UK nuclear tests 1974 – 1991

The paternity of the UK's Trident warheads has been the subject of speculation. Official statements suggest that it is a British design, but some of the components are identical to those in the US W76 warhead. Recently declassified files in the National Archives provide new light on this issue. They show that by 1979 the Atomic Weapons Research Establishment (AWRE) had demonstrated three designs: a lightweight version of the Chevaline warhead, a design with size and yield similar to the US W68 (Poseidon) warhead, and a thermonuclear device with a novel very-small primary. The latter opened up the possibility that the UK might be able to produce its own warhead with similar yield and dimensions to W76. Despite their own developments, AWRE were keen to get their hands on details of the US design.

This paper looks at British nuclear tests at the Nevada Test Site over a 17 year period. The first section is on tests from 1974 to 1981. This is the period covered by newly-released documents in the National Archives. The second section looks at tests between 1982 and 1987, when development of the UK Trident warhead was completed. The third section covers the last three tests between 1988 and 1991. The fourth section outlines how the UK obtained information from the US as a result of this test programme. The annex provides estimates of the yields of each of the tests.

<u>Part one 1974-81</u>

Fallon (Forrester)

Fallon was the US name for a test that took place on 23 May 1974. The UK name for the test was Forrester.[1] An alternate British name was Arbor.[2]

The test was carried out to demonstrate a new primary design. This new primary (Harriet) was the main modification that was made to the Polaris warhead in the Chevaline upgrade.[3]

The Polaris system, as originally deployed, was vulnerable to Anti-Ballistic Missiles (ABM). AWRE explored alternative designs for the primary of the warhead which would be less vulnerable. Following advice from their American counterparts, AWRE developed designs for a primary which was hardened against neutron effects as well as x-ray radiation.[4] This required a "complete re-design" of the primary. A large number of options were considered.[5] AWRE selected a "radically new warhead design".[6] It was described as a "new hardened design".[7]

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[1] Note of Outstanding Items at the present time, 8 May 1974, DEFE 19-208 e15. The name is spelt "Forrester" and "Forester" is different papers. It was also called "Forrester-1".

[2] The British Labour Government and the development of Chevaline 1974-79, Kristan Stoddart, Cold War History, Vol 10, No 3, August 2010.

[3] Minutes of the Warhead Safety Coordinating Committee, 29 October 1974, DEFE 19-208 e50. The secondary in the UK Polaris warhead was essentially a US design; AWRE contribution to the Chevaline payload, Kate Pyne, Royal Aeronautical Society Symposium, 28 October 2004.

[4] "in the light of strong American advice derived from US developments which the Russians are capable of matching, it has been decided that the warhead must also be hardened against enhanced neutron effects", British Strategic Nuclear Deterrent, Brief for Secretary of State for meeting with Prime Minister on 19 March 1974, DEFE 19-270 e43. There were particular concerns about the unique initiator used in the UK primary of the Polaris warhead; AWRE contribution to the Chevaline payload, Kate Pyne, Royal Aeronautical Society Symposium, 28 October 2004.

[5] In June 1973 warhead option 11 was selected, but two months later this was changed to option 13. AWRE contribution to the Chevaline payload, Kate Pyne, Royal Aeronautical Society Symposium, 28 October 2004.

[6] Chevaline – Meeting with the Prime Minister, 25 June 1976, DEFE 19-274 e31 annex 5

[7] Progress report on Super Antelope development programme, 22 January 1974, DEFE 19-270 e16

The purpose of the Fallon test was to establish that this new primary would work satisfactorily.[8]

Cabinet Secretary Sir John Hunt told Henry Kissinger that the expected yield from Fallon was "about 35 kilotons"[9]. A preliminary report said that the test was successful and that the yield was "close to the expected design figures".[10]

Banon

The Banon test, on 26 August 1976, was a follow-on test of Chevaline. The UK codename for the test was Anvil.[11] Before Fallon, the US had agreed to make provision for two additional tests, on the assumption that these would only be needed if Fallon was unsuccessful.[12] The design of the Chevaline warhead was "chilled" by 25 August 1975, one year before Banon. [13] Chilling meant that formal approval would be required for any subsequent modifications to the warhead design.

In July 1976 Defence Minister Roy Mason, wrote to Prime Minister Jim Callaghan – "only a further test can give us enough information about it [the Chevaline warhead] to guarantee that we can keep it safe and reliable over its 10 to 15 years of service life. In addition, a further test may enable us to economise is the manufacture of the warhead, especially in the use of plutonium".[14]

Although Banon produced a higher yield than Fallon it was substantially below the full 200 kiloton yield of the warhead. The yield estimated in this study is 55-80 kilotons (Annex).

Fondutta (Findhorn/Firstrate)

The Fondutta, on 11 April 1978, was to prove the performance of a "reduced weight version of the Chevaline warhead".[15] Fondutta was the US name for the event. The equivalent UK name was Findhorn. The UK name Firstrate was also used.

The introduction of Chevaline was going to shorten the range of the Polaris missile, because of the increased weight of the new front-end. This would restrict the area within which the submarine could patrol, making it more vulnerable. If the warhead was lighter, then the missile range would increase and the submarine could patrol in a larger area. The initial estimate was that the lightweight warhead would increase range by 64 nautical miles.[16] This was later revised to 56 nautical miles.[17] The plan was to introduce the lightweight warhead in 1983, on the third submarine to be armed with Chevaline.[18]

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[8] British Strategic Nuclear Deterrent, Brief for Secretary of State for meeting with Prime Minister on 19 March 1974, DEFE 19-270 e43

[9] Hunt asked Kissinger if the test could be kept secret. Record of conversation between the Secretary of the Cabinet and the American Secretary of State held at the State Department on Friday 26 April 1974, DEFE 19-270 e57a.

[10] Nuclear Matters, Letter from Vic Macklen, 23 May 1974, DEFE 19-270 e68

[11] The British Labour Government and the development of Chevaline 1974-79, Kristan Stoddart, Cold War History, Vol 10, No 3, August 2010.

[12] British Strategic Nuclear Deterrent, Brief for Secretary of State for meeting with Prime Minister on 19 March 1974, DEFE 19-270 e43; "If this test is successful this part of the development programme will be substantially complete", Progress report on Super Antelope development programme, 22 January 1974, DEFE 19-270 e16

[13] DEFE 19-170 e30

[14] Letter from Roy Mason to Jim Callaghan, 8 July 1976, PREM 16-1181 e65

[15] British Nuclear Test Programme, Vic Macklen, 19 April 1978, DEFE 13-1478 e22

[16] Chevaline Progress Report July 1978, DEFE 13-1478 e41a

[17] Chevaline Progress Report January 1979, report to Secretary of State, DEFE 25-335 e45

[18] Chevaline Progress Report July 1978, DEFE 13-1478 e41a

Although lighter than the basic Chevaline design, the Fondutta device was larger and heavier than US Poseidon and Trident W76 warheads.[19]

The secondary purpose of the Fondutta test was to improve AWRE's knowledge of a "new type of design" that was used in the Chevaline warhead.[20] This had so far only been tested twice (presumably Fallon and Banon) in comparison with "many tens of tests" that had been carried out by the US. This was also in contrast with the original UK Polaris warhead which was "based upon a UK background of about 20 tests of the basic design principle". Up until that point the UK had conducted a total of 28 tests. This suggests that the Harriet primary in the Chevaline warhead was a significant change from previous UK designs. The Fondutta device would appear to have been close to the original Chevaline warhead. But it also included "a significant design change".[21]

AWRE reduced the yield of the device to below the Threshold Test Ban Treaty limit of 150 kilotons.[22] So an operational version of this design would probably have a yield between 150 and 200 kilotons. The adoption of this design would have resulted in "some reduction in warhead yield" in comparison with the basic Chevaline design.[23]

In January 1977 there were extensive discussions between AWRE and the two US laboratories (Lawrence Livermore and Los Alamos) on the lightweight design. The Americans thought that the proposal was feasible that there was a risk that it might not work.[24]

AWRE and Lawrence Livermore Laboratory made different projections of how Fondutta would perform. Commenting on this discrepancy, Harry Reynolds of Lawrence Livermore explained that "their experience with eg thin cases was so varied that one needed to be confident of all the parameters involved to be reassured that one was not 'on the edge of a cliff'".[25] This raises the question of whether the Fondutta device had a thin radiation case. Reducing the weight of the case was a key element in the development of the American W76 design.[26]

The yield of the Fondutta test was 10-20 % below what was expected, but initial diagnosis gave AWRE confidence that they could identify the explanation for this.[27]

By January 1979 the Government had decided not to proceed with the plan for a lightweight warhead for Chevaline, largely because AWRE's effort was focused on the main Chevaline project.[28] Despite this, the Fondutta test was considered to have been "entirely justified and fruitful" because it increased AWRE's design knowledge and led to closer co-operation with the US.[29]

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[19] "There is no US warhead similar to our lightweight design (the Poseidon and Trident warheads are much lighter and smaller)" UK Test 16 March 1978, 30 November 1977, DEFE 13-1477 e32

[20] British Nuclear Test Planned for March 1978, Vic Macklen, 17 November 1977, DEFE 13-1477 e16. The Fondutta test was postponed from March to April.

[21] British Nuclear Test Programme, 27 April 1978, DEFE 13-1478 e24; Worded as "a significant advance in design" in Vic Macklen's draft, 19 April 1978, DEFE 13-1478 e22

[22] British Nuclear Test Programme, Vic Macklen, 19 April 1978, DEFE 13-1478 e22

[23] Chevaline Progress Report July 1978, DEFE 13-1478 e41a; The 225 kiloton yield of Chevaline was published in the 1998 Strategic Defence Review.

[24] AWRE contribution to the Chevaline payload, Kate Pyne, Royal Aeronautical Society Symposium, 28 October 2004.

[25] AVIS 202 Discussion with Harry L Reynolds, 17 July 1978, DEFE 19-181

[26] US nuclear deterrent is secure despite doubts case on warhead, Geoff Forden, 13 June 2005, http://web.mit.edu/stgs/pdfs/jirw76.pdf

[27] The first reports had said the yield was only 50% of what had been expected, but this was revised to 80-90% when further information was available. UK Nuclear Test, DC Fakley, 14 April 1978, DEFE 13-1478 e20

[28] Chevaline Progress Report July 1978, DEFE 13-1478 e41a

[29] Chevaline Progress Report, January 1979, Report to Secretary of State, DEFE 25-335 e45

The American laboratories revealed some of their knowledge to AWRE – "our last test put us in the picture on some US developments of strategic warhead designs in the period 1962 to 1972."[30]

At some point in 1978 the US provided the UK with more information on the effects of nuclear weapons on military systems and this influenced AWRE design work over the next decade.[31]

The published yield of Fondutta was 20-150 kilotons. The shot depth and seismic data suggest that the yield was near the top of this range. On the other hand, the planned yield was significantly below the 150 kiloton ceiling and the test only produce 80-90% of the predicted yield.[32] The yield was probably 85-115 kiloton (Annex).

Quargel (Gavel)

The Quargel test was on 18 November 1978. Quargel was the US name. Gavel was the UK name for the same event. It was "a lower yield device based on the same design principle" as Fondutta.[33] It would "largely repeat" the technology tested at Fondutta.[34] Quargel would "explore further the new warhead principles" of Fondutta.[35]

Quargel was deliberately designed to produce a lower yield than Fondutta - "the yield will be reduced to give us a second point on the performance curve for this class of warhead and so provide additional confidence in dealing with stockpile deficiencies."[36]

The Quargel device was physically smaller than the one tested at Fondutta.[37] This reduced size meant that the design would be suitable for a fast, pointed Re-entry Body (RB), rather than the blunt-nosed, slower Chevaline RB – "This is our first attempt at a device which would allow a high speed re-entry vehicle for a ballistic missile."[38]

Quargel was not affected by the shut down at Aldermaston following a radiation incident in August 1978. The device had been transported to the US by September 1978.[39]

A comparison of fielding sequence plans suggests that the sophisticated US monitoring equipment which was deployed for Nessel was not used for Quargel.[40] Quargel cost $8.8 million.[41]

A paper written on 25 July 1978 said that the maximum credible yield, which was to be submitted to the Containment Evaluation Panel, was 75 kilotons and the expected yield was "about 63 kt".[42] A report two days after the test gives a lower figure for the planned yield, 52 kilotons, and says the

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[30] British Nuclear Test Programme, Vic Macklen, 19 April 1978, DEFE 13-1478 e22
[31] Nuclear Testing: A US perspective, Troy E Wade II, in US-UK Cooperation after 50 years, Jennifer Mackby and Paul Cornish (Eds), CSIS/Chatham House, 2008, p 206
[32] UK Nuclear Test, DC Fakley, 14 April 1978, DEFE 13-1478 e20
[33] British Nuclear Test Programme, 27 April 1978, DEFE 13-1478 e24
[34] British Nuclear Test Programme, Vic Macklen, 19 April 1978, DEFE 13-1478 e22; The device name is in Gavel/Dicel, 11 August 1978, DEFE 19-181 and Telegram from Johnston to Baldwin, 1 August 1978, DEFE 19-181
[35] British Nuclear Test Programme, Vic Macklen, 21 November 1977, DEFE 13-1477 e18
[36] British Nuclear Test Programme, Vic Macklen, 19 April 1978, DEFE 13-1478 e22
[37] British Nuclear Test Programme, Vic Macklen, 19 April 1978, DEFE 13-1478 e22
[38] British Nuclear Test, Vic Macklen, 20 November 1978, DEFE 25-335 e37
[39] British Nuclear Test Programme – Note for the record. Vic Macklen, 4 September 1978, DEFE 19-181
[40] Quargel fielding sequence, SPC/AWRE, 27 June 1970 and Nessel fielding sequence, SPC/AWRE, 28 June 1978, DEFE 19-181
[41] UK Nuclear Test Programme, Jane Alexander, Treasury, 17 April 1979, DEFE 24-1361 e55
[42] Quargel – Schedule and Costs, letter from British Embassy Washington to Vic Macklen, 25 July 1978, DEFE 19-181

actual yield was 47 kilotons (+/- 5 kilotons).[43] This was "comparable with the results from the Poseidon warhead design".[44]

Quargel was the first of a proposed series of developments called Quicksilver.[45]

Nessel (Dicel)

The Nessel test was on 29 August 1979. Nessel was the US name and the equivalent UK name was Dicel. This was of a test of "a much more advanced device" than Quargel.[46] It was a "new design concept".[47] The device had "design features which extend well beyond our previously tested technology".[48] In May 1978 Vic Macklen proposed holding these two tests in the same month.[49] Nessel was based on a different design approach from Quargel.

Nessel was of "exceptional technical importance" for future nuclear weapons. It was assumed that future warheads would be constrained in size and weight.[50] The novel feature of the design was the "very small nuclear trigger".[51] The trigger is the primary or fission stage of the warhead. Nessel was "the physically smallest design we have so far attempted".[52] It was a thermonuclear device.[53]

This development would "greatly broaden our capability to design small 'packagable' nuclear warheads which could be applied to a wide range of theatre or strategic delivery systems".[54] The Nessel test would "begin to open the possibilities for increasing the yields" of warhead designs suitable for high speed re-entry vehicles.[55]

The US laboratories were particularly interested in the Nessel device and were keen that the UK should test it. It was similar in concept to a device which the Americans were planning to test in 1979.[56] In April 1978 AWRE's view was that the Nessel test would result in the US sharing information on design improvements they had made between 1972 and 1978.[57] It would be important in "securing the release of much more US design data".[58] The design of the Nessel device was fully discussed with US experts who "recognised its advanced features".[59]

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[43] Both yield figures are +/- 5 kilotons. These figures were released to the public, then the document was redacted again and the yield numbers removed. British Nuclear Test, Vic Macklen, 20 November 1978, DEFE 25-335 e37

[44] British Nuclear Test, Vic Macklen, 20 November 1978, DEFE 25-335 e37; The W68 Poseidon warhead had a yield of 40-50 kilotons.

[45] The British Labour Government and the development of Chevaline 1974-79, Kristan Stoddart, Cold War History, Vol 10, No 3, August 2010.

[46] The UK test on 16 March 1978, 30 November 1977, DEFE 13-1477 e32

[47] British Nuclear Test Programme, Vic Macklen, 19 April 1978, DEFE 13-1478 e22

[48] Telegram from Jones to Macklen, 4 October 1978, DEFE 19-181

[49] British Nuclear Test Programme, Vic Macklen, 16 May 1978, DEFE 13-1478 e36

[50] British Nuclear Test Programme, 3 November 1978, DEFE 13-1478 e77 (also in DEFE 25-335 e29)

[51] British Nuclear Test Programme, 3 November 1978, DEFE 13-1478 e77

[52] Telegram from Jones to Macklen, 4 October 1978, DEFE 19-181

[53] The diagnostic requirements included secondary measurements. Telegram Wasall 872 from Drake Seager to Macklen on AVIS 202, 24 July 1978, DEFE 19-181

[54] British Nuclear Test Programme, V Macklen, 25 October 1978, DEFE 13-1478 e70

[55] British Nuclear Test, Vic Macklen, 20 November 1978, DEFE 25-335 e37

[56] British Nuclear Test Programme, Vic Macklen, 21 November 1977, DEFE 13-1477 e18

[57] British Nuclear Test Programme, Vic Macklen, 19 April 1978, DEFE 13-1478 e22

[58] British Nuclear Test Programme, 16 May 1978, DEFE 13.1478 e36

[59] British Nuclear Test Programme, 3 November 1978, DEFE 13-1478 e77

The Americans offered to apply their latest diagnostic techniques to the test. This would give AWRE "a clearer picture in the crucial stages of the implosion of the very small nuclear trigger."[60] The diagnostic techniques proposed on 20 July 1978 were:[61]

Primary and secondary reaction history, measured by both US and UK
Pinhole experiment (PINEX) by US. PINEX produces an image of where neutrons are being emitted from the device. Six Lines of Sight were required.[62]
Temperature by neutrons experiment (TENEX) by US [63]
Ricicles DR3 and DRU by UK
Captain by US.

The Nessel test had originally been scheduled for late 1978. David Owen wrote to Jim Callaghan objecting to the test going ahead. He argued that it would mean three tests in around a year and he queried whether it had any specific objective.[64] Later Owen accepted that the test should proceed. Fred Mulley postponed it until 1979, because having two tests in the same month in late 1978 might draw attention to the nuclear weapons programme and "lend credence to the view that the UK was secretly developing a new range of nuclear weapons."[65]

In September 1978 the proposal was to carry out the Nessel test in the middle of 1979. However there was concern about the disruption to work at Aldermaston following the Pochin report into safety at the plant. It was felt that this might affect the timing of the test.[66]

In April 1979 the final cost of the Nessel test was unclear. An additional $500,000 was sought. One factor was that "additional work has been undertaken by Livermore Laboratory in the manufacture and assembly of special nuclear components. The basic reason for this was the closure of certain AWRE facilities and the resulting Pochin enquiry".[67] This means that some of the nuclear components of the Nessel device were not manufactured in the UK but at Lawrence Livermore laboratory in the US.

The maximum credible yield, for containment purposes, was 55 kilotons. The expected yield was 35-40 kilotons.[68] The initial reports were that the test was successful. The yield was as expected and "the main components of the test device appear to have operated very well".[69]

The references to Nessel during the period of the Labour government stress that the design could have a range of applications, and avoid a particular focus on a replacement for Polaris/Chevaline.

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[60] British Nuclear Test Programme, 3 November 1978, DEFE 13-1478 e77
[61] Telegram Wasall 872 from Drake Seager to Macklen on AVIS 202, 24 July 1978, DEFE 19-181. There was a potential conflict between Captain and DR3. If this was thought to be problem then the UK would not deploy DR3.
[62] Letter from US DOE to Vic Macklen, 31 July 1978, DEFE 19-181. The US Gruyere test on 16 August 1977 used seven pin holes, each with a Line of Sight (LOS). The pin holes were 55 ft from the device. 94 ft from the device was the fluor (material illuminated by neutrons). Six TV cameras covered the fluor. AVIS 202 PINEX and TENEX Measurements, DEFE 19-181. For Nessel there may have been 5 LOS for PINEX, plus 1 for TENEX.
[63] AVIS 202 PINEX and TENEX Measurements, DEFE 19-181. An accompanying diagram suggests that this was using a pinhole method.
[64] British Nuclear Test Programme, David Owen, 8 May 1978, DEFE 13-1478 e32
[65] British Nuclear Test Programme, RLL Facer (PS/Secretary of State for Defence), 25 May 1978, DEFE 13-1478 e37
[66] British Nuclear Test Programme, DEFE 24-1361 e5
[67] Telegram Waslon 055 from Lowe to Elliott, 6 April 1979, DEFE 24-1361 e51
[68] Telegram Wasall 872 from Drake Seager to Macklen on AVIS 202, 24 July 1978, DEFE 19-181.
[69] Nessel: UK underground nuclear test, CSA, 30 August 1979, DEFE 19-181

After the Thatcher government came to power, the test was described as related to "proving a British warhead design for a successor system".[70]

The three tests conducted in 1980 (Colwick, Dingbat and Serpa) were described as "important in enabling us to respond to a requirement for a warhead for any successor deterrent system".[71]

Colwick (Dingbat)

The Colwick test was on 26 April 1980. The US name was Colwick and the UK name Dingbat. It was a high-yield test.

In June 1979 Vic Macklen said the Government should plan for two or three more tests after Nessel. These would be "to ensure that a successor warhead would have sufficient yield, to demonstrate a design for future tactical nuclear weapons, and a spare slot to insure against a test failure."[72] The relatively high yield of Colwick suggests that it was designed to fulfil the first purpose – to demonstrate that a successor warhead would have sufficient yield.

Colwick was detonated at an identical depth to Fondutta, 633 metres. The yield estimate from shot depth and seismological data is 80-120(Annex). The body wave (M_b) measurement from Colwick was higher than from Fondutta, but this may have been because Colwick was detonated on the waterline, whereas Fondutta was detonated above the waterline.

Colwick involved "UK experimental equipment" called Ricicles. [73] The fact that Ricicles ~~were~~ was used in the Dingbat test was classified Secret.

In 1979 the estimated cost of the Colwick test, $14.6 million, was significantly more than Dutchess, $10.7 million.[74]

Dutchess (Lute Prime)

The Dutchess test was on 25 October 1980. Dutchess was the US name. The equivalent UK name was Lute Prime. The published yield was less than 20 kilotons. The yield estimated in this study is 10-20 kilotons (Annex).

Troy Wade, a former senior official at the Nevada Test Site, has said that Dutchess was "part of the AWRE series designed to upgrade the UK submarine warhead to the equivalent of the US Trident system."[75] However, one of the 1980 series was expected to test a tactical weapon. The Rousanne/Lute test in November 1981 was for a theatre nuclear weapon. Dutchess/Lute Prime was probably a related design. It may have been of interest to both the Trident and the Theatre Nuclear Weapon programmes.

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[70] Letter from Vic Maclen, 27 June 1979, DEFE 19-181

[71] Letter from John Elliott, Head of Defence Secretariat 2, to Jane Alexander, Treasury, 2 August 1979, DEFE 24-1361 e 70

[72] Letter from Vic Maclen, 27 June 1979, DEFE 19-181

[73] AWRE Aldermaston classification notice No. 42 classification guide for Dingbat/Colwick, 12 December 1979, DEFE 24-1361 e78

[74] The estimated cost for operations at Nevada were $8.2 million for Dutchess and $10.2 million for Colwick. The payment to Los Alamos for Dutchess was expected to be $2.5 million, whereas Lawrence Livermore was to be paid $4.4 million for Colwick. Letter from William Hoover, US Department of Energy to Kenneth Johnston, Atomic Co-ordinating Office, British Embassy, Washington, 26 November 1979, DEFE 19-181.

[75] Nuclear Testing: A US perspective, Troy E Wade II, in US-UK Cooperation after 50 years, Jennifer Mackby and Paul Cornish (Eds), CSIS/Chatham House, 2008, p 206

Prior to Dutchess, all the tests from 1974 to April 1980 had been supported by Lawrence Livermore Laboratory. Both Dutchess and Rousanne were supported by Los Alamos Scientific Laboratory (LASL).[76] In September 1979 Ken Johnston advised that an advance payment of $4 million should be made for Dutchess/Lute Prime. This was more than would normally be required at this stage in the programme. One explanation was that this would be a way of "impressing LASL with the seriousness and urgency of our commitment to Lute Prime". It would also keep LASL and LLL on an even footing as $4 million had been allocated for the LLL-supported Colwick/Dingbat.[77]

Serpa (Hurdle Prime)

The Serpa test was held on 17 December 1980. The US name was Serpa and the UK name was Hurdle Prime.

Ministerial approval for two tests in 1980 had been given in July 1979.[78] The government booked a slot for a third test as a precaution, in case of a failure in the earlier two tests. AWRE were concerned that a future Comprehensive Test Ban agreement could rule out future tests. In August 1979 the device associated with the third test was Hurdle Prime.[79]

Troy Wade described Serpa as "the first in a series of development tests under the leadership of AWRE director, Peter Jones."[80] The test was supported by Lawrence Livermore Laboratory.

The shot depth suggests that the maximum predicted yield of Serpa was relatively high, but the seismic measurements were lower than from US tests conducted at similar depth.

Rousanne (Lute)

On 12 November 1981 the Rousanne test was carried out. Rousanne was the US name and Lute the UK name. The aim of the test was "investigating further the feasibility of mechanisms for switching the nuclear yield of warheads for theatre applications".[81] The estimate of the yield, in this study, was 50-80 kilotons (Annex).

Handwritten comments on a document from April 1979 refer to a series of future tests.[82] Dingbat is annotated "Dec 79". The actual test was April 1980. Hurdle is "late 80", which is consistent with the Hurdle Prime test. There is no reference to Lute or Lute Prime. The other two tests listed are "Jarvey - late 81" and "Kandahar – late 82".

<u>Part Two 1982-87</u>

There is a lack of information on the purposes of individual UK tests conducted between 1982 and 1987. These are likely to have covered the three aspects of UK tests around this period. These were:

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[76] Telegram from Lowe to Macklen, 14 August 1979, DEFE 19-181

[77] Telegram from Johnston to Long, 21 September 1979, DEFE 19-181

[78] Telegram from Lowe to Elliott, 25 July 1979, DEFE 24-1361 e66

[79] The next devices are listed as Dingbat, Lute Prime and Hurdle Prime in Telegram from Lowe to Macklen, 14 August 1979, DEFE 19-181

[80] Nuclear Testing: A US perspective, Troy E Wade II, in US-UK Cooperation after 50 years, Jennifer Mackby and Paul Cornish (Eds), CSIS/Chatham House, 2008, p 206

[81] British NuclearTest Programme, Draft Minute from Secretary of State to Prime Minister, 7 October 1981, DEFE 25-435 e55

[82] Handwritten notes on Telegram Waslon 049 to Elliot from Lowe, 4 April 1979, DEFE 24-1361 e48

to develop a ~~successor strategic~~ warhead (Trident), to develop a warhead for a Future Theatre Nuclear Weapon (FTNW) and to conduct research and development.

UK Trident warhead design

In August 1979 Ron Mason, Chief Scientific Adviser at the MOD, said that the UK planned to have the warhead for a successor weapon system tested by the end of 1980 or mid 1981 at the latest.[83] A report to ministers in January 1982 said: "Most of the testing [for the Trident warhead] has been completed".[84]

But the tests carried out up to and including 1980 were only the first phase of the Trident warhead development programme. In December 1980 British and American officials met at their annual Stocktake meeting.[85] One item on the agenda was "choice of UK warhead package for Trident". Mason's report of this meeting says: "we described the thinking on our Trident warhead choice and on the underground testing needed to substantiate it with a view to obtaining a frank US critique of our proposals over the coming months."[86] This implies that AWRE was looking at several alternatives, that their preferred choice would require further nuclear tests and that this was subject to American advice.

Development work continued for a further seven years. The House of Commons Defence Committee reported that "The Trident warhead design was frozen in 1987 at the conclusion of what the Director of AWE described as a 'complex but highly successful development programme'."[87]

There would have been a considerable difference between establishing the principles needed for a small 100 kiloton warhead and producing a working design with the same dimensions, weight and centre of gravity as W76. The integration of components of American and British origin may also have been complicated.

The procedure at that time was that the Navy would draw up a broad statement for any proposed project in the form of a Naval Staff Target (NST). This provided the basis for detailed studies. From these a Naval Staff Requirement (NSR) was drafted, setting out what was required in detail.[88]

The initial proposal for the Trident Reentry Body Assembly, on the C4 missile, was presented in Naval Staff Target 7570. On 23 April 1981 the NST 7570 feasibility study was extended so that it also considered the Mk4 Reentry Body on the D5 missile. A timeline from August 1981 shows that the feasibility study was to be completed by 1 December 1981.[89] The resulting Naval Staff Requirement (probably NSR 7570) was to be drafted in March 1982 and endorsed by ministers in December 1982.[90]

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[83] Strategic Successor Systems, Record of meeting in Old Executive Office Building, Washington, 17 August 1979, DEFE 25-434 e3
[84] Nuclear Presentation for MISC 7, 11 January 1982, DEFE 24-2123 e95
[85] US/UK Stocktake meetings are a key feature in the implementation of the Mutual Defence Agreement 1958
[86] US/UK Stocktake Meeting – 2/3 December 1980, DEFE 69-769 e56; At this meeting Mason proposed that there should be a move towards "a true US/UK interdependence on nuclear R&D". While the idea was well received by the US delegation, it was anticipated that there might be problems trying to bring about this major change in approach.
[87] Progress of the Trident Programme, Defence Committee 5th report 1988/89, HC 374, 21 June 1989
[88] Speech by Keith Speed in a debate on Fishery Protection Vessels, Hansard, 8 November 1979.
[89] Naval Staff Target 7570 Trident Re-entry Body Assembly, letter from Captain FD Lowe, Assistant Director of Naval Warfare (Polaris), 10 August 1981, DEFE 24-2126 e8.
[90] Naval Staff Target 7570 Trident Re-entry Body Assembly, letter from Captain FD Lowe, Assistant Director of Naval Warfare (Polaris), 10 August 1981, DEFE 24-2126 e8.

Future Theatre Nuclear Weapon

In 1979 the government were planning to replace WE-177A (0.3 and 10 kilotons) and WE-177C (190-200 kilotons) free-fall bombs with a new weapon, on a one-for-one basis, during the 1990s.[91] Several designations are associated with this replacement system: Future Theatre Nuclear Weapon (FTNW), Naval and Airforce Staff Target 1231 (NAST 1231), Tactical Air to Surface Missile (TASM), and TD-127.

AWE was developing a variable-yield warhead for this weapon system from 1979 until 1991. Dutchess and Rousanne (Lute Prime and Lute) would appear to be the first stage of the FTNW warhead development programme. There were subsequent tests but it is not clear when they were.

In 1977 one of the options being considered for a WE-177 replacement was "the possible use of a very secure high explosive".[92] In the 1980s the American laboratories developed warheads with Insensitive High Explosives (IHE), based on TATB. This may have been one feature of UK tests in the same period. AWE had its own insensitive explosive formula for nuclear warheads, EDC 35. The development of an IHE warhead may have been a component of the FTNW research programme.

Analysis of 1982-87 tests

Seven tests were conducted between 1982 and 1987. Some will have been for Trident, but it is not possible to establish which ones they were.

One pointer might be the assignment of US laboratory, but it is not obvious which of the labs would have taken the lead on Trident.

The initial Chevaline tests, Fallon and Banon, had been supported by Lawrence Livermore Laboratory. This laboratory continued to support the development tests in 1978 and 1979 - Fondutta, Quargel and Nessel.

By August 1979 there had been a change in approach. Support for future UK tests would be shared between Lawrence Livermore and Los Alamos Scientific Laboratory. The reasons for this change are "not public knowledge" but there were practical implications for AWRE, because the two laboratories conducted the tests in different ways.[93] UK tests alternated between the laboratories with one exception, the low-yield Armada test in 1983.

Los Alamos designed the W76. The UK warhead uses some W76 components and has to fit within the same space and weight constraints. However, Los Alamos also supported an early test (Lute) of the theatre weapon, which was the other UK programme.

Name	Date	US Lab	Yield Estimate
Gibne	25/04/1982	LLNL	70-100
Armada	22/04/1983	LLNL	1-8
Mundo	01/05/1984	LANL	60-100
Egmont	09/12/1984	LLNL	65-100
Kinibito	05/12/1985	LANL	80-110
Darwin	25/06/1986	LLNL	70-100
Midland	16/07/1987	LANL	20-45

[91] DEFE 25-435 e27
[92] UK Nuclear Weapons Programme, 30 May 1977, PREM 16-1181 e80
[93] Nuclear Testing: A US perspective, Troy E Wade II, in US-UK Cooperation after 50 years, Jennifer Mackby and Paul Cornish (Eds), CSIS/Chatham House, 2008, p 206.

The low-yield of Armada indicates that it was a primary/fission test. Midland may have been a similar yield to Fallon and Nessel, which were both tests of new primaries. The remaining five tests would appear to be thermonuclear devices with yields between 60 and 110 kilotons. In the cases of Egmont and Darwin the shot depths were similar to Quargel (47 Kt) but the seismic data suggests yields of 90 kt, close to the maximum for the depth. Mundo and Kinibito were detonated below the water line, which exaggerates the body wave (M_b) measurement and can result in an overestimate of yield.

Part Three 1988-91

Manufacture of UK Trident warheads started in January 1988.[94] Production of the first plutonium pits began in March 1988. The first pit and HEU components were completed in December 1988.[95] Assembly of components at Burghfield took 3 months.[96] So the first production warhead could have been available by the Spring of 1989.

The three tests in 1989-91 could have included one or more stockpile tests of Trident warheads. At the same time, some or all of the tests may have been for the Future Theatre Nuclear Weapon.

Barnwell and Houston may have produced higher yields than any test since 1980. The shot depth and seismic data for Bristol suggest that the yield was at the top end of the "<20 kiloton" bracket.

Name	Date	US Lab	Yield Estimate
Barnwell	08/12/1989	LLNL	85-115
Houston	14/11/1990	LANL	75-105
Bristol	26/11/1991	LLNL	15-25

The UK planned to carry out a further test, Icecap, in 1993. The device was to be chilled to minus 42 degrees Centrigrade prior to detonation. This was to simulate the conditions encountered on a missile in space.[97] Icecap was cancelled when a testing moratorium was announced in October 1992.

Part Four Exchange of US design information

AWRE's test programme in 1978-79 gave Britain access to US knowledge on warhead design. Some of the expertise that America had developed between 1962 and 1972 was shared after the Fondutta test (1978) and more recent information was shared after the Nessel test (1979).

In the initial discussions about a replacement for Polaris, the UK tried to get hold of key information which was specific to the Trident Mk4 Re-entry Body and the W76 warhead.

British and American officials met on 16/17 August 1979. Ron Mason, Chief Scientific Adviser at the MOD, said that the UK's warhead effort had focused on developing "small, conical REBs, with high-beta warheads" and that the UK was following the same development path as the US.[98] He pointed out that the Polaris Sales Agreement allowed the transfer of warhead design and that this had happened for Polaris A3T.

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94 Hansard Oral Answer, George Younger, 23 February 1988
95 Progress of the Trident Programme, Defence Committee, HC 374, 1989
96 Progress of the Trident Programme, Defence Committee, HC 374, 1989
97 NNSA factsheet on Icecap, http://www.nv.doe.gov/library/factsheets/DOENV_1212.pdf
98 Strategic Successor Systems, Record of meeting in Old Executive Office Building, Washington, 17 August 1979, DEFE 25-434 e3. Beta, the Ballistic Coefficient of a Reentry Vehicle, is based on weight, drag and cross-section. Early designs, including Chevaline, had a low ballistic coefficient and slowed down during re-entry.

There was a discussion between Mason and Dr Aaron:

> "Dr Aaron asked why, given that the UK with its high-beta designs was following the same path as the US, it was necessary for us to see the US designs. Professor Mason explained that US design information, particularly over the configuration of US warheads, would enable us to confirm that we were working on the right, parallel path; it was a question of confirmation of UK work, rather than of total dependence by the UK on the US."[99]

On 6 August 1980, Mason told the Trident Group that the Statutory Declaration, enabling nuclear information on Trident to be passed to the UK, was due to be signed in a week's time.[100]

Mason said that he would explore whether it was possible "to achieve a greater supply of information and hardware under the 1954 Atomic Energy Act and the 1958 Agreement than in the past". He indicated that the US Department of Energy had a positive attitude towards the proposal.[101]

There are references to the US supply of "non-nuclear parts" for the UK Trident warhead in documents from June/July 1980.[102] These included the Arming, Fuzing and Firing System.[103] It has later been confirmed that the Neutron Generator and Gas Transfer system of the UK warhead were also procured from the US.

In January 1982 ministers were told: "we have now had good access to US nuclear designs."[104]

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[99] Strategic Successor Systems, Record of meeting in Old Executive Office Building, Washington, 17 August 1979, DEFE 25-434 e3

[100] Minutes of meeting of the Trident Group, 6 August 1980, DEFE 24-2125 e79

[101] Minutes of meeting of the Trident Group, 6 August 1980, DEFE 24-2125 e79

[102] "Sale of non-nuclear parts of atomic weapons will be implemented under the terms of the US/UK Agreement for Cooperation on the Uses of Atomic Energy for Mutual Defence Purposes 1958" - Sale of Trident C-4 Missiles and Equipment to the United Kingdom – Point Paper, Annex B to letter from Micheal Quinlan, MoD, to Walter Slocombe, Pentagon, 11 June 1980, DEFE 24-2124 e75-3. "the non-nuclear portion of the nuclear weapons" - telegram from Richard Hastie-Smith, Cabinet Office, to David Aaron, White House, 9 July 1980, DEFE 24-2125 e1.

[103] Sale of Trident C-4 Missiles and Equipment to the United Kingdom – Point Paper

[104] Nuclear Presentation for MISC 7, 11 January 1982, DEFE 24-2123 e95

ANNEX

Estimated yields of UK nuclear tests 1974-91

The US Department of Energy has published extensive data on the Nevada Test Site.[105] However, they have only declassified the yields of a small proportion of underground tests. Some of these published yields are unsuitable for this study. It is hard to produce reasonable yield estimates without access to classified information.[106] There are published estimates of the possible yields of six UK tests based on seismological data. [107]

Two approached were taken in this study. The first was to plot the position of UK tests, by shot depth and body wave (M_b), relative to each other and to a larger sample of US tests.

Seismological measurements of body wave, M_b(Pn), for 48 US underground tests (20-150 kiloton) were plotted against shot depth.[108] UK tests were then added to indicate the approximate position of each test within the 20-150 kiloton range (Figure 1). The same was done for 35 US tests of less than 20 kilotons and equivalent UK tests (Figure 2). At shot depths of 400-500 metres some tests are below 20 kilotons and others above 20 kilotons (Figure 3).

Shot depth is related to the highest yield likely to result from a test, rather than to the intended yield. Approval for each test was granted on the basis that the shot depth was deep enough to avoid contamination reaching the surface in the event of the maximum predicted yield. For this study, the maximum predicted yield was estimated using the formula $Y=121xD^{1/3}$ where Y is yield (kt) and D is shot depth (m) (Figure 4).[109] This formula is consistent with the published maximum yield, 55 kilotons, for Nessel. In the case of Quargel, the estimated maximum yield from this formula is 88 kilotons, whereas the published maximum yield was 75 kilotons.

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[105] Dates and precise locations are published in United States Nuclear Tests July 1945 through September 1992, US Department of Energy, DOE/NV-209-Rev 15, December 2000.

[106] Magnitude:Yield relationship at various test sites – A maximum-likelihood approach using heavily censored explosive yields, Rong-Song Jih et al, Teledyne Geotech Alexandria Laboratory, 1 May 1990.

[107] Mundo (105), Egmont (72), Kiniboto (83) and Darwin (81) in Isotropic and Deviatoric Moment Inversion of Regional Surface Waves from Nevada Test Site Explosions: Implications for Yield Estimation and Seismic Discrimination, Bradley Woods and David Harkrider, California Institute of Technology. Houston (49, 68 or 70) and Bristol (7, 8 or 10) in Monitoring nuclear test sites with GERESS, M Jost, J Schweitzer and H P Harjes, 1994.

[108] Seismology measurements, M_b(Pn), taken by the Lawrence Livermore Network around the Nevada Test Site published in Estimating Ms from short-period (<10 sec) Rayleigh waves for earthquakes and explosions at the Nevada Test Site, J Bonner et al, in Calibration of the M_s:M_b Discriminant at the International Monitorying System Array NVAR (PS-47), Weston Geophysical, September 2005. Data for tests was also published in the Bulletin of the Seismological Society of America. Yucca Flats shot depths are from Corrective Action Investigation Plan for Corrective Action Unit 97: Yucca Flat/Climax Mine, Nevada Test Site, Nevada, US Department of Energy, September 2000. Pahute Mesa Shot Depths are from Quality Assurance and Analysis of Water Levels in Wells on Pahute Mesa and Vicinity, Nevada Test Site, Joseph Fenelon, US Department of Energy, 2000. Shot depths for many tests are also in Studies of near-source and near-receiver scattering and low-frequency Lg from East Kazask and NTS explosions, IN Gupta, CS Lynnes and RA Wagner, Teledyne Geotech Alexandria Laboratories, 4 December 1991.

[109] http://lewis.armscontrolwonk.com/archive/2445/indias-h-bomb-revisited; The Containment of Underground Nuclear Explosions, Office of Technological Assessment, 101st Congress.

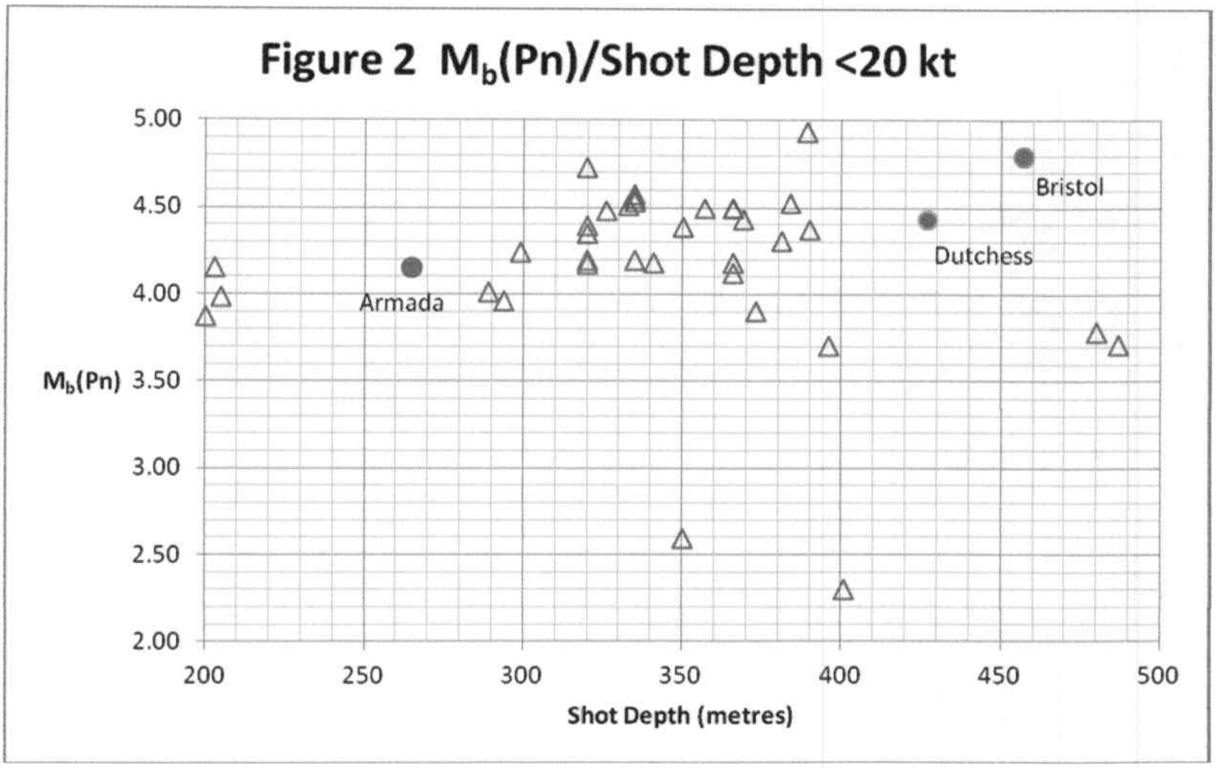

Figure 2 $M_b(Pn)$/Shot Depth <20 kt
$M_b(Pn)$
5.00
4.50
4.00
3.50
3.00
2.50
2.00
200
250
300
350
400
450
500
Shot Depth (metres)
Armada
Dutchess
Bristol

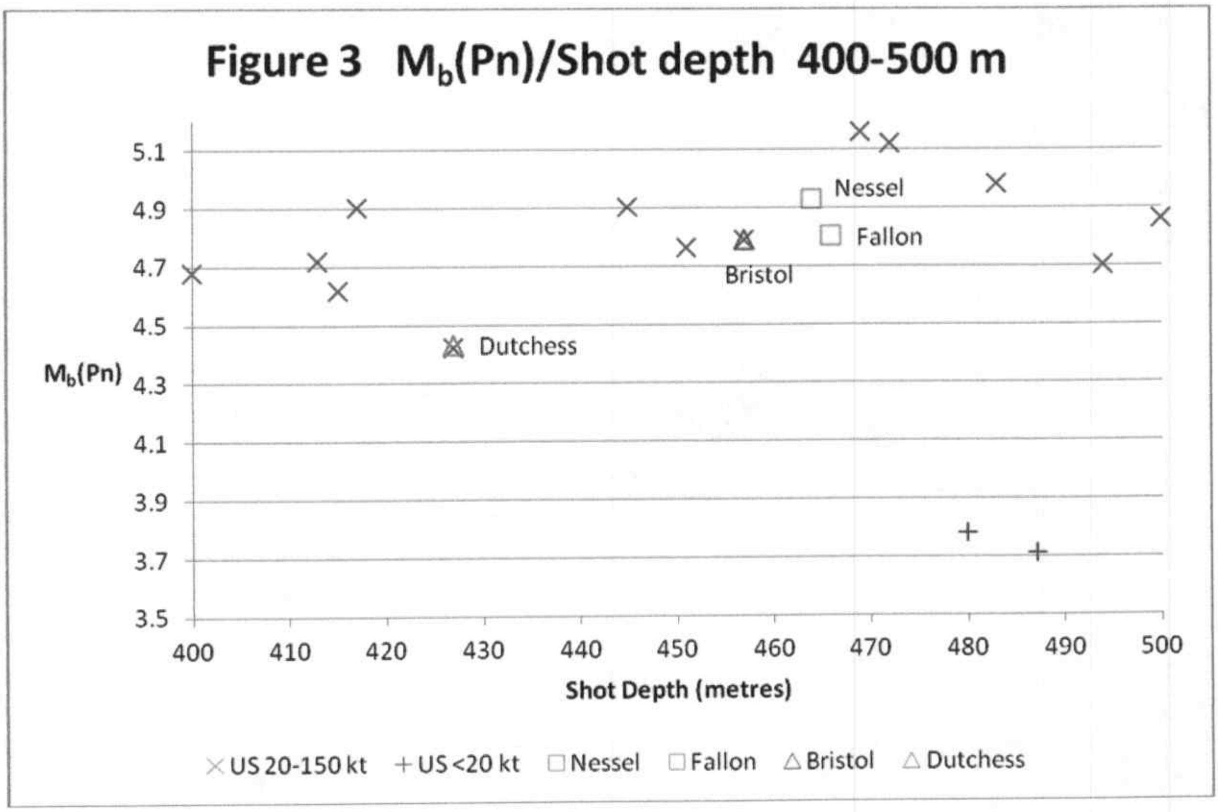
Figure 3 $M_b(Pn)$/Shot depth 400-500 m
5.1
4.9
4.7
4.5
4.3
4.1
3.9
3.7
3.5
$M_b(Pn)$
Nessel
Fallon
Bristol
Dutchess
400
410
420
430
440
450
460
470
480
490
500
Shot Depth (metres)
US 20-150 kt
US <20 kt
Nessel
Fallon
Bristol
Dutchess

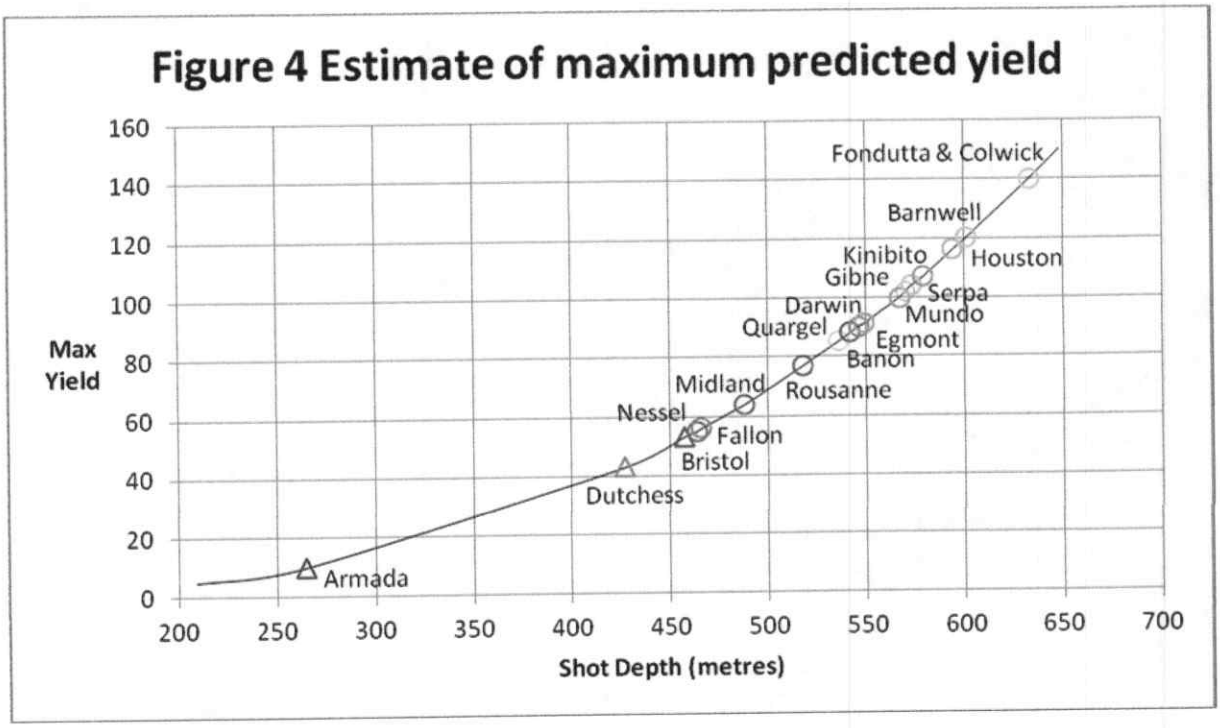
Figure 4 Estimate of maximum predicted yield
160
140
120
100
80
60
40
20
0
Max Yield
Fondutta & Colwick
Barnwell
Kinibito
Houston
Gibne
Serpa
Darwin
Mundo
Quargel
Egmont
Banon
Midland
Rousanne
Nessel
Fallon
Bristol
Dutchess
Armada
200
250
300
350
400
450
500
550
600
650
700
Shot Depth (metres)

The second approach was to gather several sets of data for tests of know yield. A plot was produced of yield against the data (body wave, surface wave or shot depth) for each data set. An estimate was made of the yield of the UK tests for each data set. The results were then combined.

Data for tests of known yield

Name	Date	Site	Depth	Water Level	M_b			M_s	Yield
					LLN	Kaz	Aus		
Scotch	23/05/1967	PM	977	B		5.7	5.7		155
Knickerbocker	26/05/1967	PM	631			5.5	5.54		76
Schooner	08/12/1968	PM	111	A		4.8	4.8		30
Benham	19/12/1968	PM	1402	B	6.49		6.3	6.87	1,150
Calabash	29/10/1969	YF	623	B	5.50		5.7	5.72	110
Labis	05/02/1970	YF	442	A		4.6	4.7		25
Cyathus	06/03/1970	YF	294	A		4.3	4.5		8.7
Snubber	21/04/1970	YF	343	A		4.4	4.6		12.7
Flask Green	26/05/1970	YF	528	B		5.5	5.6		105
Carpetbag	17/12/1970	YF	662	B	5.79	5.8	5.8	5.92	220
Baneberry	18/12/1970	YF	278	A		5.1	5.2		10
Miniata	08/07/1971	YF	529	A		5.5	5.5		83
Delphinium	26/09/1972	YF	296	A	4.54	4.4	4.4	3.85	15
Starwort	22/04/1973	YF	564	B	5.49		5.6	5.26	90
Fallon	23/05/1974	YF	466	A			4.8		35
Quargel	18/11/1978	YF	542	B	5.10	5.1	5.1		47
Jornada	28/01/1982	YF	640	B	5.76	5.6	5.9	5.67	139
Atrisco	05/08/1982	YF	640	B		5.7	5.7		138
Chancellor	01/09/1983	PM	625	A	5.52	5.5	5.5	5.31	143
Glencoe	22/03/1986	YF	610	B	5.41	5.1	5.2	4.83	29
Cybar	17/07/1986	PM	628	A	5.57	5.7	5.7	5.47	119

Site – YF – Yucca Flats; PM – Pahute Mesa
Depth – Shot Depth at which the device was detonated (metres)
Water level – whether the shot depth was above (A) or below (B) the water level
M_b – Body Wave:
LLN – M_b(Pn) based on local data from the Lawrence Livermore Network.[110]
Kaz – M_b from Borovoye, Kazakhstan.[111]
Aus – M_b published by the Australian Government.[112]
M_s – Surface wave based on local data from the Lawrence Livermore network.[113]
Yield – Published yields of US tests.[114] Plus Fallon (predicted yield) and Quargel.

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[110] Estimating Ms from short-period (<10 sec) Rayleigh waves for earthquakes and explosions at the Nevada Test Site, J Bonner et al, in Calibration of the M_s:M_b Discriminant at the International Monitorying System Array NVAR (PS-47), Weston Geophysical, September 2005.
[111] ftp://ftp.ldeo.columbia.edu/pub/wykim/Brv_archive/uk_table.pdf
[112] http://www-a.ga.gov.au/oracle/nuclear-explosion.jsp
[113] J Bonner et al, op cit; This shows two sets of Ms data, based on different formulae. The set used was labelled as "Rezapour and Pearce (1968)". The yield estimates for UK tests using the other formula were very similar.
[114] United States Nuclear Tests July 1945 through September 1992; http://www.nv.doe.gov/library/publications/historical/DOENV_209_REV15.pdf

Data for UK tests

Name	Date	Area	Hole	Shot Depth	Water Level	M_b			M_s
						LLN	Kaz	Aus	
Fallon	23/05/1974	YF	U2dv	466	548			4.8	
Banon	26/08/1976	YF	U2dz	536	544		5.5	5.3	
Fondutta	11/04/1978	PM	U19zs	633	668		5.3	5.5	
Quargel	18/11/1978	YF	U2fb	542	539		5.1	5.0	
Nessel	29/08/1979	YF	U2ep	464	531	4.93	4.7	4.8	4.37
Colwick	26/04/1980	PM	U20ac	633	630	5.66	5.4	5.5	5.53
Dutchess	25/10/1980	YF	U7bm	427	534	4.43	4.4	4.7	4.06
Serpa	17/12/1980	PM	U19ai	573	627	5.26	5.1	5.1	5.01
Rousanne	12/11/1981	YF	U4p	518	499	5.38	5.4	5.4	5.16
Gibne	25/04/1982	PM	U20ah	570	610	5.47	5.4	5.4	5.35
Armada	22/04/1983	YF	U9cs	265	590	4.15	4.0	4.0	3.59
Mundo	01/05/1984	YF	U7bo	567	558	5.47	5.4	5.3	5.32
Egmont	09/12/1984	PM	U20ai	546	A	5.51	5.5	5.5	5.34
Kinibito	05/12/1985	YF	U3me	579	496	5.60	5.7	5.7	5.32
Darwin	25/06/1986	PM	U20aq	549	574	5.58	5.5	5.6	5.39
Midland	16/07/1987	YF	U7by	488	577		4.8	4.8	
Barnwell	08/12/1989	PM	U20az	601	A	5.56	5.5	5.5	5.29
Houston	14/11/1990	PM	U19az	594	A	5.46	5.4	5.4	5.15
Bristol	26/11/1991	YF	U4av	457	482	4.79	4.6	4.6	4.34

Estimated yields of UK tests

Name	Date	Estimated Yield								
		Max	(M_b)			(M_s)	(Dp)	Ave	Adj	Range
			LLN	Kaz	Aus					
		1	2	3	4	5	6	7	8	9
Banon	26/08/1976	85		92	67		61	73	65	55-80
Fondutta	11/04/1978	143		63	99		125	95	95	85-115
Colwick	26/04/1980	143	148	76	81	125	125	111	111	80-120
Dutchess	26/04/1980	44	10	11	21	21	27	18	15	10-20
Serpa	17/12/1980	106	61	43	45	67	80	59	59	45-75
Rousanne	12/11/1981	78	80	76	67	80	53	71	71	50-80
Gibne	25/04/1982	105	97	76	81	101	78	87	87	70-100
Armada	22/04/1983	7	5	5	5	12	8	7	5	1-8
Mundo	01/05/1984	103	97	76	55	97	76	80	80	60-100
Egmont	09/12/1984	92	106	92	99	99	65	92	90	65-100
Kinibito	05/12/1985	110	129	134	120	97	84	113	100	80-110
Darwin	25/06/1986	93	125	92	120	106	67	102	93	70-100
Midland	16/07/1987	64		24	25		43	31	31	20-45
Barnwell	08/12/1989	121	119	92	99	94	98	100	100	85-115
Houston	14/11/1990	118	95	76	81	79	93	85	85	75-105
Bristol	26/11/1991	53	21	17	17	29	34	23	20	15-25

Col 1 Max – Maximum predicted yield, based on $Y=121xD^{1/3}$

Col 2 M_b – LLN – Estimate of yield based on M_b(Pn) from the Lawrence Livermore Network

Col 3 M_b – Kaz – Estimate of yield based on M_b measured at Borovoye, Kazakhstan

Col 4 M_b – Aus – Estimate of yield based on M_b published by the Australian Government

Col 5 M_s – Estimate of yield based on M_s from the Lawrence Livermore Network

Col 6 Dp – Estimate of actual yield based on shot depth

Col 7 Ave – Average of columns 2-6

Col 8 Adj – Col 7 figures adjusted to take account of maximum predicted yield, effect of water level and exaggeration of low-yield tests.

Col 9 Range – Approximate range of estimated yield

Summary of UK tests and estimated yields

US Name	UK Name	Date	US Lab	Published Yield (Kt)	Estimated Yield (kt)		Purpose
					Value	Range	
1974-81							
Fallon	Forrester-1	23/05/1974	LLNL	35	35*	25-45	Chevaline primary
Banon	Anvil	26/08/1976	LLNL	20-150	65	55-80	Chevaline
Fondutta	Firstrate	11/04/1978	LLNL	20-150	95	85-115	Lightweight Chevaline
Quargel	Gavel	18/11/1978	LLNL	47	47*	42-52*	High Speed RB
Nessel	Dicel	29/08/1979	LLNL	35-40	35	35-40*	New small primary for multiple uses
Colwick	Dingbat	26/04/1980	LLNL	20-150	111	80-120	Increased yield
Dutchess	Lute Prime	25/10/1980	LANL	<20	15	10-20	[illegible]
Serpa	Hurdle Prime	17/12/1980	LLNL	20-150	59	45-75	
Rousanne	Lute	12/11/1981	LANL	20-150	71	50-80	Yield variation for theatre warhead
1982-87							
Gibne		25/04/1982	LLNL	20-150	87	70-100	Trident development and theatre warhead development
Armada		22/04/1983	LLNL	<20	5	1-8	
Mundo		01/05/1984	LANL	20-150	80	60-100	
Egmont		09/12/1984	LLNL	20-150	90	65-100	
Kinibito		05/12/1985	LANL	20-150	100	80-110	
Darwin		25/06/1986	LLNL	20-150	93	70-100	
Midland		16/07/1987	LANL	20-150	31	20-45	
1988-91							
Barnwell		08/12/1989	LLNL	20-150	100	85-115	Trident stockpile test(s) and theatre warhead development ?
Houston		14/11/1990	LANL	20-150	85	75-105	
Bristol		26/11/1991	LLNL	<20	20	15-25	

Thermonuclear [illegible]

Name – US name for test

Device – British name for device (warhead)

US Lab – US laboratory supporting the test; LLNL – Lawrence Livermore National Laboratory; LANL – Los Alamos National Laboratory

Published Yields – Yield brackets for tests; predicted yield for Fallon and Nessel and actual yield for Quargel

Estimated Yields - * published figures; estimates for remainder