgi.com/company_info/newsroom/press_releases/2013/november/awe.html)
113. <http://www.awe.co.uk/app/uploads/2014/07/AWE-OVERVIEW-FINAL.pdf>
114. The Future of the United Kingdom's Nuclear Deterrent, December 2006, Cm 6994.
115. Strategic Defence and Security Review, 2010, para 3.15.
116. Reply by Liam Fox Hansard 3 November 2010 Col 855W.
117. Nuclear submarine infrastructure – scope to minimise future costs, DES-SM LoD-Infra-01/03, 7 July 2010, obtained under the Freedom of Information Act by Greenpeace.
118. Major Projects Report, MOD, National Audit Office, January 2015 <http://www.nao.org.uk/wp-content/uploads/2015/01/Major-projects-report-2014-appendices-and-project-summary-sheets.pdf>
119. Reply by Liam Fox Hansard 3 November 2010 Col 855W.
120. Reply by Defence Minister Dr Murrison, Hansard, 13 February 2014, Column 846W
121. Memorandum from the MOD, 19 February 2007, published in The Future of the UK's Strategic Nuclear Deterrent, the White Paper, 9<sup>th</sup> report from the House of Commons Defence Committee 2006/07, 27 February 2007.
122. Hansard 20 January 2015 Col 119
123. <https://www.rusi.org/publications/newsbrief/ref:A52D66D2E8A623/#.VKZ0F9KsWuI>
124. [http://www.ifs.org.uk/uploads/publications/budgets/as2014/as2014\\_crawford.pdf](http://www.ifs.org.uk/uploads/publications/budgets/as2014/as2014_crawford.pdf)
125. <https://www.rusi.org/analysis/videos/ref:V549164E7D47F2/#.VKZwBNK-sWuJ>
126. Hansard 20 January 2015 Col 117
127. The United Kingdom's Future Nuclear Deterrent: The Submarine Initial Gate Parliamentary Report, May 2011, para 4.2
128. [http://www.reachingcriticalwill.org/images/documents/Disarmament-fora/npt/prepcom14/statements/29April\\_UK.pdf](http://www.reachingcriticalwill.org/images/documents/Disarmament-fora/npt/prepcom14/statements/29April_UK.pdf)
129. The Future of the United Kingdom's Nuclear Deterrent, December 2006, Cm 6994, para 2-9
130. US-UK Nuclear Sharing – Deterring Disarmament, John Ainslie, 2011. Published by Reaching Critical Will for the 2011 NPT Prep Com.
131. Postscript by HS Judge Mohammed Bedjaoui in Trident and International Law: Scotland's Obligations, Rebecca Johnson and Angie Zelter (Eds), Luath Press, 2011, pp. 90-91.
132. Phillipe Sands QC and Helen Law, "The United Kingdom's Nuclear Deterrent: Current and Future Issues of Legality," in Rebecca Johnson and Angie Zelter (Eds.) *Trident and International Law: Scotland's Obligations*, Luath Press, 2011, p. 146.
133. Note by Lord Murray for a Scottish Government Summit on a Future Without Nuclear Weapons, 22 October 2007. Lord Murray is a former Lord Advocate, the senior Government law officer in Scotland, and also a former Judge on the High Court of Justiciary and Court of Session.
134. In 1992 Nick Witney, Director of Nuclear Policy at the MOD, discussed this issue with Michael Quinlan. Witney wrote that he had been told by a US official that if America was going to threaten nuclear action against Saddam Hussein then this official would urge the President to make sure that other Western nuclear powers (ie Britain and France) were involved. On Nuclear Deterrence, The Correspondence of Sir Michael Quinlan, Tanya Ogilvie-White, IISS, 2011, p. 255.
135. Unacceptable Damage, John Ainslie, 2013. <http://www.swordofdamocles.org/pdf/UnacceptableDamage.pdf>
136. "The idea of a like-for-like entirely unchanged replacement for Trident is basically saying we will spend billions and billions of pounds on a nuclear missile system designed with the sole strategic purpose of flattening Moscow at the press of a button". <http://guardian.co.uk/uk/2012/sep/26/trident-nuclear-missiles-review-downgrading>
137. If Britain Fired Trident, The humanitarian consequences of a nuclear attack by a Trident submarine on Moscow, John Ainslie, Scottish CND, 2013. <http://www.swordofdamocles.org/pdf/ifbritainfiredtrident.pdf>
138. Hansard 20 January 2015 Col 111
139. Question Time, BBC, 19 February 2015.
140. Hansard 20 January 2015 Col 104
141. Trident Alternatives Review, July 2013, [https://www.gov.uk/government/uploads/system/uploads/attachment\\_data/file/212745/20130716\\_Trident\\_Alternatives\\_Study.pdf](https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/212745/20130716_Trident_Alternatives_Study.pdf)
142. Hansard 20 January 2015 Col 170
143. <http://www.centreforum.org/assets/pubs/retiring-trident.pdf>
144. Hansard 20 January 2015 Col 112
145. No Place For Trident, Scottish Independence and Nuclear Disarmament, John Ainslie, Scottish CND, 2014. <http://www.swordofdamocles.org/pdf/noplacefortrident.pdf>
146. Disarming Trident, Scottish CND, 2012, <http://www.swordofdamocles.org/pdf/disarmingtrident.pdf>
147. Lord Hennessy, Inaugural Michael Quinlan lecture, House of Lords, 2 February 2011, quoting a statement by Quinlan to himself, <http://www.parliament.uk/documents/lords-information-office/2011%20Lord%20Hennessy%20Robing%20Room%20Lecture%20.pdf>.
148. Tony Blair, *A Journey*, September 2010.
149. "There is no evidence or likelihood that others would follow the UK down a unilateralist route." The Future of the United Kingdom's Nuclear Deterrent, December 2006, Cm 6994, p. 20.
150. Presentation by Professor Michael Clarke, Director of the Royal United Services Institute, in the Trident: Should we keep it? Debate, Edinburgh, 23 June 2011.
151. Presentation by Professor William Walker at Trident and International Law: Scotland's Obligations conference, Scottish Parliament, 12 February 2011.