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British Nuclear Warhead Design 1958–66: How Much American Help?

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With the possible exception of the value of sterling, the possession of nuclear weapons has been the most important manhood issue for post-war British governments. Politicians, historians, and journalists have disagreed, however, about the British-ness of this British symbol. Opposition leader Harold Wilson derided the 'so-called independent, so-called British, so-called deterrent' in Parliament, implying that, following the re-creation of a close Anglo-American nuclear alliance in 1958, American help now lay, very literally, at the core of Britain's nuclear weapons[1].

During World War II, the British and American governments had worked together on a range of secret defence and intelligence matters with a trust and closeness quite unprecedented among sovereign states in wartime. Many of these contacts continued after the war. In one significant area, however, the close relationship was lost: wartime cooperation in atomic energy was terminated abruptly and unilaterally with the passage through the US Congress, in July 1946, of the Atomic Energy Act, excluding all foreigners from the decisive secret of atomic weapons. Britain's 'long wait' thereafter for the resumption of meaningful exchanges with the US on atomic matters has become a popular theme for diplomatic historians[2].

Without American help, the British felt the need to establish their own atomic programme, and, although the renewal of cooperation remained a key political aim for successive British governments, a serious reconciliation was prevented for many years by internal US politics, spy scandals, and a frank suspicion on the part of the Americans that they had little to gain. During the mid-1950s, relations began to improve. Talks began to coordinate the atomic strike plans of Bomber Command and the US Air Force. American interest in British civil nuclear technology added impetus to talks on power reactors for submarines. In 1957 agreement was reached to allow Royal Air Force (RAF)

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Defence Studies, Vol. 4, No.2 (Summer 2004), pp. 207–228
ISSN 1470-2436 print/ISSN 1743-9698 online
DOI: 10.1080/1470243042000325913

aircraft to use US nuclear weapons, held in peacetime at RAF bases but under US custody, in the event of war.

Finally, in 1958, the Atomic Energy Act was revised to allow meaningful talks between America and countries that had made 'substantial progress in the development of atomic weapons' – a formula designed expressly to include Britain but not France. In July, an Anglo-American agreement was signed to allow information on nuclear weapons to be exchanged 'to improve the recipient's atomic weapon design, development, and fabrication capability', provided the originator believed this would promote its own defence and security. In 1959, the agreement was revised to allow the exchange of special nuclear materials and non-nuclear components of weapons.[3]

Various interpretations have been put upon the political and diplomatic manoeuvring behind these agreements. Some commentators have felt that the Americans owed something to the UK for help given in wartime, especially at the very beginning of the atomic enterprise;[4] others that the old-world sophistication of British diplomats extracted undeserved concessions from big-hearted American scientists and policy-makers.[5] Some have suggested an element of 'bluff' on the British side, creating the impression that exchanges would be mutually worthwhile;[6] others believe the resumption of exchanges was a political fix, following the shocks of Suez and Sputnik, and arrived at without serious consideration of the scientific details.[7]

Although the story of the resumption of co-operation has now therefore been told, historians have not yet looked closely at the years after 1958 to ask what practical use British weapons designers were to make of the information they now gained from the US. The possibilities, in particular that British weapon designers could now copy US designs, have long been recognised.[8] In 1983, John Simpson reviewed these possibilities, suggesting a range of options open to the British including buying US components, 'anglicising' US designs using British components, and so forth.[9] In 1984, Duncan Campbell stated confidently, in line with his thesis that Britain was an entirely subservient partner in the special relationship, that 'all subsequent weapons (save Chevaline in the 1970s) were more or less copies of US designs'. Two years later, however, Simpson argued that 'contrary to popular belief and the logic of the 1958 US-UK agreement and its subsequent amendments, all British nuclear warheads have been of indigenous design, rather than copies of American types'.[10]

Both authors had the benefit of discussions with insiders, but neither, at the time, had access to declassified material, which became available in quantity in the mid-1990s. This information allowed Ian Clark and others to demonstrate that the British H-bomb warhead Red Snow related to the American Mark 28, and Stan Norris and his co-authors to conclude that later British nuclear weapons were, like Red Snow, 'American designed, British manufac-

tured'.[11] John Baylis however was unconvinced, demonstrating that British scientists had made more progress in their own H-bomb design work than previous writers had acknowledged and suggesting 'a more complicated picture' of the origin of later weapons.[12]

Additional declassified documents and the recollections of some of the people closely involved in the British weapons programme now make it possible to go beyond these confusing and contradictory statements. This article presents and assesses the information now in the public domain about British nuclear warhead designs in the period 1958–66, and attempts to answer the question: how much British and how much American input to these designs can we discern?

Nuclear Weapons

In seeking to understand details of nuclear warhead design, it will be helpful to keep some definitions in mind. There are two main nuclear reactions underlying the design of nuclear weapons. One is fission, the breaking apart of heavy atomic nuclei, as in the original atomic bombs used at Hiroshima and Nagasaki. The other is fusion, the bringing together of light atomic nuclei, as in the later thermonuclear or hydrogen bomb.

Fission weapons can be made to explode simply by creating a critical mass of fissile material, usually by subjecting a sub-critical mass to extreme pressure by imploding a surrounding charge of chemical high explosive. Fusion weapons, on the other hand, as the name 'thermonuclear' suggests, require large amounts of input heat to begin the nuclear reaction. In practice this heat comes from the explosion of a fission weapon. What are usually described as 'true' hydrogen bombs therefore have two stages – a fission 'primary' which sets light to a fusion 'secondary' – although there are other possibilities including three-stage designs or simply surrounding a fission weapon with fusion fuel in a design now regarded as somewhat primitive.

The fissile material used in a fission weapon is either highly enriched uranium (enriched, that is, in the isotope uranium-235 or U235) or plutonium ('weapons-grade' plutonium mostly comprises the isotope plutonium-239). The fusion fuel used in a hydrogen bomb is generally solid lithium hydride enriched in lithium-6 and deuterium or heavy hydrogen. It is also possible to 'boost' fission weapons by the addition of small amounts of fusion fuel, usually in the form of tritium gas, another heavy isotope of hydrogen. Boosting is used to increase the safety and reliability of fission weapons and to increase their 'efficiency' – that is, the ratio of yield to mass of fissile material.

Another important technique contributing to these aims is external neutron initiation (ENI): a fission reaction needs input neutrons to begin effectively,

similar yield, was already undergoing safety tests, although its service entry with the RAF and Royal Navy was to be delayed until 1960. Its warhead was also being considered for use in an atomic landmine for the army, called Violet Mist, and an atomic depth charge. A smaller warhead design, Indigo Hammer, was also being considered for Violet Mist, the surface-to-air guided weapon (SAGW) Red Duster (later Bloodhound), and the army surface-to-surface weapon Blue Water. Both Red Beard and Indigo Hammer had in addition potential applications as thermonuclear primaries.[17]

Still smaller warheads included Pixie, being considered for the naval SAGW Seaslug, and Yellow Anvil, intended for use in a six-inch artillery shell for the army.[18] These small warheads had problems: they used extravagant amounts of fissile material and their yields were inadequate for some applications.[19] AWRE was hoping to be able to increase the yields of Red Beard and Indigo Hammer, at least, by using U235-plutonium mixtures.[20]

An active programme of British nuclear tests was underway in Australia and in the Pacific. Warheads to meet specific service requirements had been tested, and AWRE had made great advances during 1957 and 1958 in general knowledge of warhead design. In particular, various derivatives of a two-stage thermonuclear device originally codenamed Green Granite had been tested in the Pacific. By the end of 1957 British scientists knew how to build a one-megaton two-stage H-bomb warhead weighing a ton, but realised it would be expensive in fissile material and vulnerable to neutron irradiation from defensive nuclear explosions (the 'R-1 effect').[21] Both ENI and boosting for fission warheads were now understood, and the Grapple-Z tests in the autumn of 1958 included improvements in use of fissile material and protection against R-1.[22]

More could still to be done, as H-bomb project chief William Cook certainly recognised, and further test series were planned.[23] But recently declassified information confirms John Baylis's conclusion that 'Britain's Grapple tests provided an indication not only that she was intent on developing the H-bomb but also that the scientific and technological expertise existed to achieve an operational thermonuclear capability in due course'.[24] It also shows that British designers had made significant progress on a variety of kiloton, tactical weapons requirements.

Anglo-American Exchanges

Historians have explored progress at the first Anglo-American scientific discussions of nuclear warheads during August and September 1958 in some detail.[25] British and American representatives met for substantial talks on

nuclear weapons design in Washington on 27–28 August, and at the Sandia laboratory in Albuquerque, New Mexico, on 15–17 September.[26]

The highest British priority, going into these meetings, was for information on lightweight thermonuclear warheads and fission primaries immune to R-1. As we have seen, a megaton warhead weighing no more than a ton was certainly required for the key deterrent weapon Blue Streak. An immune megaton warhead weighing as little as 500–700lb would be still more desirable.[27] At the Cabinet Defence Committee, during discussion of the forthcoming talks, interest was expressed in using a lightweight megaton warhead on American Thor missiles instead of Blue Streak, and in relying on the US for some kiloton weapons and/or warhead designs.[28]

At the August meeting, British scientists received detailed information on nine US nuclear warhead designs. Three were H-bombs (Marks 15/39, 27, and 28), the lightest being the Mark 28 at 1,700–2,300lb. The other six were kiloton designs: the eight-inch shell warheads Marks 19 and 33, the missile warheads Marks 25 and 31, and the multipurpose warheads Marks 7 and 34. In return, the British briefed the US on at least: Green Grass; 2,200lb and planned 1,500lb, two-stage and three-stage H-bombs; Yellow Anvil; and at least one small boosted warhead design.[29]

The following month, information was passed by the US on a further series of warheads: one was the multi-megaton three-stage H-bomb Mark 41; one the 'clean bomb' Mark 46; one the lightweight (600–700lb/400kt) Polaris missile warhead Mark 47; one the six-inch artillery shell warhead Mark 48; and the other two were boosted tactical warheads (Marks 44 and 45).[30] It is interesting that the US now chose to pass information on boosted weapons, a six-inch artillery warhead, a lighter-weight megaton warhead, and a three-stage bomb, having presumably been impressed at the first meeting by Britain's equivalents. It is interesting also to consider certain warheads the Americans were already developing but chose *not* to discuss, for example the 1,500lb megaton weapon Mark 43 and the Thor missile warhead Mark 49.

Absorbing the Information

Where did the new information leave Britain's warhead designers? The key objective of access to a practical 500lb megaton warhead appears not to have been met – not because the Americans were unwilling to help, but because they had no such design available off-the-shelf. Interesting possibilities had been raised, however, and a period of intensive discussion at ministerial and official level was to follow, under some pressure to produce early decisions on ways forward for the weapons programme.[31]

The Cabinet Defence Committee discussed new nuclear possibilities on several occasions in the summer of 1958. It is not clear however that a simple yes-or-no decision on whether to produce American warheads in future, rather than continuing with British designs, was made at this level. It may have been implicit: why would the UK have toiled for so many years to rebuild the nuclear relationship, if not to take advantage of American knowledge in this way? Instead the declassified papers of the committee record forward-looking discussions of the possibility of joint Anglo-American work, for example on lightweight thermonuclear warheads for Thor or Blue Streak, and on extending the exchanges to include physical transfers of fissile material.[32]

Ministers were also acutely aware of US President Eisenhower's proposal, the Friday before the August meeting, of a year-long US/UK/Soviet nuclear test moratorium pending discussions of a complete test ban. The talks, and the moratorium, began on 31 October and were to last until 1961. The impossibility of testing became an important constraint on nuclear warhead possibilities during these years.

At official level, discussions appear to have been hampered to some extent by security restrictions; the RAF was frustrated that MoD Chief Scientific Adviser Frederick Brundrett, on US instructions, was limiting the circle of knowledge.[33] One line of enquiry, however, was clear to all. At the September meeting, the British had expressed, and the Americans had welcomed, an interest in producing British versions of the US Mark 28 and Mark 47 warheads for key requirements including Blue Streak. Mark 28 appealed as a well understood and well engineered warhead, just about light enough to incorporate in any or all of Yellow Sun, Blue Steel, and Blue Streak, and having a range of possible yields. It seemed to offer a much easier route to a fully operational H-bomb than weaponising one of the Grapple-Z warhead designs, given that further tests to perfect the latter were, in the short term, impossible. Mark 47, a lighter design, indeed approaching the sought-after 500lb mark, was unfortunately a good deal less mature and used more fissile material than Mark 28 for a lower yield.[34] It was also clear that it might be possible to use US designs in place of Indigo Hammer, Pixie, and Yellow Anvil.[35]

Detailed decisions were made on 11 November 1958 by the Defence Research Policy Committee's atomic sub-committee, known by the initials DRP(AES) and chaired by Brundrett. Red Snow, a UK megaton version of the US Mark 28 warhead, would be developed for production at the highest priority for Yellow Sun, Blue Steel, and Blue Streak. Green Grass would not be developed further, but would continue in production, for use in Yellow Sun, until Red Snow became available. A version of the US Mark 44 warhead would also be produced for use in SAGW in place of both Indigo Hammer, which 'was now out of date', and Pixie. Yellow Anvil was also dropped 'since the US had

nuclear weapons would in future be 'virtual copies' of US designs and therefore require no testing.[54] The following month, the Cabinet Defence Committee approved the indefinite suspension of British nuclear testing. At the end of the year, the committee finally approved a series of decisions on future warhead production, stating that Britain should 'end production of megaton weapons of British design and start production of a warhead of American design'. The first American-designed warheads would be produced in 1960–61.[55]

Copying and 'Anglicisation'

The recollections of nuclear weapons researchers, and new published work from the official historian of atomic energy, allow us now to understand a little better what was meant in these ministerial briefings by 'virtual copies'. There can be no doubt that American design information was made available to the UK without limitation to underpin British work on specific warheads including Red Snow.[56] British scientists visited US production facilities and were given several crates of drawings and documents.[57] However, Peter Jones, a former Director of AWRE, contests the belief of 'non-technical observers who see the blueprint as the answer whereas actually it is only the challenge', and Lorna Arnold also stresses that 'it was by no means the case ... that, once given the American engineering drawings and specifications, it was a simple and relatively unskilled matter to produce "Chinese copies".'[58]

Jones elaborates further on the problems encountered: Mark 28 'would need some interface and configuration changes for Blue Steel, Yellow Sun, and Blue Streak, and specifications for material process, mechanical, and electronic fabrication would ... be required for consistency with UK standards ... some subsystems would consequently have to be redesigned'. Arnold also mentions British specifications, manufacturing standards, and alternative materials; and a Ministry of Aviation (MoA) document of 1962 stated that 'British designs differ from the US for a number of reasons, which include the use of British materials,British manufacturing techniques, and the necessity to comply with British standards of safety'.[59]

A specific safety issue arose relating to the high explosives used in US fission warheads and primaries. American PBX9404, a plastic-bonded explosive, was regarded with some justification as dangerous, and a British equivalent, EDC11, was used in its place in both Tony and Red Snow.[60] One result of this change was that the dimensions of the warhead increased, as a greater amount of the less sensitive British explosive seems to have been required in order to guarantee the appropriate yield.

Another was that implosion and safety calculations had to be repeated: as Jones puts it: 'the US view was straightforward. Whatever the UK made the

UK would have to underwrite ... [and] check ... against the US test data'. We know that computing capacity was limited at Aldermaston during this period,[61] and it seems as a result that using US designs saved a good deal less effort than a lay observer might originally have assumed. Nor was the availability according to the 1959 agreement of US non-nuclear components a useful short-cut: only half a dozen or so electronic and polyurethane components for Red Snow were eventually procured through this route.[62]

We now know, in addition, that the specific US designs of interest to the British were in themselves not without problems. Both Tsetse (the basis for Tony) and Python (the Mark 28 primary) were discovered in the early 1960s to have been affected by a 'tritium cross-section miscalculation'. This will have affected the likely yield and/or overall functioning of the warhead.[63] The declassified documents in the UK are silent on this subject, but some British scientists perhaps now regretted going down the road of Anglicisation. One author at least believes this to have been a decisive issue: 'never again would Aldermaston simply copy a US warhead design'.[64]

Other Avenues

It is also now clear that, even before the implications of anglicising US designs had been fully explored, other design avenues were being examined. Weapons requirements were emerging that could not be related directly to US warhead designs. We have seen, for example, that a requirement for a successor to Red Beard had been suggested. Investigations were also underway into multi-megaton warheads, low-altitude delivery, megaton weapons for naval aircraft, kiloton and megaton weapons for the new RAF tactical strike reconnaissance aircraft TSR.2, depth charges, and no doubt other ideas.[65]

During 1959, work began in joint Anglo-American groups to explore 500–600lb (megaton) and 100–200lb (yield unknown) warhead designs.[66] The possibility of a UK lightweight warhead (400kt/700lb) – either for Skybolt, instead of Mark 47, or for the atomic depth charge or Red Beard replacement – was also discussed.[67] In April 1960 the Red Beard replacement and its warhead became joint Royal Navy/RAF requirements. Following several DRP(AES) discussions, Defence Committee approval for the weapon, which was later to enter service as WE177, was received in August 1961.[68] Perhaps significantly, the warhead associated with this requirement, Una, was not expected to become available until around 1965; it may not therefore have been an off-the-shelf US design.[69]

At the start of 1960, after much agonising, ministers took the decision to cancel Blue Streak. This was announced in April, along with the US government's commitment to supply Skybolt in its place.[70] Blue Streak's demise had

an immediate impact on warhead plans, for it now became impossible to consider using a warhead under US custody for Skybolt, suddenly the UK's main deterrent system. Nor indeed was it possible simply to copy the US Skybolt warhead, for no decision had yet been made on which warhead to use: only in January 1961 did the US decide on the Mark 59.[70] By May 1961 the British had received design information on this warhead, which incorporated the Tsetse primary, already being anglicised as Tony.[72]

The War Office's concern that Tony had insufficient yield to destroy some of the targets intended for Blue Water also resurfaced during 1960, and it became apparent that War Office and Air Ministry requirements for 10–300kt warheads might converge.[73] Indeed, the possibility that warhead requirements more generally might be made to converge was discussed several times in 1960–61 by the DRP(AES) sub-committee: 'there was a need for a new approach to warhead development ... One possibility was to use the same primary for all warheads'.[74]

Ministers were again told in March 1961 that warhead development was 'confined almost entirely to copying US designs'.[75] In the light of the information presented above, this appears to have been an over-simplification. Joint US/UK working groups had been set up and were considering, among other things, future lightweight warheads; various weight/yield combinations for new warheads were being put forward; important new requirements, for Skybolt and a Red Beard successor, were driving work in new directions; and the War Office was striving to get its own new requirements accepted by aligning itself with the Air Ministry. By the summer of 1961 a knowledgeable MoD official noted that the Skybolt warhead was now likely to be used as the 'basic design for a multipurpose warhead' but also, interestingly, that 'the precise characteristics of the Skybolt warhead [were still] ... being worked out by AWRE and US labs'.[76] These statements suggest strongly that Aldermaston was by now modifying and even influencing, not simply copying, American designs.

By October 1961, three warhead types were in production or at an advanced stage of development in the UK: the British kiloton warhead for Red Beard and the American designs Red Snow and RO106/Tony. The US and USSR had recently ended the test moratorium, and UK testing was once again under discussion: a firing of the 'UK stockpile version' of RO106 was considered for the first quarter of 1962, along with a test of a new *British* implosion system for lighter and more reliable warheads, of about 10kt yield, in which the US had expressed considerable interest as long ago as 1958, and which was thought to have potential in the primary for Skybolt.[77] This is further evidence that British warhead design work was back underway.

In November 1961, Macmillan was briefed on the need to test the new implosion system, codenamed Super Octopus. The nature of the design advance involved in Super Octopus is unclear from the declassified documents, although it presumably related to Octopus, described in the title of an AWRE report dating back to 1957 –*before* any talks with the US – as a 'possible implosion system to replace baratol and air lenses'. Significantly, one account indicates that the new implosion system 'facilitated scaling of yield and so made it a suitable design for ... differing applications', including not only Skybolt but also the improved kiloton bomb and later Polaris.[78] The test took place in March 1962 at the US range in Nevada, and was judged a success.[79]

Fewer Requirements

Meanwhile in Whitehall, ministers had called for a comprehensive review of warhead requirements in the autumn of 1960. The context for the review was financial stringency, but also the changed strategic situation of the 1960s, and the opposition of the new MoD Chief Scientific Adviser, Solly Zuckerman, and others to the idea of warfighting using tactical nuclear weapons. The review confirmed in February 1961 the need for Red Beard, Red Snow, the Skybolt warhead, and RO106/Tony but delayed into 1962 a number of other decisions on kiloton and sub-kiloton warheads.[80] Eventually almost all such requirements were to be cancelled.

By May 1962, the Nuclear Requirements for Defence Committee (NRDC), another group chaired by the MoD Permanent Secretary, was looking at specific proposals. First, the Skybolt programme might be reduced from 170 to 100 or even 70 missiles (corresponding to a requirement for 158, 90 or 60 warheads). Second, the Red Beard replacement programme might be reduced to 334 weapons using Tony as the warhead. War Office requirements for atomic landmines and artillery shells, and all other requirements for over 10kt yield, including presumably any high-yield Red Beard replacement and certainly any high-yield Blue Water warhead, were now threatened. The proposals were explained with reference to intelligence, strategic considerations and the need to save £130 million.[81]

Two decisions, independent of the warhead review, now served to reduce nuclear requirements still further. The Seaslug nuclear warhead requirement was cancelled by the Admiralty in June 1962, and Peter Thorneycroft, the new Secretary of State for Defence, cancelled the Blue Water project in August.[82] These decisions undermined the requirement for RO106/Tony, work on which had been 'well advanced' at AWRE as early as February, and components for which had now been produced.[83]

When the Cabinet Defence Committee discussed the warhead review in June, they received a paper from the Secretary of State for Air, horrified in particular at the proposed reduction in Skybolt numbers. A compromise figure of 100 missiles and 90 warheads seems to have been decided.[84] The requirement for the Red Beard successor, for use in 'laydown' mode or against underwater targets, also survived, although it is not clear whether the need for a yield above 10kt was accepted. Committee papers suggest that a 100kt yield requirement was still associated with this weapon, but disputed by the Treasury; a later account suggests that by October 1962 only the Skybolt warhead and the 10kt Red Beard successor remained in the nuclear weapons programme.[85] A depth-charge capability for the Red Beard successor does seem to have been agreed, however, also in October.[86]

In summer 1962, the Ministry of Aviation took stock of the British warhead programme. RE179 was a British version of the US Skybolt warhead design Mark 59, using RO106/Tony as its primary. Unfortunately, the substitution of British for American high explosive in RO106/Tony had reduced its yield unacceptably. As we have seen, its other potential applications had also been, or were about to be, cancelled. Cleo, a design using the Super Octopus principle tested in March, was more compact than RO106/Tony for the same yield, and the Americans were said to be keenly interested in the design. It was thought possible to adapt Cleo, by using a larger high-explosive supercharge, as the Skybolt primary. If so, a similar design, downgraded in yield by the removal of some material from the secondary, could also be used as a high-yield warhead for the Red Beard successor. A further test of the Super Octopus principle, using more high explosive and less fissile material, was recommended, with the words 'any other British nuclear warhead is likely to follow this line of development'.[87] The test took place on 7 December 1962 in Nevada.

In an atmosphere of political crisis, the Skybolt missile was cancelled by the US, and Polaris promised to the UK in its place, just weeks later.[88] These momentous events caused but little concern for warhead designers however: the December test had been a success, and the device had potential for use in Polaris, as in Skybolt.[89] The end of Skybolt did have implications, however, for the Red Beard successor WE177. Polaris would not enter service until 1968, and as a stop-gap the Air Ministry was able to gather urgent weight behind a requirement for 140 of a high-yield version of WE177 for use by V-bombers at low level in laydown mode.[90] This, and the fact that around 240 Polaris warheads might now be required, compared to 90 Skybolt, also had the effect of increasing the UK's requirement for fissile material.[91]

A Steady-State programme

Norris, Burrows, and Fieldhouse have suggested that the high and low-yield versions of WE177 were copies of the US Marks 61 and 57 respectively, and Polaris a copy of Mark 58,[92] but these ideas are not supported by the emerging documentary evidence. This shows, rather, that a single warhead design or family of designs, based on ideas developed for Skybolt and incorporating the UK Super Octopus principle, was used for all three weapons.[93] The WE177 warhead was reduced in size and changed in weight distribution to squeeze it into the Polaris re-entry vehicle.[94] With fewer requirements now on the stocks – only Polaris and the high and low-yield versions of WE177 – big changes were now anticipated at AWRE, focusing effort on the completion of existing weapons projects, post-design services, and quality research in physics, materials, and technology, but reducing professional staff by half by 1967.[95]

The final choice of Polaris warhead did remain subject to discussion with the US, and was several times called into question. A decision seems to have been taken in 1963 to use 'exact copies' of the US Mark 58 Mod.1 warhead, rather than the UK Super Octopus idea.[96] This decision was in line with a wider principle of the Polaris programme: for simplicity and speed, there was to be as much commonality as possible with the US system. There was also concern that any change to the Polaris warhead might fail to meet the deadline for the design to be frozen, but nevertheless in March 1964 the warhead seems to have been under discussion again, the choices remaining a 'Chinese copy' of the US Mark 58 or the version with a British primary.[97] Insurmountable problems were apparently faced, no doubt relating to those of Anglicisation more generally, in manufacturing the 'Chinese copy' in the UK at this period.[98] In June, the first references appeared to the possibility of a 'Polaris economy test'.[99] In October the test, using 450g less plutonium in the primary, went ahead but failed because of a fault in US neutron injection equipment.[100]

In January 1964, AWRE was seeking approval in addition for a three-year programme of nine research tests, looking into smaller kiloton weapons, improved yield-to-weight ratios in lightweight megaton warheads for the laydown weapon and Polaris, 'clean' weapons, weapons with high neutron output, and weapons using civil plutonium.[101] One test, in July 1964, went ahead, although its nature remains obscure. It may not have been entirely successful.[102]

At the start of 1965, the NRDC discussed test priorities again, weighing the options of completing the planned series of research tests and/or repeating the Polaris economy test. The recently elected Labour Prime Minister, Harold Wilson, approved only the repeated economy test in September 1965, which was Britain's last for nearly a decade.[103] The outcome of the test is not

completely clear from the public record, although a success seems likely; no more was heard of the possibility of a 'Chinese copy' of Mk. 58.

During 1966, suggestions for future nuclear weapons requirements were reviewed by the Chiefs of Staff. Options included a supersonic standoff air-to-ground weapon to replace WE177; a retarded sub-kiloton very-low-level weapon; a field artillery rocket system; an advanced depth charge; a British warhead for Lance (a US Army missile) or an eight-inch shell; variable-yield warheads; and high-neutron-flux devices.[104] No such requirements were accepted, however. Wilson, at Zuckerman's eager prompting, had insisted there would be no new generation of British nuclear weapons – a decision Zuckerman was quick to relay to the Americans.[105]

By the end of 1966, AWRE was working, as planned, on current weapons projects, post-design services, and research. The warhead programme comprised three related designs: PT176 (for the low-yield WE177A, due to enter service in December 1966); ZA297 (for the high-yield WE177B, due in June 1966); and ET317 (for Polaris, due in June 1968).[106] Decision-makers were conscious of an impending shortage of warhead work. This 'what next?' feeling, and an accompanying lack of enthusiasm on the part of the US for continued exchanges, were to become significant factors as the political foundations were laid in the following several years for work on Polaris improvement and Chevaline.[107]

Conclusions

For a time after 1958, it seems that Aldermaston's efforts were devoted largely to Anglicising US nuclear warhead designs. Britain's own tested designs, notably the two-stage 'Granite-type' H-bomb, were quickly abandoned because the moratorium made further improvements to them impossible. The process of Anglicisation, however, seems to have become rather more difficult than had at first been hoped. British high explosives had to be grafted onto American designs, necessitating time-consuming recalculation. Problems surfaced with the designs themselves, and although Red Snow continued into production and service, the military requirements for Tony were cancelled in 1962 and the design found no further application.

Even during this period, however, military requirements survived that could not easily be met by off-the-shelf US warheads. These included Skybolt, the Red Beard replacement, and the high-yield warhead for Blue Water. Once Blue Streak had been cancelled in 1960, the Skybolt warhead assumed great importance. By 1961–62 it seems that some original British thought was being given to these requirements. Although information on US warheads relevant

reasonably clear: we can discern some original British design input, in particular fission implosion systems and non-nuclear components, and some American input, in particular thermonuclear secondaries. British nuclear weapons after 1958 appear to have been conceived somewhere in mid-Atlantic.

NOTES

1 House of Commons debates, 16 Jan. 1964, vol. 687, col. 437; Peter Hennessy, *The Prime Minister: The Office and its Holders since 1945* (London: 2000) p.290.
2 See e.g., Andrew Pierre, *Nuclear Politics: The British Experience with an Independent Independent Nuclear Force 1939–70* (Oxford: OUP 1972); Margaret Gowing, *Independence and Deterrence: Britain and Atomic Energy 1945–52* (2 vols., London: Palgrave Macmillan 1974); Jan Melissen, 'The Restoration of the Nuclear Alliance: Great Britain and Atomic Negotiations with the United States 1957–58', *Contemporary Record* 6 (1992) pp.72–106, and *The Struggle for Nuclear Partnership: Britain, the United States and the Making of an Ambiguous Alliance* (Groningen: 1993); Timothy J. Botti, *The Long Wait: The Forging of the Anglo-American Nuclear Alliance 1945–58* (New York: Greenwood 1994); Ian Clark, *Nuclear Diplomacy and the Special Relationship: Britain's Deterrent and America 1957–62* (Oxford: Clarendon Press 1994) Ch. 3.
3 Cmnd.537, 'Agreement for co-operation on the uses of atomic energy for mutual defence purposes', 3 July 1958; Cmnd.733, 'Amendment to the agreement for co-operation on the uses of atomic energy for mutual defence purposes', 7 May 1959, reproduced in John Baylis, *Anglo-American Defence Relations 1939–80: The Special Relationship*, 2nd edn (London: Palgrave Macmillan 1984) pp.112–25.
4 Pierre, *Nuclear Politics* (note 2) esp. pp.118–19.
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31 Melissen (note 2) p.50.
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44 Class list for ES10, PRO.
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