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A History of the United Kingdom's WE 177 Nuclear Weapons Programme

From Conception to Entry into Service 1959–1980

Dr John R. Walker

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Executive Summary

A great deal has been written on Britain's strategic nuclear forces, but very little on its tactical nuclear weapons programmes. There is a wealth of detail now available in The National Archives at Kew that enables the historian to assemble a detailed account of these programmes covering the origin, development, acquisition, deployment and maintenance of operational capabilities of Britain's tactical nuclear weapons programme. This history confines itself to the period covered by releases of papers to The National Archives – roughly the mid-1980s. The purpose here is to chart the main features in the history of one of the United Kingdom's air delivered nuclear weapons, the WE 177 from its conception to entry into service with the RAF and Royal Navy, as a contribution to wider transparency and confidence building on nuclear weapons related matters. Much of the detail is of the sort that could be required as the world moves towards nuclear disarmament. This history offers a chronological account of the WE 177 from 1959 through to the decision to provide a third variant of the design for the RAF in the 1970s, and then onto the late 1970s when the final weapon emerged from the Royal Ordnance Factory at Burghfield and issues of refurbishment, life extension and eventual replacement started to arise.

The history draws five key conclusions. First, WE 177 development and acquisition faced a protracted process, caused primarily by disputed requirements coupled with financial and political pressures. Second, there was a clear linkage between the design of the aircraft initially planned to carry the new weapon and the weapon itself, which had impacts on the design of both. Third, the changes enforced by the cancellation of *Skybolt* in 1962 meant that the RAF ended up with a high yield weapon first rather than one was suitable for the priority hardened NATO and UK targets in Eastern Europe. Fourth, financial pressures were acute throughout the 1960s ensuring that the path to an operational capability is never as smooth as the services would like. Fifth, the surveillance and refurbishment programme was complex and required careful planning, extensive industrial and engineering support networks, and a trials programme to sustain the WE 177 in service. This is a key feature of a nuclear weapons programme and has a significant footprint, which has potential implications for the verification measures needed for a meaningful and effective nuclear disarmament treaty at some future point.

A Yellow Sun Mark II ballistic casing carrying the Red Snow one megaton warhead. Photo taken by Tom Oates, 2011.

Introduction

' … in all his years that he had been involved in the nuclear field, there had never been any positive UK Government policy on theatre nuclear weapons; all that had been achieved had resulted from what could be got through Ministers on an ad hoc basis.'

Vic Macklen, DCA (PN), MOD, October 1977.[1]

A great deal has been written on Britain's strategic nuclear forces, but very little on its tactical nuclear weapons programmes.[2] There is a wealth of detail now available in The National Archives at Kew that enables the historian to assemble a detailed account of these programmes covering the origin, development, acquisition, deployment and maintenance of operational capabilities of Britain's tactical nuclear weapons programme. This history confines itself to the period covered by releases of papers to The National Archives – roughly the mid 1980s. The purpose here is to chart the main features in the history of one of the United Kingdom's air delivered nuclear weapons, the WE 177 from its conception to entry into service with the RAF and Royal Navy, as a contribution to wider transparency and confidence building on nuclear weapons related matters. Much of the detail is of the sort that could be required as the world moves towards nuclear disarmament.[3] The intent here is to offer a history of the WE 177 from 1959 through to the decision to provide a third variant of the design for the RAF in the 1970s, and then onto the late 1970s when the final weapon emerged from the Royal Ordnance Factory at Burghfield and issues of refurbishment, life extension and eventual replacement started to arise. A total stockpile of 270 weapons was eventually

achieved by 1977.[4] It also charts the complexities and interrelationships between nuclear weapon design, development, production and operational deployment with the parallel developments in the design and procurement of the aircraft intended to deliver such weapons.

A nuclear weapons programme is very much more than just the acquisition of fissile material, undoubtedly essential though that is, the development and sustainment of an operational military capability for the potential use of nuclear weapons represents a considerable undertaking. Even in the cases of small medium programmes such as the UK's, the range of activities and organisational structures needed to support and sustain such a programme is considerable – the UK's requirement for a new generation of tactical air delivered nuclear weapons first articulated in 1959 led to a complex, diverse and protracted effort. This covered specifying, agreeing and reconciling conflicting operational requirement(s) – ground and/or maritime strike/depth charge for example, determining the tactics and doctrine for use, working out which aircraft and how many would be needed, building up and sustaining operational squadrons of aircraft – selecting and training aircrew and ground crew, the engineering facilities and expertise and refurbishments for keeping the weapon in service in a safe and reliable state. Moreover, all this requires effective but complex policy making and policy execution structures to make it function.[5] This entails a diverse range of military, scientific, engineering and civilian organisations and a raft of policy and review committees to plan, direct, review and implement the programme decisions. Essentially from the Prime Minister and Cabinet Ministers down to technical experts in the Royal Navy, RAF, Aldermaston, other research establishments and even in private engineering companies.

The information used to assemble this narrative comes almost exclusively from state papers publicly available in The National Archives and other official sources, supplemented by published works that also draw extensively on archival sources.[6] There are inevitably some gaps in this story, which will require further research to address. There is also a lot of further detail available in the files consulted that is not written up here.

Origins: a new operational requirement

The first and second generation UK nuclear weapons from the 1950s, *Blue Danube* and *Red Beard* were large and cumbersome and had operational limitations that made them increasingly unfitted for the sorts of missions that were required of them. *Red Beard,* for example, was aerodynamically unsuitable for external carriage at high-speed low-level flight. Its problems also included environmental limitations (temperature and vibration), which imposed maintenance and support complexities. Nor was it suitable either for underwater use as a depth charge. It had a single low yield – nominally 15 kilotons, which the Naval and Air Staff considered completely inadequate for most tactical nuclear weapon requirements from 1965 onwards.[7] This led to a joint naval/air staff operational requirement for a new weapon, the first draft of which was produced in August 1959 and carried the designation Air Staff Requirement 1177 (ASR 1177).[8] As Richard Moore has observed this prompted what turned out to be a rather lengthy period of discussion of the requirements for a more operationally flexible successor to *Red Beard*.[9] ASR 1177 called for an *'improved kiloton bomb'* for low-level delivery from the high performance aircraft then under development, such as the British Aircraft Corporation's Tactical Strike Reconnaissance (TSR.2), and was frequently characterised in Whitehall discussions for several years as the '*Red Beard replacement*' or the '*Laydown Bomb'*. This sought a weapon in the 100 kiloton range.[10] It also had a bearing on the future work of the Atomic Weapons Research Establishment (AWRE).[11]

There was much uncertainty at this time – early 1960s - over the nuclear weapon that the TSR.2 would carry once in service – and the Air Ministry was concerned that this would impact adversely on the design and operating characteristics of the aircraft.[12] There was thus a need for a firm statement from the RAF on the operational use of the TSR.2 in order to ensure that the final version of OR 1177 reflected these requirements.[13] A compromise in aircraft design was required until the OR could be agreed.[14] This was not a satisfactory situation. OR 1177's requirements in summary called for a 300 kiloton warhead, all weather capability, a delivery accuracy of 1,200 feet circular error probable, a damage probability of about 0.8 and one weapon delivery per target.[15] As it evolved into the 1960s this weapon went on to become Joint Naval/Air Staff requirement GD.10/OR.1177 in May 1960 and was the product of strenuous efforts to reconcile the different operational requirements of the RAF and Royal Navy in a common weapon casing (eventually expanded to two – one short and one long[16]) containing members of a *'common family'* of nuclear warheads. At this time OR 1177 was mainly directed towards carriage in the planned TSR.2, though it was required to be compatible with all the V-Bombers – the Valiants, Vulcans and Victors, the Canberras and other planned high performance aircraft.[17] Design considerations at this time were whether to have a single aerodynamic shape of the weapon for both internal and external carriage in the aircraft planned to carry the new weapon – TSR.2 and N.A.39, which would later become the Buccaneer maritime strike aircraft.[18] Aerodynamic drag would have a significant impact on the performance of the aircraft if the bomb were mounted on external pylons on the wings – there were also implications for the size and shape of the bomb if internal carriage were required given the size of the aircrafts' bomb bays. Although originally conceived as an aircraft for tactical use and for which OR 1177 was developed, by March 1961 there was some talk within the Air Staff of the TSR.2 also having a strategic role. This uncertainty complicated the designs of both aircraft and weapon.[19] If changes were required, it could threaten the planned date for the first operational squadron of TSR.2s, which was set in early 1961 for the end of 1965.[20] Air Staff Requirement No. O.R.1176, which called for a standard nuclear warhead capsule with fixed yields in the 10 to 300 kiloton range for use in different weapon systems,[21] was an important parallel step. This capsule also had to be capable of functioning at depths of up to 1,000 feet.

Entering service in 1955, the Vickers Valiant was the first of the RAF's "V-Bombers" drop live nuclear weapons during the British nuclear tests from 1955 - 57. The Valiant was withdrawn from service before the first WE177 was delivered to the RAF in 1966.

Decisions: the Cabinet Defence Committee 1962

The Cabinet Defence Committee – the prime decision making body on UK nuclear weapons policy at this time - was divided on the need for a high yield replacement weapon for *Red Beard*. Plans for the numbers of warheads (as well as their yields) were subject to much debate and came sharply to a head at Ministerial level in 1962. Henry Brooke, Chief Secretary to the Treasury wanted to cancel this project. Ministerial differences in the Cabinet Defence Committee continued over the spring and early summer of 1962 to impart their own uncertainties and confusions on the project. Air Ministry, Ministry of Defence and Treasury officials all had strongly diverging views.[22] One of the main reasons for reducing the weapons programme was certainly financial – that was the view of senior UKAEA officials. The Treasury had been putting pressure on the defence departments to cut down their demands for fissile material, particularly with a view to reducing the output of Capenhurst and thus saving its operating expenditure.[23] (The gaseous diffusion enrichment plant was extremely costly to run.) This was to prove a pivotal period in British nuclear weapons history, as it would determine the direction of the design and force structure of Britain's tactical nuclear weapons. A preferred requirement on *Red Beard* replacement in April 1962 called for a force composition of 68 weapons each with a yield of 300 kilotons; 18 weapons at 100 kilotons – both types for the TSR.2.[24] There were plans for 63 weapons with two different yields – 0.5 kilotons and 10 kilotons for naval airstrikes.[25] The RAF's concept of operations sought to neutralise an enemy's air capability. Most targets at the outset of operations would be airfields – in particular, those with runways of up to 2,000 yards, associated air headquarters and communication centres. Hard targets comprised 70% of those currently assigned to RAF tactical strike forces in the initial phase of any war in support of the Central Treaty Organisation (CENTO) and

the South East Asia Treaty Organisation (SEATO). Given the delivery accuracy achievable by the TSR.2 and the damage required to ensure destruction of these priority targets a weapon of 300 kilotons was required.[26]

Julian Amery, the Secretary of State for Air, argued in June 1962 for 84 warheads of 100 kilotons yield, primarily to equip TSR.2s intended for CENTO/SEATO roles.[27] Although the Air Ministry believed that the military case for a weapon with a yield of 100 kilotons existed, there were questions whether the importance of this project was such as to justify the expense involved.[28] The Air Ministry, however, could not accept the MOD call to limit the *Red Beard* replacement to 10 kilotons as that would undermine the utility of the TSR.2.[29] The essence of the Air Ministry's argument was that a low yield weapon would not make the best use of the TSR.2's performance capabilities. A limitation on yield would mean that the RAF would be unable to attack targets that required higher yields to ensure their destruction. This would inevitably become clear to the United States Air Force (USAF) with whom joint target planning was underway.[30] RAF officers were afraid that this would impair their nuclear cooperation with the USAF.[31] The RAF wanted to exclude the possibility of using two lower yield bombs rather than one of a higher yield to deal with a single target unless plans were to permit a major increase in the establishment of aircraft and bombs. Such plans were clearly unlikely given the extreme financial pressures on the defence budget in 1962. Weapon assemblies for the high yield variants would be more expensive than their lower yield weapons – lithium compounds would also be required, so it seems that costs were a critical consideration and Treasury officials were certainly interested in making substantial cuts to the nuclear weapons programme.[32]

The Air Ministry argued that as the TSR.2 was capable of attacking airfields and tank concentrations in Europe, the Middle and Far East and that a limit of 10 kilotons was inadequate for these targets, this would be wasteful of the TSR.2's capabilities. If the R&D programme needed for the high yield version (100 to 300 kilotons) of the *Red Beard* replacement were not put in hand in mid 1962, such a weapon would not be ready to meet the anticipated entry into force date for the TSR.2. In sharp contrast, the counter argument from the MOD and Treasury was that no decision had yet been taken to order any aircraft and absent a firm commitment, it was unwise to invest in such large sums - £13.5 million of which £8 million would be for R&D.[33] Moreover, the MOD believed that nuclear warheads of more than 10 kilotons were intrinsically unsuitable for tactical use – a view held strongly by the then MOD Chief Scientific Adviser Sir Solly Zuckerman.[34] There were strong arguments, in Harold Watkinson's (Minister of Defence) view, of a general and political nature against stretching the definition of tactical nuclear weapons to include weapons almost in the megaton range.[35] Indeed, Watkinson argued that 10 kilotons should be the limit for all UK tactical nuclear weapons. The Secretary of State for Air, however, remained opposed.[36]

The Cabinet Defence Committee noted in its discussions at its 11th meeting on 9 July 1962 that while on operational grounds it would be desirable to provide TSR.2 with the flexibility which the proposed high-yield *Red Beard* replacement would provide, it would be unrealistic to plan defence expenditure on the basis that every desirable option could be kept open. No decision to order the TSR-2 itself had yet been taken and on the assumption that it would be decided to order it, its performance was still speculative. It would thus not be right to commit at this stage substantial expenditure to the provision of this particular new weapon for use with TSR-2, if and when it came into service, against the many competing demands on the defence budget. The Committee thus agreed to defer a decision on the possible development of the high yield replacement for *Red Beard* until further progress had been made with the TSR.2 itself.[37] UKAEA officials noted that this programme was accepted under protest.[38] Ted Newley, Director AWRE, felt that Aldermaston would regard the changes more in the nature of a temporary stop than a cancellation of some of their favoured projects. This outcome led to a requirement for 63 10 kiloton warheads for the Royal Navy and 102 for the RAF and a cancellation of all other kiloton nuclear weapons.[39] However, there was to be much turbulence and uncertainty even with this, as we shall see shortly.

Macmillan and Defence Minister Peter Thorneycroft met on 15 January 1963 to consider the choices required to give effect to the Polaris programme following the Nassau conference the previous December

when President Kennedy agreed to provide Polaris submarine launched ballistic missiles to the UK. They also agreed at that meeting that in order to meet a perceived deterrence gap before Polaris entered service, a new high yield 'lay-down' bomb for the V-Bombers would be needed rather than embark upon an expensive development of a longer range Blue Steel Mark 2 stand-off air delivered weapon.[40] On 23 January 1963, the Cabinet Defence Committee agreed that priority was to be given to producing a high yield weapon (the WE 177 B) following cancellation of *Skybolt;* a US air launched ballistic missile, the previous month.[41] *Skybolt* had been the intended delivery system of choice for the UK strategic deterrent. There was now a pressing need to provide the V-bomber force with a low-level delivery strategic capability as an interim deterrent weapon to defeat Soviet air defences during the period until Polaris became operational at the end of the 1960s.[42] Formal Treasury approval for the order of the 10 kiloton version of the WE 177 (but not for the depth bomb variant) came on 29 January 1963.[43] These weapons were for the TSR.2 – about half of the existing order of 102 warheads for the lay down bomb would come in the high yield version (450 kilotons – the WE 177 B).[44] An order was placed late in 1963 for 53 weapons; including five spares, with production planned to begin in November 1965 to meet an in-service date with RAF Vulcan squadrons of June 1966. The Air Staff normally calculated provision of warheads by on a basis of one weapon per aircraft plus an addition of ten percent to cover maintenance and any accidental losses (in-service damages to casings or components). This figure of 53 emerged from previous plans for two weapons each for 24 TSR.2 aircraft operating in the strike role plus 10% spares.[45] We can also see that as there were plans at that stage for 88 Vulcan and Victor Bombers in front-line squadrons, 40 of which would be armed with *Blue Steel*, that left a difference of 48 plus five (the ten percent) for a requirement of 53 WE 177 B weapons.[46]

As of early August 1963 Air Staff plans called for a worldwide TSR.2 force armed with 76 plus eight reserve WE 177As. Originally all were to be low yield and therefore for certain targets it would have been necessary to employ stick bombing to compensate for this low yield i.e. two or more bombs on the same target, and this would make the weapon delivery requirements for the aircraft more complex.[47] Keeping development and production of delivery systems and the weapons that they were to carry in lock step continued to be a challenge for the UK's nuclear weapons programme throughout the late 1950s and early 1960s. In spring 1962 the Admiralty wanted 63 *Red Beard* replacements to cover maritime strike roles as well as requiring 75 depth charges.[48] This latter requirement was later abandoned since Royal Navy needs could be met by the low yield WE 177 As.

Exploring American options

In 1960 the Air Ministry considered whether the US TX57 nuclear weapon amongst other US weapons then under development might meet the UK's needs as expressed in the evolving operational requirement.[49] UK experts from the Ministry of Aviation, Admiralty, Royal Aircraft Establishment and Air Ministry visited the Sandia Corporation in Albuquerque, New Mexico in October 1960 to look at US approaches to development of a lay down weapon.[50] This visit took place under the auspices of the 1958 Mutual Defence Agreement between the United Kingdom and United States on the Military Uses of the Atomic Energy. Service and civilian experts considered any weapons, less warheads, or components that would meet UK requirements for OR 1177 and which might be available for purchase from the US. Adoption of the US TX 57 was eventually rejected because it had limited development potential and operational limitations for UK aircraft such as the TSR.2.[51] The variety of delivery techniques and airborne selections specified in the first issue of OR 1177 resulted in a very complicated weapon system especially from the operational as well as from the design and engineering points of view. A new version was needed to simplify the aircraft part of the weapon system whilst retaining a reasonable degree of operational flexibility.[52]

Issue 3 of the OR 1177 was approved on 14 November 1962 by the Ministry of Defence's Defence Research Policy (Atomic Energy Sub-Committee).[53] This specified a weapon enabling future high-performance aircraft to exploit their low level strike capability. It would also be free from the severe handling and storage conditions that constrained the operational utility of *Red Beard*, which was not effective enough against hard targets. Air Staff plans now called for internal single or dual carriage of the weapon in the Valiant, Vulcan, Victor Marks 1 and 2 and the TSR.2 as well as single internal carriage on the Buccaneer and Canberra B15 and B16.[54] A key change was that the warhead would have two different yields to meet Royal Navy needs for depth charges – however Air Ministry specifications remained unaltered.[55] By this time, the new weapon was known as the WE 177, using Ministry of Aviation terminology.[56] Treasury approval for a full twelve months of development work eventually came on 19 December 1962. (As noted above, 53 of these weapons were subsequently built as a high yield variant.) OR 1177 called for the weapon to be cleared for operational use in 1965. The weapon casing would be based on the 1,000 lb High Explosive bomb forging. Impact trials took place at the War Office's Chemical Defence Experimental Establishment at Porton Down in Wiltshire to test the casing as a suitable option.[57] Given the wide variety of environments in which the weapon would be used in various modes of weapon delivery, the Royal Aircraft Establishment (RAE) at Farnborough originally envisaged a large trials programme, but this would be expensive. In order to reduce the costs, RAE used models of the impact and parachute retardation phases instead with ground trials to back these up, using air trials only for confirmation of final configurations.[58]

The wide requirements for delivery in one basic weapon casing led to a complex fuzing and selection system making the achievement of safety in handling and delivery much more difficult than in earlier UK nuclear weapons. Air Staff officials decided that the Ordnance Board[59] should be involved with the project at an early stage so that safety considerations figured prominently as the design progressed, rather than asking the Board to assess and approve the system at a later stage as had been done with the first and second generation of UK nuclear weapons.[60] The requirement for a lay down option meant that the ballistic casing had to protect the warhead arming and fuzing system from damage during impact on concrete and buildings at high velocity and from all angles of attack. At this stage an aluminium alloy structure was the preferred material for the design. Feasibility studies took place with industry and five working parties began to study the requirements and formulate specifications for the design studies. These covered aircraft escape problems, weapon system design, fuzing, component design, development, and aircraft installation. Weapon engineering was thus a critical part in the design, development and construction process of nuclear weapons.

A WE177 A training round - an inert ballistic casing used for ground crew instruction in weapon handling and loading.

The warheads

Initially, as noted above, the Air Ministry and Admiralty envisaged that the weapon to meet GD 15/ASR 1177 would be required for tactical operations against point targets on land and against maritime and coastal targets. For these purposes, yields of between 10 and 300 kilotons were called for. The bomb had to be capable of fulfilling the roles set for it at various levels of release - from high altitude, dive toss delivery, low altitude loft release, low altitude level flight delivery in the laydown mode, retarded delivery after a pop-up climb, and delivery as a nuclear depth charge from both helicopters and anti-submarine guided missiles.[61] In 1961 AWRE was considering two possible warhead designs to meet OR 1177's specifications for use in future aircraft tactical weapons: R.E 179, a warhead intended for *Skybolt* and a small warhead of the R.O.106 type.[62] A Cabinet Defence Committee meeting in April 1962 was unable to resolve the matter.[63]

In March 1962 the UK tested a new multi-point implosion system at the Nevada Test Site in the United States (the *Pampas* shot), which produced the expected yield of about ten kilotons.[64] The test took place under the auspices of the 1958 Mutual Defence Agreement between the United Kingdom and United States on the Military Uses of the Atomic Energy. It was hoped that this could lead to a more rugged, reliable and lighter type of warhead than existing UK designs, as it was inherently single-point safe and used the new EDC11 high explosive. This British design, given the UK code name *Cleo*, became the basis for the greater part of the post-1965 UK nuclear weapons stockpile (all the WE 177 variants and the later ET 317 warhead for Polaris). A refinement of this design through use of a larger high explosive supercharge producing increased compression on a smaller, inherently one-point-safe core dispensed with the need for mechanical safing was re-tested in the *Tendrac* test on 7 December 1962.[65] This amended design known as *Katie* was first used in the 420 kiloton WE 177B.66 A series of necessary safety and other experiments on the design as part of the validation and approval process then took place at the Maralinga Test Range in Australia in

March-April 1963.67 Other weapons engineering development trials for the WE 177 took place over the next two years.68 The designation for the in-service warhead for the WE 177 B was ZA297;69 some of the fissile material required came from recovered withdrawn *Red Snow* warheads.[70] Initiation of the weapon to give its designed nuclear yield required a minimum of five discrete inputs or actions and the need for the correct power input and release conditions from the aircraft.[71]

The original specifications called for various yield options at 10, possibly 40, 100 and 300 or 450 kilotons. These were deemed necessary to meet a range of tactical targets such as airfields and hard targets such as bridges, passes, submarine pens and harbour installations[72]; the Navy was only interested in a 10 (or lower – 0.5 or 2) kiloton yield to serve as a depth bomb. The weapon also had to be ruggedized to cope with the planed lay down means of delivery.[73] It seems that the Cabinet Defence Committee meeting's outcome in July 1962 was interpreted by the planning branches in the RAF and Ministry of Aviation to mean that UK tactical weapons should not have a yield greater than 10 kilotons and that this was a Prime Ministerial directive. However, the Cabinet Defence Committee meeting minutes record no such overt steer from Harold Macmillan.[74] That said a high yield device of 450 kilotons would be produced for strategic use. The Chiefs of Staff and Defence Research Policy Committee had also approved these yields.[75] However, the Assistant Scientific Adviser (Operations) for the Air Staff concluded that a 10 kiloton yield was inadequate for the sorts of targets that the planners had in mind. Individual targets for WE 177s were soft missile sites, rail facilities, bridges, runways and railway lines, whilst area targets were aircraft on airfields, airfield buildings, airfield fuel installations and bomb stores, supply dumps and armoured fighting vehicle concentrations.[76] Such a yield (10 kilotons) for OR 1177 would make it adequate only against soft pinpoint targets such as unhardened missile sites.[77] Data for these assessments derived from the target response trials during the *Buffalo* nuclear tests programme in Australia in September and October 1956.[78] Options considered by the Air Staff to restore the effectiveness of TSR.2 included increasing the numbers of weapons to be carried and delivered by single aircraft.[79] However, these measures had inherent disadvantages. They were more expensive. Moreover, they would increase the vulnerability of aircraft having to make more than one pass on a target; and mean a loss in strike capability in attacking more than one target per sortie.[80] On weapon cost/effectiveness considerations, the Assistant Scientific Adviser (Operations) at the Air Ministry noted that it was more expensive in terms of weapon costs per attack, to use several 10 kiloton weapons instead of a single higher yield weapon.[81]

Despite all of this, the Air Ministry came to the view in early 1962 that it would have to proceed with the 10 and 450 kiloton versions of the WE 177. If there were further and agreed requirements for a 100 kiloton or 300 kiloton version in future, then this would not be too difficult to arrange, as it would only require a simple change of materials in one component of the secondary (thermonuclear) stage in the warhead.[82] This versatility in design would prove useful in the late 1960s, but more of that below.

Development: from design to deployment

The WE 177 was a highly complex project with over 200 separate clearances required to certify its components against a range or specifications and requirements.[83] The Airfield Radio Laboratory (ARL) at the Royal Aircraft Establishment Farnborough (RAE) was the lead design authority for the development of the WE 177 weapon's ballistic casing. Hunting Engineering Ltd based in Ampthill, Bedfordshire became the co-ordinating design authority for the non-nuclear components for the WE 177. The main reason for this was staffing shortages at Farnborough.[84] The WE 177 body sub-assembly was at the company's Ampthill site with major assemblies at the Pinehurst site.[85] Irving Ltd designed and developed the quadruple parachute assemblies used to retard the weapon on release, whilst Pye designed and developed the radar fuse and J.Langham Thomson dealt with the fuzing components.[86] The Ordnance Board and the Aeroplane and Armament Experimental Establishment were also intimately involved in the development and safety certification of the WE 177.[87] These arrangements look similar to the organisational and procurement structure that Jonathan Aylen has called a distributed network, a process used in the development and production of *Blue Danube* components in the 1950s.[88] Design study contracts issued in October 1961 with a target date of April 1962. The design had stabilised by September 1962. However, final approval came in early 1963 with the full development contract placed later that year. The Atomic Weapons Research Establishment at Aldermaston manufactured the radioactive components, with the final weapon assembly taking place at the Royal Ordnance Factory (ROF) at Burghfield in Berkshire. Unlike its predecessors the *Blue Danube* and *Red Beard*, which had insertable fissile cores stored separately from the ballistic casing and high explosive supercharge, the WE 177 carried its arming unit and warhead assembly in a sealed centre section inside the ballistic casing.

Prior to acceptance into service both the RAF and Royal Navy had to be convinced that weapons of this new type were in a fully operational condition when eventually delivered to service ordnance storage facilities. A development programme was therefore drawn up to provide adequate evidence of the functioning and safety of the weapon system. Some 400 separate trials were required.[89] Both the Navy's Chief Inspector of Naval Ordnance and the Air Ministry's Director General Weapons accepted these plans.[90] Trials were required to ensure that the WE 177 would remain operative in real service conditions without going to the point where a fissile charge was fired. In any case, the UK had decided against any further underground nuclear testing in 1965.[91] Instead, rigorous testing of the non-nuclear components of the weapon was essential to its operational effectiveness. The cycle of service acceptance trials to meet these requirements was as follows:

- Ground initiation trials – the principles and basic engineering was first checked by putting the weapons through the sorts of conditions that would be met on an operational sortie;
- Fuze trials – the effects of impact were tested by firing trial weapons against a hard target;
- Flight trials – vibration, temperature and other effects encountered in flight were measured over some 150 hours of flying;
- Parachute release trials – release and other airborne equipment were tested by dropping non-fissile weapons from an aircraft in flight; thirty four hours flying time for carriage and release trials in Vulcan aircraft was a requirement here.[92]

The first two types of trial took place at the United Kingdom Atomic Energy Authority's (UKAEA) establishment at AWRE Ordfordness in Suffolk. The other two were at the rocket range at West Freugh in south–west Scotland using aircraft (a Scimitar, a Canberra and two Buccaneers[93]) based at the Royal Aircraft Establishment (RAE) at Farnborough in Hampshire and the Aeroplane and Armament Experimental Establishment (AAEE) Boscombe Down in Wiltshire.[94] Some trials with scale models of the ballistic casings took place at the AAEE's Guided Weapons Range at Larkhill (Wiltshire).[95] Hunting Engineering faced challenges in the design of the test vehicles required for the development and proofing stages of the WE 177 weapon – particularly the parachute test vehicles where much greater effort and more re-design work was required. Much the same applied to the design of the training and practice inert rounds – again more effort had been required than had been estimated. Overall if seems that the trials programme needed some 70 test vehicles.[96] Flight trials of the WE 177 B were planned to start later in December 1964 from RAF Cottesmore with flights over the UK.[97] The plan was to follow these in 1965 by trials at Akrotiri with flights over Cyprus and Libya on standard training routes and over deserts, and finally by flights from Tengah over Malaya. The Foreign Office initially opposed plans for environmental trials involving flying over foreign territory even though these were with inert rounds that did not contain any fissile material, but eventually relented.[98] Planning called for the whole programme to continue, with breaks, until March 1968.[99] However, by June the political situation in the region – the Indonesia-Malaysia confrontation – led to the abandonment of plans for test flights in the Far East.[100] Instead, RAF Akrotiri hosted additional trials; and these finished by early March 1966 as the fourth of the trial vehicles deployed back to the UK in the week of 3–9 March 1966.[101] Surveillance flights of the *Yellow Sun Mark 2* in this period also provided background information for the WE 177 programme.[102]

Nuclear weapon production faced two main constraints in the mid 1960s: the capacity at the Royal Ordnance Factory, Burghfield (where construction of two new warhead assembly facilities had been completed in 1961[103]) and the availability of fissile material (both plutonium and highly enriched uranium - HEU).[104] There was a distinction made between the *'policy'* date and '*target'* date for entry into front line service with the RAF; the former was six months later than the *'target date'*.[105] This distinction was almost certainly contractual. The RAF only had a requirement for one drill round for the WE 177 B.[106] This had to be ready by June 1965; a requirement for an overall total of 30 training rounds was also specified, and these were required in six monthly intervals starting in July 1965 as part of the build-up of an RAF operational capability.[107] Original Air Staff plans called for production of six weapons in 1965-66, with 47 following in 1966-67.[108] The first live weapon did not enter service with RAF Vulcan B2 medium bombers until September 1966, although Controller Air Release for carriage of the live WE 177 B came in May 1966.[109] The final deployment delay was caused by warhead modifications, a safety requirement and the need to obtain the Prime Minister's approval for road movement of the weapon. The MOD's Nuclear Weapons Safety Committee accepted the arrangements for the road movement of the WE 177 B and the Prime Minister subsequently authorised the movements from Burghfield to the RAF Vulcan B2 airfields at Cottesmore, Scampton and Waddington.[110] There had also been delay in the supply of non-nuclear components (primarily in the firing cables) and faults in others such as connectors to mate the weapons to the aircraft, which had been the primary cause of the deployment programme slippage.[111] The safety requirement appears to have stemmed from a decision taken by the WE 177 Steering Committee in March 1964 to adopt a safety lock to fit to the Ground Control Unit in order prevent access to the weapon's setting switches, which would prevent irregular detonation or dudding.[112] There were also issues with failures of the warhead's thermal batteries, the fuzing system and of the radio frequency filter's ability to survive environmental tests.[113] All the RAF's Vulcan B2s were modified for the carriage and release of the WE 177 B, but because of delays in the retrofit programme, it was late in 1967 before the Vulcan force was at full strength. The order for WE 177 B itself was completed on the 26 October 1967 when the final weapon emerged from the assembly bays at Burghfield.[114]

Avro Vulcan B. Mk 2 © IWM RAF-T 3594

Deployments: afloat, Cyprus, Germany and the United Kingdom

The Royal Navy and the WE 177A

In 1965 it seems that the formal justification for the tactical role for the WE 177 had stemmed from a statement in a Chiefs of Staff paper COS 27/65 (Revised) The UK Nuclear Role – need for tactical deterrent outside Europe. When it came to WE 177 A orders, priority became equipping the Royal Navy's new Buccaneer aircraft for the maritime strike role. RAF requirements were still linked to the deployment of the TSR.2;[115] and as a replacement for the 100 or so RAF *Red Beards* deployed in Cyprus and Singapore to fulfil commitments to CENTO and SEATO.[116] The Royal Navy's requirement for WE 177 A was for tactical use worldwide. The Navy by this stage wanted nuclear depth bombs as a contribution to deterrence (to the initiation of submarine warfare against the UK) and to enhance the defensive capability of the fleet. The number of weapons envisaged was split between 43 for the depth bomb role and 20 for maritime strikes against surface vessels and land based targets, though the Air Staff thought that the Navy were not that committed to the strike role.[117] The Treasury held up financial approval for the Royal Navy's order for the WE 177 A pending the outcome of the Defence Review initiated by the Labour government in 1965.[118] Thus, the

earlier delays between 1963 and 1964 in placing orders were now further extended by the new Labour government's major defence review.

The Navy's original plans called for 20 of their WE 177 A's with a 10 kiloton yield allocated to a strike role from carrier borne aircraft against surface vessels and land targets. However, as noted above, it seems that the Navy was not overly forceful in stressing this particular requirement in mid 1966.[119] The remainder of the order would be committed to an anti-submarine role.[120] The nuclear depth bomb variant (the 0.5 /10 kiloton yield WE 177 A) would meet this requirement and earmarked for delivery by helicopters.[121] The 1968 Statement on the Defence Estimates announced that the date for the carrier force withdrawal would be brought forward when the withdrawals of East of Suez had been completed.[122] Nevertheless, the first order for 63 WE 177 As for the Royal Navy was finally placed in 1966 following eventual Treasury approval in August that year[123] just as the WE 177 B was about to come into service – the design having been finalised in 1965.[124] Following the demise of plans for new Aircraft Carriers, the Navy's order reduced to 43 weapons.[125] Production weapons came off the production line from January 1969 onwards – some twenty-eight months after the initial Navy date set back in early 1964,[126] with the last weapon produced in October 1970.[127] The WE 177 A weapons were produced steadily in spite of delays caused by a shortage of components – late delivery of components to Burghfield in particular, as well as faults in cable connectors and dimensional errors in components, which sometimes necessitated the breaking down and rebuilding of completed weapons.[128] By 1970 the Royal Navy intended that most fleet escorts and some additional major fleet units for delivery by helicopters would carry the WE 177 A. New WE 177 As at this time (June 1970) were stored in two ships, HMS Eagle and HMS Blake – and in HMS Ark Royal from August 1970 and subsequently in the cruiser HMS Tiger.[129] Although initially intended to carry WE 177, HMS Lion would never have received the weapon as her planned refit for an anti-submarine role was cancelled.[130] In contrast, *Red Beard* had been carried operationally in at most two strike carriers.[131]

New authorised procedures were required for the control, security, and selective release of these new naval nuclear weapons. The objective was to ensure political control of release procedures, which depended on the physical security of the strike enabling keys, with which the weapons would be armed, and of the signal authentication tables. Each fleet unit kept these keys and tables in combination safes (an inner and outer safe) and by application of the two man rule.[132] Officials sought the Defence Secretary's formal agreement for these new arrangements, but it seems that the 1970 June General Election may have delayed their adoption.

The RAF and the WE 177A

The Defence Review did not affect the WE 177 B programme, although there was still a chance in mid 1965 that the overall numbers might be reviewed. In contrast, RAF WE 177 A orders, however, were very much caught up in the Defence Review.[133] Cancellation of the TSR.2 in April 1965 further complicated RAF plans as this had been the aircraft originally intended as the prime carrier for the WE 177. The Defence Review thus had an adverse impact on RAF planning assumptions and timelines, which suffered further delays. Uncertainties over plans to acquire the US designed F-111k bomber for the RAF as well as the roles that it would fill no doubt did not help matters.[134] Original plans had set a target date of April 1968, which later slipped to October 1968, for WE 177 As to enter into service with the RAF. However, this would have required the first orders to be placed no later than 1 October 1966.[135] The RAF was obliged to delay seeking Treasury approval for ordering its WE 177 As to replace its *Red Beards* for non-strategic targets given the continuing uncertainties over the roles and size of its future V-Bomber strike force following the entry into service of Polaris in 1969 as the UK's primary deterrent.[136] Cost factors affected the numbers of aircraft and crews retained and allocated for nuclear roles. Such were the delays that RAF Strike Command[137] complained in late 1967 that WE 177 A orders had been deferred so many times that the Air Ministry felt that it ought to resist any further postponement. Even if the weapons were ordered in December 1967, there would have

been a shortfall of weapons for frontline aircraft. A delay of a further three months would increase this shortfall (when related to Unit Establishments – the number of aircraft per squadron) between the third quarter of 1969 to the end of 1970 by approximately 20%.[138] This was a problem because the Canberras armed with *Red Beard* were scheduled to be phased out from the NEAF in early 1969 and from the Far Eastern Air Force (FEAF) by the end of the second quarter of 1970. As this weapon could only be delivered at level flight at 25,000 feet, this was a serious operational limitation and was why the acquisition of the WE 177 A was seen as being so critical to Strike Command's effectiveness.[139]

In September 1968 the RAF had new plans for 106 WE 177 As allocated as follows: eight for a Unit Establishment of 16 aircraft for the Near Eastern Air Force (NEAF) at RAF Akrotiri. Two Vulcan B2 squadrons (9 and 35) from RAF Cottesmore were to provide the UK's nuclear contribution to CENTO as well as national UK nuclear war plans;[140] 16 weapons for 32 Vulcans based in the UK; 72 weapons for 72 Buccaneers (one per Unit Establishment, with a proviso of carriage of two weapons) plus ten spares.[141] At the end of 1968 the Air Staff plans wanted authority to order 52 10 kiloton WE 177 As for operational use by the RAF, backed up by 8–10 spares earmarked for essential maintenance purposes, including servicing and reliability tests, amounting to 60/62 in all. Delivery for service use would be spread over a two year period at a rate of about 2.5 per month. However, it was June 1970 before authority was finally given for the purchase of 56 weapons for the RAF plus a reserve of 8 for essential servicing and quality assurance for 64, with delivery of the first expected in October 1970 with a further six by end of that year. Thereafter a production rate of four weapons per month up to and including July 1971 followed by two weapons per month until the order was completed.[142] Fissile material was recovered from obsolescent *Red Beard* weapons deployed overseas for use in the WE 177A.[143] So from the original operational requirement in 1959, it had taken more than a decade for the RAF to get its new improved tactical bomb. In the summer of 1966 the Air Staff noted, as it contemplated its long term future nuclear weapons requirements, even before the first WE 177B was deployed, that in the period from 1962 to 1966 tremendous advances had been made in the US and in the UK in the nuclear weapons field notably in the miniaturisation of warheads and components. In short, all this technological progress had come since the WE 177 programme was originally committed in November 1962.[144] As so often is the way policy, budgetary and programme delays mean that by the time a weapon system is eventually agreed upon, designed, tested, built and entered service, it may already be yesterday's technology. Not that this really mattered in the context of UK tactical nuclear weapons – at least until the mid 1970s when replacements might be needed with a stand-off capability to overcome likely defences.

The first RAF WE117A was delivered to RAF Scampton in October 1970, pending transfer along with a further three weapons to the NEAF in Cyprus.[145] The fifth and subsequent weapons went to RAF Honington from late December 1970 onwards.[146] Longer term plans required 20 weapons for SACLANT strike plans and 34 for SACEUR. Forty WE 177 Bs were allocated to SACEUR for his General Strike Plan.[147] WE 177 A orders used recycled fissile material from the *Red Beards* withdrawn from service, so no new plutonium production was required.[148] All the one hundred plus *Red Beards* had been withdrawn from service by 1972 – a few were held in reserve at RAF Faldingworth, Lincolnshire against a failure of the planned production schedule for the WE 177 A bombs.[149] As early as 1963 the RAF had indicated that it wished to retain 26 (24) *Red Beards*.[150] RAF plans at the end of the 1960s called for two squadrons of Buccaneers (24 aircraft) to be deployed to Germany starting in early 1971 with a planned deployment completion date of the second half of 1972; these aircraft would be allocated to SACEUR as part of the 2nd Allied Tactical Air Force in a low level penetration role. This represented a significant shift – politically and militarily - in UK nuclear weapons policy. As Kristan Stoddart has written, British military strategy was henceforth to focus its nuclear forces on being a European state, rather than a global imperial one.[151] WE 177As were deployed to Laarbruch shortly after the first aircraft.[152] Building and refurbishment work at the Supplementary Storage Area (SSA) at Laarbruch for the nuclear weapons was not ready to receive the first six new WE 177 C weapons until April 1973 at the earliest.[153] The origins and nature of the WE 177 C follows below.

WE 177 A: note the munition identification colours: orange role band marking for nuclear and the yellow hazard band marking for high explosive.

The 1969 Long Term Costings on Nuclear Weapons Assumptions prepared in March 1969 for the period up to 1979/80 assumed that there would be 108 WE 177As for the whole of the Buccaneer force. The eventual Plan R combat front-line of dual capable aircraft called for 120 Multi Role Combat Aircraft (Tornado)/ Buccaneers, 60 Jaguars and 32 Nimrods, a force level that would achieved in 1977 if plans were implemented in full. Together with spares and surveillance rounds the total WE 177A requirement would be about 230.[154] These plans changed in light of the new requirement for the WE 177 C.

WE 177 drill and training rounds

As part of the process of building and maintaining operational capabilities for the WE 177 in service with the RAF and Royal Navy non-live rounds were built for a number of purposes. In UK ammunition handling nomenclature practice rounds were for use in training, evaluation and trials to simulate the weapon's operational (combat) equivalents i.e. for dropping, carriage, ranging and spotting from aircraft; they were not for drill purposes such as training personnel in weapons assembly, loading and handling. For this purpose, there were separate drill rounds. These were intended chiefly to teach drill of assembly, handling, loading – some special drill rounds had separate insertable parts or dummy electronic components.[155] One drill WE 177 A and one drill WE 177 B, a sectioned version of the WE 177 A weapon and one training weapon for each type were planned for the Bomber Command Armament School at RAF Wittering. Four training rounds for both the A and B weapons were planned for each eight aircraft squadron.[156] Inert training rounds (body and tail components) were produced for ground crew. WE 177 A bodies were also made for the Royal Navy; there were also spare nose and tail sections. The point to note here is that there were more ballistic casings and tail sections than live weapons; and as noted above on the surveillance programme, other non-nuclear weapons components existed for testing purposes too. Initial Air Ministry plans set a requirement for 30 training rounds for the WE 177 B and 31 for the WE 177 A.[157] The Admiralty had a separate requirement for eleven, but it also asked for a large number of practice inert casings – ten rounds initially for January 1966 and 80 per year thereafter (60 with parachutes and 20 with smoke). It seems that a final figure saw 36

training rounds built for the WE 177A along with 20 practice rounds for retarded delivery and 18 for ballistic delivery; two were for demonstration purposes in Ammunition Processing Buildings (probably Burghfield, but that is conjecture) and one was for drill purposes.[158] Comparable figures for the WE 177 B were two for drill and demonstration purposes and 25 for training use. This provides an insight into the training requirements essential for the acquisition and retention of an effective operational capability. Procedures were also put in place by AWRE for explosive ordnance disposal of the WE 177s in the event of accident or other major failures.[159] Drill rounds were made of wood, lead and steel and had the same weigh, centre of gravity and moment if inertia as live weapons.[160]

A common pool of RAF and Royal Navy WE 177 As

In order to improve the management and refurbishment schedules of the stockpile of WE 177 A bombs, the Ministry of Technology proposed in September 1969 that there should be a common pool of weapons for the RAF and Royal Navy.[161] Weapons allocated to the Navy were normally stored on ships at sea, although a shore based store was made available at RAF Waddington in 1968.[162] The then current plan for the separate storage of WE 177 As would cause severe difficulties in weapon refurbishing schedules. These could lead to a failure to meet both RAF and Navy requirements for operational weapons (i.e. those available for use) and to an unavoidable need to replace components in naval weapons before they were life expired, which would be wasteful and expensive. After reviewing the practicalities of the proposal – identifying a suitable location, the transportation aspects, staffing and quality assurance inspection - the RAF agreed in March 1970 that there should be a common stockpile.[163] The initial plan proposed to store all non-operational weapons at a non-operational air base, RAF Cottesmore, which had ceased to be a V-Bomber base in 1969. This would take effect in early 1972.

As part of the new arrangements, the Navy's Chief Inspector of Naval Ordnance and the RAF's Electrical Quality Assurance Directorate weapons would jointly inspect weapons during their final assembly at the Royal Ordnance Factory Burghfield prior to their acceptance into service. Following a decision that the Royal Navy would cease to operate maritime strike aircraft in 1972, the RAF took over the order for the last 20 WE 177 A weapons originally ordered by the Navy.[164] Overall a 107 WE 177 As were ordered for the RAF and Royal Navy with an average production rate of two per month;[165] making for a total stockpile of 160 WE 177 As and Bs. The Royal Navy and RAF WE 177 As finally received its WE 177 As by the end of production in September 1972.

New requirement: the WE 177 C

In 1969 the Air Force Department was interested in the development of a warhead design, particularly to the possibility of developing the current production WE 177 to produce a medium yield warhead suitable use against hardened airfield targets.[166] Such a development could be fed in at a later stage of the then current production run of WE 177s for the RAF.[167] By 1972 a new NATO requirement for additional WE 177s had also appeared.[168] This requirement for a new tactical weapon had arisen from a long-standing internal NATO commitment to target its weapons above 200 kilotons only against Warsaw Pact targets in the western USSR. This prevented use of the existing 450 kiloton WE 177 Bs by SACEUR against other large or hardened Warsaw Pact targets in Eastern Europe, which formed the majority of objectives allocated to the 2nd Allied Tactical Air Force.[169] SACEUR required a weapon with a larger yield than the WE 177 A for these purposes and in 1970 he asked the UK for more WE 177 Bs for the Buccaneers, but the Air Staff felt that this would be prohibitive in terms of money and fissile material.[170] All this of course echoes the yield debates in the early 1960s through the iterations of OR 1177 and the Cabinet Defence Committee debates.

Separately the Air Staff was at that time considering a need to provide a nuclear capability for the new Jaguar light strike aircraft – operational requirements staff noted in this context that the planned WE 177 A order for the RAF would only address the needs of the Buccaneer.[171] All this was to lead the UK to offer SACEUR a new version of the WE 177 family after much debate and difference of opinion within the Chiefs of Staff, Air Staff and Air Force Department in the MOD on the options and possible yields of a new weapon.[172] A mix of three different yields would require additional design effort by AWRE; and to avoid this extra cost and delay the preferred option came down in favour of a single yield of about 190 kilotons – this became known as the WE 177 C. The design for a 190 kiloton variant was finalised in 1972 and the warhead for this device was designated SW641.[173]

Tests during the development of the WE 177 B in the early 1960s had shown that a variant could be produced without altering the basic design.[174] The last time that Ministers had authorised a new round of plutonium production was in 1967, which led to a further 500 kilograms produced at Calder Hall and Chapelcross. This reserve was largely used up for the WE 177 C and the later Chevaline warhead.[175] There was no need for any new underground nuclear test to certify this new design as the used WE 177 A, B and ET 317 Polaris warhead same primary, and only the secondary (the thermonuclear component) had to be modified. The secondary of the Polaris warhead ET.317, codenamed *Reggie*, derived from the US W-59 - RE.179 secondary lineage, and was codenamed *Simon* in the WE 177 B. As used in Polaris, *Reggie* was a downsized version of *Simon*, and was salvaged and re-used in the *Chevaline* warhead with a newly designed super-hardened primary.[176] However, there were three warheads on each Polaris missile, but only two on its successor, Chevaline. The one-in-three spare Reggie secondaries were then salvaged and re-used as the secondaries for WE 177 C, matched with a 'converted' *Katie A* as the primary.[177] The Air Force Department wanted to provide the WE 177 C for both the Buccaneer and the Jaguar and to reduce the stock of WE 177 As, which was the most cost-effective option.[178] It was also politically important given US attitudes to burden sharing in Europe for the UK to shoulder some of that burden by adopting a greater and more flexible nuclear role.[179]

The WDC (NS) approved purchase of an intermediate yield nuclear weapon (the WE 177 C) on 28 July 1971 with the Ministerial Nuclear Policy Committee endorsing this on 18 February 1972.[180] A first draft of Air Staff Requirement 1223 set out operational attributes for an intermediate yield nuclear bomb and issued on 22 February.[181] The WE 177 C was required to be in service and cleared for operational use by 1974; it had a planned service life of 20 years.[182] It also had to be capable of accepting the existing mechanical and electrical interfaces with the same aircraft as the WE 177 B and be suitable for medium and high altitude

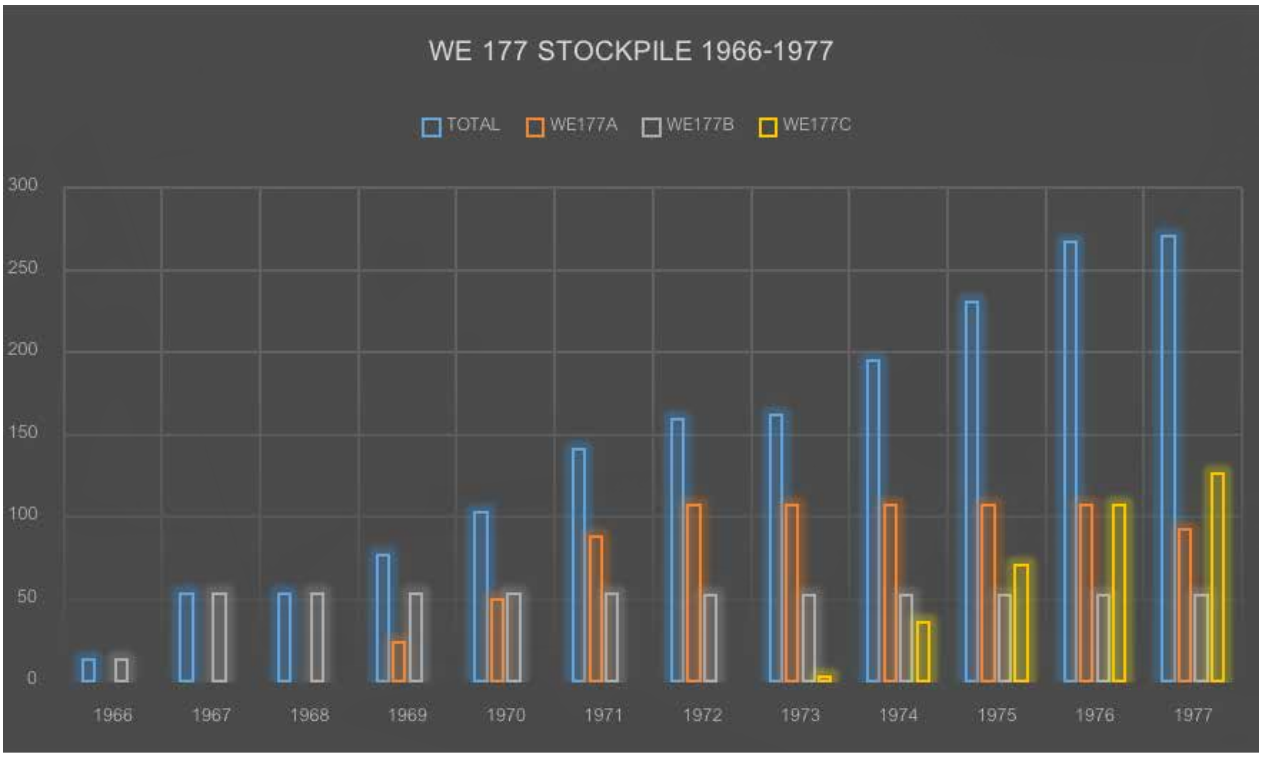
delivery as well as low altitude delivery and a range of burst heights. As to states of readiness, the weapon was to be capable of being at take-off readiness for periods of up to 30 days and to permit first line servicing of aircraft whilst loaded. Periodic refurbishment after three and a half years was required, which was then in line with the WE 177 As and Bs. If technically feasible and cost-effective, the aim was to design components that would have a minimum service life of seven years. The final draft emerged on 8 May 1972[183] and the approved version issued for action by the MOD Procurement Executive and MOD Central Staffs on 5 July 1972.[184] The WE 177 C programme was subject to annual review, but no decisions were felt necessary for any future nuclear weapons for the future Multi Role Combat Aircraft (MRCA - Tornado) after the WE 177 C production run ended in 1977.[185]

Initial plans envisaged 209 WE 177 Cs, but just 125/6 WE 177 Cs were ordered and delivered to the RAF from 1973[186] through to the end May 1977.[187] The slow rate of production (three per month) allowed annual review of the split between the numbers of WE 177 As and Cs and the total requirement.[188] Fifteen of the WE 177 C order was for maintenance and service purposes.[189] Other figures suggest that only 111 WE 177 Cs were produced. Fourteen of the original RAF order for WE 177As were planned to be rebuilt as WE 177Cs, which would make for a total of 125. [190] The WE 177 C programme as a whole does not seem to have been curtailed under the MOD Long Term Costings (LTC) exercises in 1972 and 1973.[191] One file noted that a production programme of WE 177C, comprising 111 new weapons and a further 15 converted from A weapons was to continue to completion. Deliveries were to start in 1973-4 and end in 1976-7.[192] The total cost of programme for the 10 year costing period, including maintenance was put at £22 million. However, £11m of this was necessary in any event to maintain essential surveillance and production facilities and technical expertise at AWRE and the ROF Burghfield The net cost of the proposed programme was thus £11m.[193]

WE 177 C production was held up as a result of a strike by workers at the plutonium facility at the Atomic Weapons Research Establishment and the three-day week imposed by the government as a result of the global energy crisis and coal miners' strike in the UK in winter 1973/4.[194] However, the delivery programme was back on programme by end of March 1975.[195] Plans called for two weapons per Buccaneer aircraft in the UK and Germany and one per Jaguar aircraft based in Germany. All of which would result in a requirement for:

- 175 WE 177 A and C weapons - including 15 for maintenance – the split between the low yield and intermediate yield would be 50 for the former and 125 for the latter.
- Of these weapons, 110 would be for the Buccaneer and 65 for the Jaguar.[196]

The Jaguars were to take over the strike/attack role of the Phantoms, which were armed with US nuclear weapons.[197] MOD policy staff advised the Secretary of State for Defence that the question of numbers was admittedly difficult, and in the final analysis, based on subjective judgment on requirements for a credible deterrent.[198] Indeed the MOD's own Chief Scientific Advisor Sir Herman Bondi had commented earlier that there were great difficulties in arriving at a rational justification for any proposed number of weapons.[199] However, the two different yields from the WE 177 A and WE 177 C would give a useful degree of flexibility to both aircraft.[200] This was the essential technical rationale for the numbers of WE 177 Cs acquired.



Probable WE177 production rates based on known and estimated manufacturing rates and schedules

The WE 177 in service

By October 1977 the WE 177 As, Bs and Cs equipped 50 Vulcan B2 bombers, 48 RAF Buccaneers and 14 Royal Navy Buccaneers on HMS Ark Royal, and these would transfer to the RAF when Ark Royal came out of service, as well as RN helicopters. The weapons original shelf life was 16 years with possible two or four year extensions.[201] Only the following fixed wing aircraft were cleared to carry weapons in the WE 177 family: the Vulcan B2, Royal Navy and RAF Buccaneers, the Jaguar, the Tornado and the Sea Harrier FRS 1 from 1981. The Tornado was scheduled to replace the Vulcans and three of the Buccaneer squadrons from 1981.[202] The Fleet Air Arm's Sea Vixen was also cleared to carry the weapon, but it did not do so operationally as this aircraft was withdrawn from service in 1972. Rotary wing aircraft were the Royal Navy's Wasp, Wessex, Lynx and Sea King helicopters. It was only intended that the WE 177 A would be used for detonations with its 0.5 kiloton yield in shallow coastal waters below 140 feet. Both it and the 10 kiloton version could be used in oceanic deep waters below 350 feet.[203] In peacetime Royal Navy WE 177s were intended in light of plans in 1974 to be deployed as follows: up to 18 on HMS Ark Royal, 14 each on HMS Tiger and HMS Blake and 9 on HMS Hermes. Thirty-five weapons were available at any one time. Other ships could carry two weapons on upper deck storage areas in wartime.[204] The only warships (excluding Royal Fleet Auxiliary ships) to carry live weapons during the Falklands operation in 1982 were HMS Hermes and HMS Invincible (carriers) and HMS Broadsword and HMS Brilliant (frigates). All weapons, surveillance rounds and training rounds were transferred to the carriers as the Task Force approached the south Atlantic as they had dedicated armour protected magazine deep in the ships.[205] Neither Hermes nor Invincible entered territorial waters around the Falkland Islands, South Georgia or the South Sandwich Islands, which ensured that UK met its obligations under the 1967 Treaty of Tlatelolco that established a nuclear weapons free zone in the region.

Weapons were deployed to several RAF stations in the UK and overseas over the years from 1966 to 1978 at various times in specially constructed Supplementary Storage Areas (SSAs). Cottesmore, Honington, Marham, Scampton and Waddington in the UK, Bruggen and Laarbruch in Germany from 1973[206] and Akrotiri on Cyprus until the last resident Vulcan B2 squadron left in January 1975 all stored WE 177s.[207] Planners allocated 16 WE 177 Bs to the RAF's Near Eastern Air Force with transfer from RAF Cottesmore to Akrotiri taking place between 1 December 1968 and 29 March 1969, replacing the *Red Beard* Weapons previously stored there.[208] This deployment and withdrawals involved a total of sixteen flights each way.[209] These weapons were required to support the CENTO Strike Plan 4.[210] Four WE 177 Bs were later returned on 30 December 1970 to the UK to make up a shortfall in the RAF's contribution to NATO strike plans following the withdrawal from service of the last remaining *Blue Steel* missiles on 31 December 1970.[211] Four WE 177 As were also destined for the Near East Air Force to replace the WE 177 Bs.[212] No WE 177s were permanently deployed to Singapore following the withdrawal of the last *Red Beard* weapon in the autumn of 1971, which was done in phase with the withdrawals of the Canberra aircraft. Instead, Vulcan aircraft based in the UK would provide UK commitments to nuclear support to SEATO Plan 4 until the end of 1971.[213] They would be deployed in an emergency with their weapons transported separately by the west about route if required.[214]

Two squadrons of Buccaneers deployed to Germany equipped with the WE 177 A to replace the Canberra squadrons armed with US nuclear weapons under Project E – a programme dating from 1957.[215] The Buccaneers had already been fitted to carry British nuclear weapons for the Royal Navy, so it was matter of costs and practicalities that dictated that these aircraft would carry the WE 177 A. A programme to modify all Buccaneer Mk 2 aircraft for WE 177 was underway by January 1968 and planned for completion in August 1971.[216] Each Buccaneer would carry two weapons for delivery by toss mode.[217] One Buccaneer had been allocated to flight clearance trails at Boscombe Down for both the WE 177 A and WE 177 B. Air Staff expectations were that the single carriage of the store would be cleared in December 1969/January 1970 followed in April 1970/August 1970 by the clearance of twin carriage.[218] The same schedule applied to the Jaguars, which replaced the Phantom F4s.[219] There were problems with opting for continuing with US weapons alongside UK weapons. This would involve a considerable slippage in the delivery programme, would necessitate modifications to both the Buccaneer and Jaguar aircraft and would result in a mix of weapons that would lead to operational inflexibility and storage complications given the different custodial arrangements applied by the UK and US. In the case of the Jaguar, modifications would delay the certification of the aircraft for nuclear carriage to some eighteen months after its introduction into squadron service in Germany.[220] This was complete by 1976/7.[221] Plans in 1970 for RAF Germany called for 24 WE 177 As.[222]

The question of UK nuclear weapons forward deployed in Germany was still moot in the late 1960s as political clearance from the German government was needed; the alternative of putting US weapons on the Buccaneers was problematic as it would have taken several years to clear and fit such weapons whereas they had an immediate capability for British weapons.[223] Ministers agreed in 1967 that new British tactical nuclear weapons would be allocated to SACEUR to support his targeting plans. An expectation in 1969 was that if approval were given, RAF Strike Command would consist of the following force in 1973 when the full complement of Buccaneer squadrons was operational: 32 Vulcan B2 bombers with 35 WE 177 Bs; 16 Vulcan B2s for the NEAF with 16 WE 177 Bs; 48 Buccaneers with 44 WE 177 As in the UK and 24 Buccaneers in RAF Germany with 20 WE 177 As – the weapons inherited from the Royal Navy order.[224] All the UK based WE 177 As would be stored at RAF Honington, though some thought was given to the possible storage of a few weapons at RAFs Lossiemouth and Kinloss in Morayshire, Scotland.[225] One of the original five WE 177 B spares was withdrawn in this period.[226] Ministers agreed on 3 September 1970 that officials should seek formal German agreement to the deployment of British nuclear weapons.[227] Moreover, as Lord Carrington, Secretary of State for Defence, noted in a minute to the Prime Minister in 1971, it was essential to 'regard the stationing of nuclear weapons on the continent under British control for the first time as a matter of considerable political significance from the European point of view.'[228] This marked a turning point in British

tactical nuclear weapons history – the focus would now been exclusively on meeting NATO requirements, the out-of-area nuclear commitments to CENTO and SEATO were soon to be a thing of the past,

Front line Tornados squadron strength was set at 144 aircraft with 84 of them assigned to SACEUR in the overland strike/attack role: two strike/attack squadrons totalling 36 aircraft at Laarbruch, two strike/attack squadrons at RAF Marham (32 aircraft) and one strike/attack squadron (16 aircraft) at RAF Honington.[229] All front line strike-attack Tornado crews trained to deliver both conventional and nuclear weapons. The concept of operations envisaged a possibility that Tornados could be required to carry two nuclear weapons against two separate targets, which depending on flight profiles and load, could strike from Marham and Honington as far as 18 degrees east (660 nautical miles) and recover to base.[230]

The overarching political rationale for the WE 177 C was that the capability that it represented, along with replacement of the Army's *Honest John* short-range nuclear missile with *Lance*, was needed to maintain an effective deterrent to aggression in the UK sector of the Central Front in Europe after 1975.[231] Deployment of UK WE 177 A and C weapons to Germany raised some command and control questions in relation to the role of SACEUR, UK government permission for nuclear release and the need to consult the German government if time permitted. Policy staff proposed to Lord Carrington, Secretary of State for Defence, that the same arrangements that applied for the Canberra aircraft previously based in Germany would also apply for the Buccaneers and that SACEUR would be so informed. He would also be reminded of his obligation to seek specific British permission for the release of British nuclear weapons and disclose to him that embodied in the UK's Memorandum of Understanding with the German government was an undertaking to consult them if time allowed before authorising use of nuclear weapons allocated to the Buccaneers. Engineers installed a 'hot-line' between London and Bonn for this purpose and probably became operational as of end of November 1971.[232] Carrington had agreed to these procedures on 13 January 1971, subject to final Prime Ministerial approval.[233] All of this was pressing in early 1972 as the first Buccaneer squadron was due to be declared operational in the nuclear role on 1 February 1972.[234] (Although subsequently this was slightly delayed following the result of a Tactical Evaluation.) The Prime Minister agreed subject to the views of the Foreign and Home Secretaries;[235] the Foreign Secretary agreed on 24 January[236] and General Goodpaster (SACEUR) was duly notified on 3 February 1972.[237] Buccaneers deployed in Germany would not be included in UK national strike plans.[238]

WE 155 transport container for the WE177.

Keeping the WE 177 serviceable: the surveillance programme and component replacements

Complex weapons systems, especially nuclear, do not simply sit on the shelf - there is much more to it than that. They are monitored to ensure that they remain reliable and safe and fit for operational service conditions. The characterised this as surveillance. The initial aim of a proposed WE 177 surveillance programme in 1965 was to exercise each of the WE 177 types about one year in advance of a three to four year overhaul of the weapons in service. These new weapons, unlike the *Blue Danube* and *Red Beard* were designed in such a way that it would not be practicable for RAF or Royal Navy personnel to carry out any maintenance functions or serviceability checks, as the nuclear warhead was a sealed unit. Failures of components because of service conditions would not become apparent in the field.[239] To observe any changes that might become apparent due to ageing of the weapon systems in their operational environment, different types of trials were required as well as periodic break down of the weapon to check the conditions of its myriad components, both large and small. A useful life of about 12 years for these weapons was assumed and this meant that the surveillance requirements called for four WE 177 As and six

WE 177 Bs weapons. These numbers would cover both warhead and weapon aspects and would at the same time allow one type A and two type B weapon for contingency use.[240]

The MOD's Weapons Development Nuclear Sub Committee endorsed the programme at an estimated cost of £574,000 over 12 years on 4 May 1965.[241] Thereby an annual surveillance and life evaluation programme was established for the WE 177 in service with the first annual programme report produced for the period 1 July 1968 to 30 June 1969. The warheads were serviceable for three years.[242] There had been similar programmes for the second generation of UK strategic and tactical nuclear weapons; for example, there had been eleven flight trials with the *Yellow Sun Mark 2* involving over 52 hours of flight.[243] The WE 177 weapons were complex pieces of engineering and could not be stored indefinitely given the limited shelf life of some of the components. Refurbishment of the first WE 177 B weapons was scheduled to begin in September 1969.[244] As many as six warheads would be out of service at any one time covering periods when the weapons were either in transit to and from ROF Burghfield and the RAF stations and undergoing refurbishment.[245] There were two elements in this programme.

The first part of this programme saw weapon assemblies and components placed in store in natural environments; similar to those that they would see in operational service for a fixed number of years, with batches tested after predetermined periods. The second part aimed to simulate more closely the service environments and to this end several stores, termed surveillance rounds, were placed with the RAF and Royal Navy to be treated as normal service rounds subject to the same storage, handling, and transportation and flying conditions as a service weapon.[246] For example, there was a flight trial in February 1968 with a Vulcan B Mk 2 carrying a WE 177 B surveillance round to obtain information on the ability of the weapon to stand up to service handling in operational conditions. This flight simulated actual operational conditions with low level phases of flight undertaken over a sea bombing range (Luce Bay off the Galloway coast in Scotland) with the bomb doors open.[247]

The programme reported on design shelf life of the weapon's nuclear and non-nuclear components. Regular and extensive safety and reliability trials were conducted on a range of the weapon's components to maintain quality assurance.[248] The original overall WE 177 contractor Hunting Engineering ran this programme as a post design service. Hunting Engineering Limited were responsible for structural, environmental and general issues, Pye Dynamics Limited dealt with the weapon fuzing, Marconi handled the radar aspects and the Royal Armament Research Development Establishment at Fort Halstead addressed conventional explosives such as the line cutting charge for the drogue parachutes and detonators.[249] Some surveillance rounds were fitted with telemetry to check on the performance of components during dynamic trials, such as carriage and dropping from aircraft. These would assess the functioning of the arming unit whilst in flight after release.

The surveillance programme required construction of a number of *'surveillance rounds'*.[250] These '*vehicles*' were identical to the live weapons using all the same components and in their response to service handling conditions (all-up weights and centres of gravity), but the fissile material components were replaced by depleted uranium and inert substances in order to minimise risk of an accident. Some seventeen of these were ordered as follows: three for the Royal Navy WE 177 As, four for the RAF WE 177 As, six for the WE 177 B and four for the WE 177 C. There was a requirement for a surveillance flight at high speed of the WE 177 A at an interval of roughly every eighteen months.[251] By the early 1970s this number appears to have reduced to seven on the completion of certain trials; and of the remainder, three were used to assess weapons stored on ships at sea and flown from ships and four for RAF storage, transport and flying conditions. Checking WE 177 ground clearance, air compatibility, flight carriage vibration and temperature, flight load measurement as well as weapon release in ballistic, laydown and loft mode required a massive programme of continuing flight and ground trials with a range of aircraft, such as the new Tornado. From the early 1970s through to the early 1980s almost two hundred trials ran to support this programme.[252]

A new surveillance programme became necessary in the mid 1970s given the changes in the weapon system as a whole since the mid 1960s. The original exercise involved stores with early fuzing and warhead systems that were not representative of future and increasingly large numbers of current service stores. The changes in weapon components by 1976 were as follows:

- New radar,
- Velocity Sensing Unit Mk2,
- Firing Unit Mk 3 (AWRE),
- Sylgard cabling throughout the weapon,
- Hydrostat modifications, and
- Water sensor modifications.

The need for a new radar height switch first emerged in early 1974. The Air Force Department at the MOD deemed an operational requirement for airburst nuclear weapons as essential and this would be needed for the foreseeable future as the weapons were expected to remain in service until the mid 1990s.[253] Airbursts were essential to optimise blast effects at heights consistent with weapon yields and types and to comply with SACEUR's yields constraints policy, which aimed at minimising fallout. The then present fuses had a life span of eight years after which replacements were needed by new production. In addition, they were difficult to make, already obsolete and had some operational shortcomings; for example, over terrain with poor reflectivity such as forests and arable land impacting adversely on the high air burst requirements for the WE 177 B and C weapons. There was thus a compelling need for development of a new switch to address these deficiencies.

Plans called for a new design and specified production of 300 new switches to cover the entire stockpile with some spares. Production was scheduled to start in December 1977 with completion due in 1981/82. Prior to the production run a series of approval trials and aircraft drop trials using pre-production standard fuses were required; the new fuses were planned for a service life of at least sixteen years. EMI Electronics Ltd's new design incorporating phased modulated radar principles was adopted.[254]

Generally over 1000 modifications to the weapon's non-nuclear components as a whole were made during the surveillance programme and the cumulative effect of these changes could only be assessed over time, hence the need for a new surveillance programme.[255] The scale of the effort required to keep the weapons serviceable and safe emerges from the planned second refurbishment programme for the WE 177 A in 1975. Each weapon had 790 separate non-nuclear components ranging from humble washers to the ballistic casing nose and centre assemblies. In the 1975 refurbishment, over fifty components were replaced, whilst some others were to be re-used subject to testing; the remainder could be re-used or replaced if required on inspection.[256]

Essentially the same process applied to all classes of WE 177s throughout their life cycle. Surveillance flights continued to check the reliability and safety of the various components in the weapons; for example, a trial on a WE 177 B surveillance round took place in December 1974, the first since November 1972, whose purpose was to subject the bomb to a flight environment typical of an operational sortie.[257] Trial objectives were to:

- subject the simulated weapon to the flight environmental conditions of a typical operational sortie in order to provide information on the effect of service environments upon the weapon and its components;
- provide early warning of any deterioration that could affect safety or reliability;
- obtain data for determining weapon/component life cycles; and,

- obtain an indication of the spares needed and the work to be done during the established weapon refurbishing periods.[258]

This entailed a Buccaneer aircraft flying two consecutive sorties over the West Freugh range, with bomb doors open for part of the flight, to simulate an operational turn-round following an abortive mission with the first sortie on a simulated lay down delivery with the second on a simulated 'varitoss' delivery.[259]

The WE 177 weapons went back to ROF Burghfield at intervals of just less than four years for the replacement of a 'lifed' item – the need to replenish the tritium reservoirs used in the gas boosted primaries of the weapon.[260] The shelf-life for some other components was also restricted to four years, primarily the arming unit, the Ground Control Unit (GCU, which enabled the weapon to be armed pre-flight), the Velocity Sensing Unit (VSU - pop-out pressure-sensing vanes on each side of the weapon[261]) and the water sensors. Other weapon components had a minimum life span of eight or ten years, subsequently extended to twelve.[262] Silicone rubber 'O' seals, on the other hand, used in the nuclear and non-nuclear parts of the weapon had a service life of 16 years if they were left undisturbed.[263] This was later extended to twenty years.[264] Such an extension did not apply to the tritium gas bottle, neutron generator, arming unit electronics, the fuzing and arming electronics or the radar fuze – all of which were replaced in four or eight year cycles.[265] Burghfield's capacity for refurbishment was between two and four weapons a month, though for most of the time the normal throughput was three.[266]

The original design requirement for the WE 177 B was for a minimum life of eight years[267], though a life extension programme increased this to twenty years.[268] This required withdrawal of four weapons from frontline service to provide components for assessment.[269] This was not always an easy process. During 1969–1970 the agreed programme for the first refurbishment of the WE 177 B was delayed by a shortage of electrical components, especially where these were common items for the assembly of the WE 177 A.[270] Dummy radars had to be fitted as 'live radars' were diverted to the A weapon for the Royal Navy.[271] However, the second refurbishment programme for the WE 177 B ended in May 1974 – seemingly without any issues.[272] The warhead components for which AWRE had the responsibility initially had a minimum life of ten years.[273] However, in the late 1960s AWRE had estimated that UK warheads would have a life of eight years – an assessment based on laboratory measurements of rates of out gassing from lithium compacts[274], the effects of radiolysis on components and estimated rates of corrosion amongst other things.[275] Aldermaston thought that in the event the warheads may have lives greater or less than this eight year period. Longterm ageing tests would continue as part of AWRE's programmes with two or three weapons withdrawn each year for examination as part of this effort. Information arising from the underground nuclear tests conducted in 1974 and 1976 (*Fallon* and *Banon* as part of the Chevaline programme) had produced a design that was also compatible with the WE 177 weapon if the then existing lifespan of 18 years required an extension.[276]

By the end of January 1979 two considerations shaped the refurbishment programme – the need to accommodate the work loading requirements at the Royal Ordnance Factory at Burghfield and the RAF and Royal Navy requirement to reduce the number of road convoys moving weapons from RAF stations to and from Burghfield. The aim was a gradual reduction in the numbers of weapons refurbished per year. Therefore, Burghfield's plans for the third refurbishment of the WE 177 A were initially based on the weapons being in service for a full four year tour *before* they were returned for their fourth refurbishments, and all subsequent refurbishments. Plans for the WE 177 B rested on the weapons being in service for an average of three years and nine months before being sent back for their fifth refurbishment. After this the WE 177 Bs were programmed to remain in service for a full four year tour. The programme for the first refurbishment of the WE 177 Cs was based on the weapons being in service for an average of three years and four months before coming back for their second refurbishment. Subsequently the plan was that they would remain in service for an average of three years seven months; this interval later stretched to four years for all subsequent refurbishments. However, the full four year period for all the variants was dependent on the

granting of a permanent concession for the extension of the life of a key component in the weapon - Unit 16004 - by up to a further six months, but approval was still pending from the design authority (AWRE) as of October 1979.[277] This Unit was the tritium gas bottle used to boost the yield of the fission primary.[278]

Overall, it took some twelve months to obtain a ruling on this question, and it was finally decided in May 1980 that no permanent life extension of Unit 16004 could be approved. This led to a revised current and long term refurbishment programme up to March 1983. The new programme for WE 177 A and C based itself on the existing life of Unit 16004. However, in the case of WE 177 B, a concession for a three months extension existed to cover programme requirements up to March 1983. Thus, the programme for WE 177 B reflected this fact. After March 1983, however, the programme for all weapons revolved around the existing life of Unit 16004.[279]

AWRE Aldermaston had a positive programme for the withdrawal of normal service stockpile weapons, about one per year for each type, for breakdown and examination during the in-service downstream life.[280] These were replaced into the stockpile by drawing on the spares of non-operational warheads, but once production had finished it was necessary either to have stocks of component parts for rebuild as required or for such components to be specially made at the time they were required. This led to adoption of what Aldermaston called the '*Trickle philosophy*', which was simply a programme of continuously refurbishing the stockpile at the lowest meaningful rate to ensure that facilities and expertise exercised periodically to produce consistent hardware. The complication was that the rate varied from component to component, but Aldermaston believed that an emphasis on consistency was a vital factor in reliability. AWRE chose a rate of about one tenth of the stockpile per year for final weapon assembly, with the sub-components matching where possible, but each considered on its own merit. Some components were made in batches whereas others with high process control content needed to be made continuously.

Conclusion

This note has charted the complex and convoluted history of the UK's main non-strategic nuclear weapon over a roughly twenty year period. There are perhaps five key conclusions that one can draw from this programme. First, WE 177 development and acquisition faced a protracted process, caused primarily by disputed requirements coupled with financial and political pressures. The path to deployment was long – seven years for the first weapon to enter service with the RAF, which it could not then plan to use against targets in Eastern Europe given its yield. It took more than ten years for the RAF to get its first tactical weapon low yield weapon, but its yield was too low if it had ever to be used successfully against priority hard targets. However, by comparison with contemporary weapons acquisition rates, such timescales are remarkably swift. Second, in the UK case there was a clear linkage between the design of the aircraft initially planned to carry the new weapon and the weapon itself, which had impacts on the design of both. Ultimately the actual number of weapons procured was closely linked to the numbers of aircraft that had been authorised, especially in the case of the WE 177 C. Numbers were kept to the minimum. Third, the changes enforced by the cancellation of *Skybolt* in 1962 meant that the RAF ended up with a high yield weapon first rather than one was suitable for the priority hardened NATO and national targets in Eastern Europe. In addition, although the WE 177 initially had a role to play in both the FEAF and NEAF, these roles had ended on 31 October 1971 and 31 March 1976[281] respectively – reflecting Britain's retreat from a global role. Fourth, financial pressures were acute throughout the 1960s, first at the planning and development stage in the early 1960s and again in the mid to late 1960s at the ordering and deployment stage. Moreover, in both phases delays and uncertainties constrained the WE 177 programme to the exasperation of the RAF. The path to an operational capability is never as smooth as the services would like. Fifth, the surveillance and refurbishment programme was complex and required careful planning, extensive industrial and engineering support networks, and a trials programme to sustain the WE 177 in service as an operational weapon for both the RAF and the Royal Navy. This is a key feature of a nuclear weapons programme and has a significant footprint, which has potential implications for the verification measures needed for a meaningful and effective nuclear disarmament treaty at some future point.

Appendix

Likely production rates based on known and estimated manufacturing and scheduled in-service dates.

Month/Year	Production	WE177 A	WE177 B	WE 177 C	Total
September 1966	1		1		1
October 1966	4		5		5
November 1966	4		9		9
December 1966	4		13		13
January 1967	4		17		17
February 1967	4		21		21
March 1967	4		25		25
April 1967	4		29		29
May 1967	4		33		33
June 1967	4		37		37
July 1967	4		41		41
August 1967	4		45		45
September 1967	4		49		49
October 1967	**4**	**0**	**53**	**0**	**53**
January 1969	2	2			55
February 1969	2	4			57
March 1969	2	6			59
April 1969	2	8			61
May 1969	2	10			63
June 1969	2	12			65
July 1969	2	14			67
August 1969	2	16			69
September 1969	2	18			71
October 1969	2	20			73
November 1969	2	22			75
December 1969	2	24	52		76
January 1970	2	26			78
February 1970	2	28			80
March 1970	2	30			82
April 1970	2	32			84
May 1970	2	34			86
June 1970	2	36			88
July 1970	2	38			90
August 1970	2	40			92
September 1970	2	42			94
October 1970	**1**	**43**	**52**	**0**	**95**

October 1970	1	44			96
November 1970	3	47			99
December 1970	3	50			102
January 1971	4	54			106
February 1971	4	58			110
March 1971	4	62			114
April 1971	4	66			118
May 1971	4	70			122
June 1971	4	74			126
July 1971	4	78			130
August 1971	2	80			132
September 1971	2	82			134
October 1971	2	84			136
November 1971	2	86			138
December 1971	2	88			140
January 1972	2	90			142
February 1972	2	92			144
March 1972	-	-			144
April 1972	-	-			144
May 1972	-	-			144
June 1972	-	-			144
July 1972	-	-			144
August 1972	-	-			144
September 1972	-	-			144
October 1972	**-**	**92**	**52**	**0**	**144**
December 1973	3			3	147
January 1974	3			6	150
February 1974	3			9	153
March 1974	3			12	156
April 1974	3			15	159
May 1974	3			18	162
June 1974	3			21	165
July 1974	3			24	168
August 1974	3			27	171
September 1974	3			30	174
October 1974	3			33	177
December 1974	3			36	180
January 1975	3			39	183
February 1975	3			41	186
March 1975	3			44	189
April 1975	3			47	192
May 1975	3			50	195
June 1975	3			53	198
July 1975	3			56	201

August 1975	3			59	204
September 1975	3			62	207
October 1975	3			65	210
November 1975	3			68	213
December 1975	3			71	217
January 1976	3			74	220
February 1976	3			77	223
March 1976	3			80	226
April 1976	3			83	229
May 1976	3			86	231
June 1976	3			89	234
July 1976	3			92	237
August 1976	3			95	240
September 1976	3			98	243
October 1976	3			101	247
November 1976	3			104	250
December 1976	3			107	253
January 1977	3			110	256
February 1977	4			114	260
March 1977	4			118	264
April 1977	4			122	268
May 1977	**2**	**92**	**52**	**126**	**270**

Endnotes

1 The National Archives (TNA) DEFE 19/195, Future UK Tactical Nuclear Weapons, Note of a meeting, Friday 7 October 1977. Ted Newley, Director of Aldermaston, noted in the mid 1960s that the non-strategic part of the UK's nuclear weapons programme was 'often euphemistically called the 'tactical weapons programme'.' See TNA AB 48/783, Atomic Energy Authority, Work Load for the Weapons Group, Note by Mr. E.F.Newley, 1964–65.

2 See for example Matthew Jones' magisterial official histories, *UK Strategic Deterrent Volume I: From the V-Bomber Era to the Arrival of Polaris, 1945-1964* and *UK Strategic Deterrent Volume II: The Labour Government and Polaris Programmes, 1964-1970*, Routledge, London, 2017; and John Baylis and Kristan Stoddart, *The British Nuclear Experience The Role of Beliefs, Culture, and Identify,* Oxford University Press, Oxford 2015. On tactical weapons see Brian Burnell, nuclear weapons a guide to British nuclear weapons projects updated 15 April 2018 http://www.nuclear-weapons.info/vw.htm#cite_ref-vw1643

3 The NTI Report *Innovating Verification; New Tools & New Actors to Reduce Nuclear Risks Building Global Capacity*, July 2014 called on nuclear weapon states 'to preserve programme records, supporting data and institutional memory … better documentation can increase the level of confidence in verification findings and reduce workloads.' See page 32.

4 TNA DEFE 19/195 Future UK Tactical Nuclear Weapons, Note of a meeting, Friday 7 October 1977. See Annex A. See also John R. Walker, *British Nuclear Weapon Stockpiles, 1953–1978*, The RUSI Journal 156:5, 66-72.

5 As we can see from the range of committees, boards, branches, departments, organisations cited in the footnotes to this history.

6 Records on the UK nuclear weapons programme are in a broad range of classes of files at The National Archives (TNA): AB, ADM, AIR, AVIA, CAB, CO, DEFE, DSIRR, ES, FCO, FO, PREM, SUPP, T and WO.

7 TNA AIR 2/17323, A.G. Steele, Wing Commander, O.R. 19, Ministry of Aviation to D.D.O.R.2, 17 March 1961; TNA AIR 2/17323, Joint Naval/Air Staff Requirement G.D.A10/O.R.1177 (Issue 2) An Improved Kiloton Bomb, 1961.

8 This is in TNA AIR 2/17322, OR 1177: improved kiloton bomb, 1959-1960.

9 Richard Moore, Nuclear Illusion, Nuclear Reality Britain, the United States and Nuclear Weapons, 1958–64, Palgrave Macmillan, Basingstoke, 2010, page 252.

10 TNA CAB 131/27, Cabinet Defence Committee, page 4, D (62) 10th Meeting, 6 June 1962. This meeting had also agreed to cancel the '*high yield replacement for Red Beard*'.

11 TNA DEFE 13/409, The Nuclear Warhead Programme, Minutes of a Meeting between the Minister of Defence, Secretary of State for Air, 2 and 3 July 1962.

12 TNA AIR 77/654, Science 2 Memo No.344, The Limitations of a 10 KT Free-Fall Tactical Weapon as a replacement for Red Beard, March 1963.

13 TNA AIR 2/17323, A.G. Steele, Wing Commander, O.R. 19, Ministry of Aviation to D.D.O.R.2, 17 March 1961.

14 TNA AIR 2/13702, Tactical strike reconnaissance aircraft nuclear weapon systems, 1957-1965.

15 TNA AIR 77/654, Science 2 Memo No.344, The Limitations of a 10 KT Free-Fall Tactical Weapon as a replacement for Red Beard, March 1963.

16 The RAF designation for the WE 177A weapon was Bomb Aircraft HE 600 LB MC and was nine feet four inches in length with a diameter of one foot four and a half inches, whereas the designator for the WE 177B and C was Bomb, Aircraft, HE 950 lb MC No.1 and No.2 - both were eleven feet long and one inch with a diameter of one foot and four and a half inches. See TNA AIR 2/17331, Nomenclature for Bombs to WE 177 , Types A and B, Squadron Leader N. English to O.R. (30) (RAF), 13 March 1964.

17 TNA AIR 2/17323, Nuclear Weapons for the TSR.2 aircraft, A.C. Steel, O.R. 19, Ministry of Aviation to D.D.O.R 2, 17 March 1961.

18 TNA AIR 2/17323, C.W. Rhodes, C Division Armament Department to J.Harrison, Head Armament Department, Air Ministry, Shape of Bomb to O.R.1177, 25 May 1960.

19 TNA AIR 2/17323, A.G. Steele, O.R.19 to D.D.D.R., Nuclear Weapon for the TSR.2 Aircraft, 17 March 1961.

20 See Humphrey Wynn, RAF *Nuclear Deterrent Forces*, London, HMSO, 1994, Chapter 28.

21 TNA ADM 1/30991, Air Staff Requirement No. O.R.1176 Standard Nuclear Warhead Capsule with Fixed Yields

in the 10 to 300 Kiloton Range, 21 July 1961.

22 TNA CAB 131/27 (D) 62, 7TH Meeting 18 April 1962.

23 TNA AB 16/3240, The Kiloton Nuclear Weapons Programme D (62)24, J.A. Jukes to Sir William Penney, 16 April 1962. In his book *The American Bomb in Britain US Air Forces' Strategic Presence*, 1946–64, Manchester University Press, 2016 Ken Young notes that, 'Financial stringency is the constant factor in the two decades covered by this book. Even when the defence need was recognised, the willingness to meet the costs was absent.'

24 TNA CAB 131/27, Cabinet Defence Committee, The Kiloton Nuclear Warhead Programme Memorandum by the Minister of Defence, Appendix A Red Beard Replacement, D (62) 24, 16 April 1962.

25 TNA CAB 131/27, Cabinet Defence Committee, The Kiloton Nuclear Warhead Programme Memorandum by the Minister of Defence, Appendix C, D (62) 24, 16 April 1962.

26 TNA CAB 131/27, Cabinet Defence Committee, The Nuclear Programme, Memorandum by the Secretary of State for Air, D (62) 34, 4 June 1962.

27 TNA CAB 131/27, Cabinet Defence Committee, The Nuclear Programme Memorandum by the Secretary of State for Air, D (62) 34, 4 June 1962.

28 TNA CAB 131/27, Cabinet Defence Committee, page 4, D (62) 10th Meeting, 6 June 1962.

29 TNA CAB 131/27, Cabinet Defence Committee, The Nuclear Programmer Memorandum by the Secretary of State for Air, D (62), 4 June 1962.

30 See Humphrey Wynn, *RAF Nuclear Deterrent Forces*, HMSO, London, 1994, pages 270–279.

31 TNA CAB 131/27, Cabinet Defence Committee, The Nuclear Programme Memorandum by the Secretary of State for Air, D (62) 34, 4 June 1962.

32 TNA CAB 131/27, Cabinet Defence Committee, The Nuclear Warhead Programme Memorandum by the Ministry of Defence, Appendix B, D (62), 2 July 1962.

33 TNA CAB 131/27, Cabinet Defence Committee, D (62) 11th Meeting, 9 July 1962.

34 Zuckerman argued re the Red Beard high yield replacement that, 'the most important of these assumptions, concerning the accuracy of the means of delivery, the impossibility of attacking the same targets twice and the requirement for a specified level of damage, were all matters of judgment which it was not possible to substantiate by reference to any relevant experience.' See Cabinet Defence Committee, D (62) 11th Meeting, 9 July 1962.

35 TNA CAB 131/27, The Kiloton Nuclear Warhead Programme Memorandum by the Minister of Defence, Cabinet Defence Committee, D (62) 24, 16 April 1962. (In UK parlance, anything above 500 kilotons was in the megaton range.)

36 TNA DEFE 13/291, Minutes of a Meeting between Harold Watkinson, Minister of Defence and Julian Amery, Secretary of State for Air, 2/3 July 1962.

37 TNA CAB 131/27, Cabinet Defence Committee, D (62) 11th Meeting, 9 July 1962.

38 TNA AB 16/3240, J.L. Gillam to Sir Alan Hitchman, The Weapons Programme, 15 August 1962.

39 TNA AB 16/3240, Appendix, MOD, 22 August 1962, R.H.Scott, MOD to F.F. Turnbull, Office of the Minister of Science, 22 August 1962

40 Matthew Jones, *The Official History of the UK Strategic Nuclear Deterrent, Volume I: From the V-Bomber Era to the Arrival of Polaris, 1945–1964*, Routledge, 2017, electronic version location 11130.

41 TNA CAB 131/28, Cabinet Defence Committee, D (63) 1st Meeting, 23 January 1963; TNA CAB 131/28, Cabinet Defence Committee, D (63) 2, The Deterrent in the Pre-Polaris Period, Memorandum by the Minister of Defence, 15 January 1963. This noted that the yield was 300/450 kilotons.

42 TNA DEFE 19/103, Chief Scientific Adviser, The WE.177 Nuclear Weapons System, undated.

43 TNA AIR 2/17330, Development Diary, O.R. 1177, January 1968.

44 TNA CAB 131/28, Cabinet Defence Committee, D (63) 2, The Deterrent in the Pre-Polaris Period, Memorandum by the Minister of Defence, 15 January 1963; TNA CAB 134/443, Tactical Nuclear Weapons for the RAF Annex B, February 1972.

45 TNA AIR 2/17325, W. A. Harrison, Wg Cdr A/D D.O.R.2 to D.O.R (C), 8 January 1964.

46 TNA AIR 6/152, Future Warhead Programmes for the V-Force, Annex C to AC (63) 9, 1963.

47 TNA AIR 2/13702, A.Ingle (Group Captain) D.D.Air Plans 1 to D.D.Ops. (B) et al, 6 December 1963.

48 TNA CAB 131/27, Cabinet Defence Committee, D (62) 7th meeting, 18 April 1962. See also Richard Moore, The Royal Navy and Nuclear Weapons, Frank Cass, London, 2001, page 174.

49 See Chuck Hansen, *U.S. Nuclear Weapons the secret history*, Aerofax, Orion books, 1988 page 164. The

development programme for this was released by the Sandia laboratory in mid-June 1960. Production engineering began in January 1961. The US Navy was assigned as the '*primary user organisation*', but the US Air Force had requirements too. TX57 became the Mk 57 bomb and could be delivered by helicopter or fixed wing aircraft as a depth bomb, free-fall airburst weapon, or as a retarded '*laydown*' bomb.

50 TNA AIR 2/17323, Report on a Visit to Sandia Corporation, Albuquerque, New Mexico to Discuss Retarded and Laydown Nuclear Weapons – 13th October 1960 to 27 October, 1960. See also TNA AIR 2/17323, Interim Report on a Visit to USA to study Retarded/Laydown Nuclear Weapons, 18 November 1960.

51 TNA AIR 2/17325, Future Tactical Nuclear Weapon Development Possible Adoption of the American Bomb TX 57, N.Coles, D.C.Q., Ministry of Aviation to A.C.A.S (OR) Air Ministry and D. CNS Admiralty, 13 July 1962. The TX 57 as noted above became the US MK 57, which entered service in the US in 1964.

52 TNA AIR 2/17323, Explanatory Notes – Draft Joint Naval/Air Staff Requirement G.D.A./10/O.R.1177 (Issue 2), 21 April 1961.

53 TNA AIR 2/17330, Development Diary OR 1177, An Improved Kiloton Bomb, 1963-1964.

54 TNA AIR 2/17323, Joint Naval/Air Staff Requirement G.D.A./10/O.R.1177 (Issue 2), An Improved Kiloton Bomb, 21 July 1961.

55 TNA AIR 2/17325, Minutes of the WE 177 Weapon System Working Party Meeting Number 9, 22 October 1962; TNA AIR 2/17325, Group Captain A.G. Steele, D.D.O.R.2 to D.D. Air Plans 1 et al, Yield Requirements for the Weapon to O.R.1177, 27 November 1962.

56 Chris Gibson, *Vulcan's Hammer V-Force Projects and Weapons Since 1945*, Hikoki Publications, Manchester, 2011, page 53. The Ministry of Aviation had taken over the nuclear responsibilities of the Ministry of Supply when it was disbanded in 1959. There are references in TNA AIR 2/17324 and TNA AVIA 65/1862 to the allocation of the reference number WE 177 in late 1961.

57 TNA AIR 2/17325, Minutes of the WE 177 Weapon System Working Party Meeting Number 9, 22 October 1962. See also TNA AVIA 65/1862, ASR 1176 and 1177: nuclear weapon requirement, 1959-1963.

58 Roy Dommett, *RAE Farnborough and the British Nuclear Weapons Programme*, Fifth Seminar on the History of the UK Nuclear Weapons Programme, Mountbatten Centre for International Studies, University of Southampton, Thursday 9 October 2003.

59 The Ordnance Board was an inter service body. Initially presided over by the army with a permanent naval vice president, the presidency was rotated between all three services after the inclusion of a vice president (Air) in 1940. The board provided independent authoritative advice on the development and design of weapons, ammunition and explosives. See http://discovery.nationalarchives.gov.uk/details/r/C1084

60 Roy Dommett, *RAE Farnborough and the British Nuclear Weapons Programme*, Fifth Seminar on the History of the UK Nuclear Weapons Programme, Thursday 9 October 2003.

61 TNA DEFE 19/103, Chief Scientific Adviser, The WE.177 Nuclear Weapons System, undated.

62 TNA AIR 2/17325, Draft R&D Board Paper, G.D.A10/OR 1177, 6 July 1962.

63 TNA AIR 2/17325, R&D Board Paper G.D.A.10/OR 1177, 6 July 1962. See TNA CAB 131/27, Cabinet Defence Committee, D (62), 7th Meeting. 18 April 1962.

64 TNA PREM 11/3706, Roger Makins to Prime Minister, 2 March 1962. According to a US Department of Energy Openness Press Conference Fact Sheet 27 June 1994 p. 179, the yield of PAMPAS was 9.5 kilotons and that it released radioactivity detected off site; TNA AB 49/14, Roger Makins to Lord President, CH (62) 22, 12 March 1962. See John R. Walker, *British Nuclear Weapons and the Test Ban 1954-1973, Britain, the United States, Weapons Policies and Nuclear Testing: Tensions and Contradictions,* Ashgate, Farnham, 2010, pp 104–106 and 202.

65 TNA AVIA 65/1836, Future UK atomic weapons trials: policy, 1961-1966.

66 TNA ES 11/41 Climatic trial for an instrumented KATIE supported as in WE 177 B, 1964. This is a closed file at TNA, but an open title.

67 TNA AVIA 65/1771, Nuclear Requirements for Defence Committee, Future of United Kingdom Nuclear Weapon Test and Experiments (Memorandum by the Ministry of Aviation), N.D. (63) 8, 11 October 1963.

68 See closed TNA files titles for an indication of this work: TNA ES 11/44, Some further observations on the vibration tests specified for WE 177, 1964; TNA ES 11/45, Predicted temperatures for WE 177 A in transit container WE155 when subjected to an external fire source, 1964; TNA ES 2/175, WE 177 approval trial; report on AWRE trial No 14237/1 (…) external neutron initiator survival trial, 1965. See also TNA AIR 20/11515, Nuclear Weapon ASR 1177 handling and environmental trials, 1964-1968,

69 TNA DEFE 19/195, DCA (PN) Atomic Warhead Approval No.7 – Issue 9, Warhead ZA297 for use in Bomb,

Aircraft, HE, 950 lb MC under cover of minute from V.H.B. Macklen, DCA (PN) WE 177 Warheads for Bomb, Aircraft, HE, 950 lb MC and 950 lb MC No.2 to CA et al, 7 October 1977.

70 TNA AB 16/4675, Atomic Weapons Production Committee, AWP/P (64) 1st meeting, 28 August 1963.

71 TNA DEFE 69/27, Director General Weapons (Naval) to DNSY, M11, 18 September 1969; Director General Supplies and Transport (Naval), M1, 2 April 1969.

72 TNA AIR 2/17323, Joint Naval/Air Staff Requirement G.D.A10/O.R.1177 (Issue 2) An Improved Kiloton Bomb, 1961; TNA 2/17325, A.J. Peart, Group Captain D.D.O.R 2 to D.O.R. (C), 28 February 1963.

73 TNA AVIA 65/1862, ASR 1176 and 1177: nuclear weapon requirement, 1959-1963.

74 TNA AIR 2/17325, A.D. Frank, Air Commodore D.O.R (C) to D.O.R. (A) et al, Nuclear Weapons for T.S.R. 2 November 1962; TNA 2/17325, A.J.Peart, Group Captain, D.D.O.R. 2 to D.O.R. (C). Consequences of a 10 KT Limit on the Yield of O.R.1177, 31 October 1962; TNA 2/17325, A.J. Peart, Group Captain D.D.O.R. 2 to D.O.R. (C). 28 February, 1963. Macmillan had previously raised doubts in July 1958 over whether UK kiloton weapons were appropriate for the limited war scenarios that could be envisaged. See Matthew Jones, *The Official History of the UK Strategic Nuclear Deterrent, Volume I: From the V-Bomber Era to the Arrival of Polaris, 1945–1964*, Routledge, 2017, electronic version locations 3659. Jones also notes that 'in the realm of tactical nuclear weapons, the growing scepticism amongst ministers (not least Macmillan himself) that British forces would ever be faced with protracted periods of 'limited war' where they would fight without US support appears to have been translated into a much reduced requirement for kiloton and sub-kiloton weapons.' See Jones location 6671.

75 TNA AIR 2/17325, A.J. Peart, Group Captain D.D.O.R. 2 to D.O.R. (C). 28 February 1963.

76 TNA AIR 77/654, Science 2 Memo No.344, The Limitations of a 10 KT Free-Fall Tactical Weapon as a replacement for Red Beard, March 1963.

77 TNA AIR 77/654, Science 2 Memo No.344, The Limitations of a 10 KT Free-Fall Tactical Weapon as a replacement for Red Beard, March 1963.

78 Lorna Arnold and Mark Smith, *Britain, Australia and the Bomb The Nuclear Tests and Their Aftermath*, Palgrave Macmillan, Basingstoke, 2006, page 141. This included exposure of six Swift aircraft, three Centurion tanks; guns of various types; ammunition and explosives; structures including bridges, runways and sheds. Many of the structures used were models scaled down so that the atomic explosion would have a similar effect to a thermonuclear explosion on a full-scale structure.

79 TNA AIR 2/17323, A.J. Peart, Group Captain to D.O.R. (C), Consequences of a 10 KT limit on the Yield of O.R.1177, 31 October 1962.

80 TNA AIR 2/17323, A.J. Peart, Group Captain D.D.O.R. 2 to D.O.R. (C), 28 February 1963.

81 TNA AIR 77/654, J.E. Henderson (A.S.A. (O)) to P.S. to V.C.A.S, P.S. D.C.A.S, A.C.A.S. (P) et al, Science 2 Memo. No.344, The limitations of a 10 KT free-Fall Tactical Weapon as a Replacement for Red Beard, March 1963.

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83 TNA AIR 2/17327, OR 117 Improved Kiloton Bomb, 1963. Folio 23 B, 13 May 1963.

84 Roy Dommett, *RAE Farnborough and the British Nuclear Weapons Programme*, Fifth Seminar on the History of the UK Nuclear Weapons Programme, Mountbatten Centre for International Studies, University of Southampton, Thursday 9 October 2003.

85 TNA AVIA 65/2284, Meeting to discuss financial progress on the Hunting Engineering Limited WE 177 Contracts held 27th October, 1964. It seems that the main project cost involving Hunting and other companies came to £11,320 028 – TNA AVIA 65/2284, N. W. Lyon, Air B.3 (d) to A D. A. Arm. 3, Project WE 177 Cost Estimates, 14 September 1964.

86 Roy Dommett, *RAE Farnborough and the British Nuclear Weapons Programme*, Fifth Seminar on the History of the UK Nuclear Weapons Programme, Mountbatten Centre for International Studies, University of Southampton, Thursday 9 October 2003.

87 TNA SUPP 6/958, Volume 3 Book 1 of the proceedings of the Ordnance Board in joint session with Aeroplane and Armament Experimental Establishment (A&AEE): bomb, aircraft, HE 900lb MC No. 1 and No. 2, and bomb, aircraft, HE 600lb MC - weapon system (WE 177), Apr 01 1965 - Apr 30 1975.

88 Jonathan Aylen, First Waltz: Development and Deployment of Blue Danube, Britain's Post-War Atomic Bomb, *The International Journal for the History of Engineering & Technology*. 2015; 85 (1):31-59.

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90 TNA AIR 2/17330, Proof of WE 177, D.A. Arm (D.B. Hatfield) to D. G. A., Admiralty, 2 January 1964.
91 See John R.Walker, *British Nuclear Weapons and Test Ban* op. cit. page 273.
92 TNA AIR 2/17331, Minutes of a Meeting held at R.A.E. Farnborough on 26th February 1964 to discuss the provision of a Vulcan aircraft for the WE 177 Weapon System Carriage and Release Trials.
93 Alan Morrison, *Sonic to Standoff The Evolution of the British Nuclear Deterrent*, Glasgow Cross Press, Glasgow, 2016, pages 172–4.
94 TNA AIR 20/11515, Minister of Aviation to Prime Minister, 14 May 1964. See also Paddy Heazell, Most Secret *The Hidden History of Orford Ness*, The History Press, Stroud, 2010, pages 173–175; and Wayne D. Cocroft and Roger J.C. Thomas Edited by P.S. Barnwell, *Cold War Building for Nuclear Confrontation 1946–1989*, English Heritage, Swindon, 2005, pages 249–250.
95 TNA AVIA 6/22601, Free-flight measurements of the drag of the WE 177 weapon including measurements of pressures associated with a spoiler-type pressure sensor, 1965. See also TNA DSIR 23/33818, Free-flight measurement of drag of WE 177 weapon including measurements of pressures associated with a spoiler-type pressure sensor (M = 0.7-1.9) (RAE TR 65269), 1966.
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97 TNA AIR 6/167, Quarterly Progress Report to the Air Force Board on New Aircraft and Weapon Systems, Annex to AFB (65) 14, June 1965.
98 TNA AIR 6/166, Nuclear and Chemical Weapons, Annex to AFB (64)14, 7 July 1964.
99 TNA PREM 13/3126, Arthur Hockaday, MOD to J .O. Wright, 10 Downing Street, 14 December, 1964. PM approves Wright to J. E. Carruthers, MOD 16 April 1965.
100 TNA PREM 13/3126, Minister (RAF) to Foreign Secretary, Movement of Nuclear Weapon Assemblies, 6 June 1966.
101 TNA PREM 13/3126, D. Hanson, MOD to D. I. Morphet, Foreign Office, Movement of Nuclear Weapons Assemblies, 26 January 1966.
102 TNA PREM 13/3126, P.D. Nairne, MOD to J .O. Wright, 10 Downing Street, 26 July 1965.
103 Wayne D. Cocroft and Roger J.C. Thomas, Edited by P.S. Barnwell, *Cold War Building for Nuclear Confrontation 1946–1989*, English Heritage, Swindon, 2005, page 253.
104 TNA AIR 2/17330, Wg Cdr W. A. Harrison, AD/D.D.O.R. 2 to D.O.R. (C), Nuclear Weapons for the TSR.2, 8 January 1964.
105 TNA AIR 2/17331, paragraph 2.3, Introduction of WE 177 Weapon System into Service Meeting held 19th February, 1964
106 TNA AIR 2/17331, paragraph 3.1, Introduction of WE 177 Weapon System into Service Meeting held 19th February, 1964. Such items were to enable crews to practise their drills and undertake instruction. They were not designed to be initiated, projected or individually dropped from aircraft.
107 TNA AIR 2/17331, paragraph 3.10, Introduction of WE 177 Weapon System into Service Meeting held 19th February, 1964.
108 TNA AIR 2/17331, paragraph 2.6, Introduction of WE 177 Weapon System into Service Meeting held 19th February, 1964. See also TNA AVIA 65/1845, Planning and estimates for POLARIS warhead, 1964-1965.
109 TNA AIR 2/17330, Development Diary OR 177, An Improved Kiloton Bomb. Controller Air Release was the formal technical authorisation that the weapon was cleared for safe carriage by a particular aircraft having met all the specified testing and performance requirements, 1963-1964.
110 TNA PREM 13/3126, A.S. Trimbe, PS to M.H.K. Reid, 10 Downing St, Road Movement of Nuclear Weapons, 9 September 1966.
111 TNA AIR 6/169, Annex to AFB (66) 35, 25 October 1966; TNA AIR 6/167 Air Force Board Memoranda, Annex to No 14 1965, Quarterly Progress Report to the Air Force Board on New Aircraft and Weapon Systems, British Nuclear Weapons, 19 May 1965. See also TNA AIR 2/17330, Development Diary OR 1177 An Improved Kiloton Bomb, 1963-1964 and TNA SUPP 5/1398, Royal Ordnance Factory Burghfield, Report for Year Ending 31 March 1968.
112 TNA AIR 2/17330, Development Diary, O.R. 1177, January 1968; TNA AIR 2/17331, Weapons Department Working Note No.164, The Intentional Ground Functioning or 'Dudding' of WE 177 by Flt Lt R.J. Hayter and A. Teale, Weapons Department, RAE Farnborough, March 1964; TNA AIR 2/17339, Wg Cdr W.A.Harrison, C.R.30 (RAF) to D.D.O.R. 10 (RAF), Safety and Reliability WE 177, 19 March 1964.

113 TNA AIR 6/169, Quarterly Progress Report to the Air Force Board on New Aircraft and Weapon Systems, British Nuclear Weapons, 13 January 1966.
114 TNA AIR 2/17330, Development Diary OR 1177 An Improved Kiloton Bomb, 1963-1964.
115 TNA AIR 6/166, Annex to AFB (64) 29, Nuclear Weapons, 1964.
116 TNA DEFE 19/103, WE 177 A, T.J. Shaw to DCSA (S), 19 May 1966; TNA DEFE 19/103, T.J. Shaw to DCSA (S), WE 177 A, The Navy's Requirement for the WE 177 A, 19 May 1966. .See also Richard Moore, *The Royal Navy and Nuclear Weapons*, Frank Cass, London, 2001, pages 139–146.
117 TNA DEFE 19/103, WE 177 A, Draft Minute from CAS to Secretary of State, May 1966.
118 TNA AIR 6/169, Annex to AFB (66) 3, Progress Report to the Air Force Board on New Aircraft and Weapon Systems, British Nuclear Weapons, 13 January 1966.
119 TNA DEFE 19/103, A.H. Cottrell, DCSA (S) to CSA, WE 177 A, 19 May 1966.
120 TNA AIR 2/13755, Ministry of Defence Operational Requirements Committee, RN-Ikara Requirement for the Nuclear Payload, Note by the Navy Department, OR/ P (64), 1964; Closed file TNA DEFE 69/589, RN deployment of Aircraft bomb 600 lb MC (WE 177 A), 1966-1977.
121 TNA AIR 2/17372, R. Haynes AUS (AS) to ACAS (Pol), draft submission from Chief of the Air Staff to Secretary of State, 26 November 1968. The order for the RAF weapons was delayed pending decisions on the strike force size. TNA AIR 2/18209, (Requirements for WE 177 A Background Note Annex B to ACAS (Pol)/A890 dated 7 January 1969). Some of the naval orders were converted to RAF use. The original plan was for 20 in the strike role, with 43 for anti-submarine warfare - see TNA AIR 20/11515, Requirements for WE 177 A, Background Note to L.D. Mavor ACAS (Pol), to PS to CAS, 23 January 1968.
122 Statement on the Defence Estimates 1968, Cmnd.3540, HMSO, 1968 page 28. See also Eric Grove, *Vanguard to Trident: British Naval Policy Since World War II*, Naval Institute Press, 1987.
123 TNA AIR 6/169, Annex to AFB (66) 35, British Nuclear Weapons, 25 October 1966.
124 Hansard, House of Commons Debates volume 315 Column 11 Written Answers, 29 June 1998; The service warhead for the A variant was designated PT.176 - TNA 19/195, DCA (PN) Atomic Warhead Approval No.7 – Issue 9, Warhead PT.176 for use in Bomb, Aircraft, HE, 600 lb MC, 7 October 1977.
125 TNA AIR 2/18209, Background Note, Annex B to ACAS (Pol)/A890 dated 7 January 1969.
126 TNA AIR 2/17331 paragraph 2.7., Introduction of WE 177 Weapon System into Service, Meeting held 19th February 1964.
127 TNA AIR 2/18209, Background Note, Annex B to ACAS (Pol)/A890 dated 7 January 1969.
128 TNA SUPP 5/1399, Royal Ordnance Factory Burghfield, Report for the Year Ending 31 March 1970.
129 TNA DEFE 13/545, A.R.M. Jaffray, MOD to P.J.S. Moon, PS/PM, 1 June 1970.
130 Hansard, House of Commons Debates, Volume 805 Column 430, Written Answers 5 November 1970.
131 TNA DEFE 13/545, CDS to Secretary of State, Naval Airborne Nuclear Weapons, 28 May 1970. Another document notes that the Navy had 34 Red Beards shared between the five strike carriers – although only two carries would have been at sea at any one time, which may explain the discrepancy. TNA DEFE 19/103, T.J. Shaw to DCSA (S), WE 177 A, The Navy's Requirement for the WE 177 A, 19 May 1966.
132 TNA DEFE 13/545, Chief of Defence Staff to Secretary of State, Naval Airborne Nuclear Weapons, Annex Release Procedures for Naval Airborne Nuclear Weapons Type 177A 600 lb Nuclear Bomb, 28 May 1970.
133 TNA DEFE 19/103, Sir Solly Zuckerman to CDS, The WE 177 Surveillance Programme, 10 May 1965.
134 See Richard Moore, F-111K: *Britain's Lost Lost Bomber*, Air Power Review, Vol.18 No.3 Autumn/Winter, 2015.
135 TNA AIR 6/169, Annex to AFB (66) 35, British Nuclear Weapons, 25 October 1966; TNA AIR 20/11782, Chief of the Air Staff, Chiefs of Staff Committee, Wednesday 17th August, 1966, DCAS: ACAS(Pol): DS.9, Future Nuclear Programme (C)S 1803/1/8/66, 16th August 1966. This latter document noted that, 'requisitions must be placed in September 1966.'
136 TNA AIR 6/169, Annex to AFB (66) 35, British Nuclear Weapons, 25 October 1966; TNA AIR 6/171, Air Force Board, Future Size and Shape of the V Bomber Force, Note by the Vice Chief of the Air Staff, draft, 3 February 1967. This suggested that the RAF should only acquire 34 WE 177 As. Responsibility for Britain's strategic nuclear deterrent passed to the Polaris submarines of the Royal Navy on 30 June 1969.
137 Strike Command was formed on 30 April 1968 by the merger of Bomber Command and Fighter Command – see https://www.raf.mod.uk/history/rafhistorytimeline196069.cfm
138 TNA AIR 20/12080, J.D.Thirlwell Group Captain A/D of Ops (B&R) (RAF) to D. Air Plans, WE 177 A – Weapon Requirement, 21 November 1967.
139 TNA AIR 20/12080, C.M. Clementi, Air Commodore D. Air Plans to Head of DS, WE 177 A - Weapon

Replacement, 29 November 1967.

140 Humphrey Wynn, *RAF Nuclear Deterrent Forces*, HMSO, London, 1994, page 546.

141 TNA DEFE 58/200, Movement of Section 76 Equipment, Sqn Ldr S.A. Armstrong, 30 September 1968.

142 TNA DEFE 58/200, Wg Cdr W. Bradley, Plans 2 RAF to Grp Cpt P & P et al, WE 177 Stocks, 4 June 1970.

143 TNA PREM 13/3126, Denis Healey to Prime Minister, Tactical Nuclear Weapons, 16 June 1969.

144 TNA AIR 2/18509, Weapon Development for Future Nuclear Strike Air Forces, Note by the Air Staff, OR (30) RAF, 15 June, 1966

145 TNA DEFE 58/200, Wg Cdr G. Bryan, for Deputy Director Operations (Strike) (RAF) to Wg Cdr G. Bradley, Headquarters Strike Command, WE77 Stocks and Deployment, 4 June 1970.

146 TNA AIR 2/18210, Nuclear Weapons Policy, 1969-1970. RAF Waddington also held Royal Navy WE 177s.

147 TNA DEFE 58/200, Air Vice Marshal R.L. Wade, HQ No.1 (Bomber) Group, RAF to Air Vice Marshal D. Hawkins, HQ Strike Command, RAF, 2 November 1970.

148 TNA AIR 2/12198, Draft minute from Secretary of State for Defence to Prime Minister under cover of a minute from D.C. Humphreys, Head of DS 9 to DUS (P) through AUS (AS). Nuclear Weapons, 12 May 1969; TNA PREM 13/3126, Denis Healey to Prime Minister, Tactical Nuclear Weapons, 16 June 1968.

149 TNA AIR 2/18456, Note on the Amalgamation of the RN and RAF bombs Aircraft HE 600 lb MC Into a Common Stockpile – Prepared by DD Mech. Eng. 3 (RAF), September 1969.

150 TNA AB 16/3240, Atomic Weapons Production Committee, H.C. Hudspith to Mr Gillams, 29 August 1963; Ministry of Aviation, Atomic Warheads Production Committee, Minutes of Meeting held on Wednesday, 30th September 1964.

151 Kristan Stoddart, *The Sword and the Shield Britain, America, NATO and Nuclear Weapons, 1970–1976*, Palgrave Macmillan 2014, page 115.

152 TNA AIR 20/12198, Deployment of British Nuclear Weapons in Germany, May 1969.

153 TNA AIR 2/18147, L.A. Jones, Group Captain for Air Marshal Commander in Chief RAF Germany (Second Tactical Air Force) to Ops (5) 3 (RAF), Deployment of Nuclear Weapons, 19 July 1972.

154 TNA DEFE 19/124, L.T.C.1969 – Nuclear Assumptions, D.C. Humphreys, Head of DS 9, 24 March 1969.

155 TNA AVIA 65/774, Ammunition and Ammunition Package Markings, Admiralty, War Office, Air Ministry, 1958

156 TNA AIR 2/17330, WE 177 Associated Equipment, W.S. Frost Wg Cdr Eng 2 to O.R. 19, Ministry of Aviation, 21 January 1964.

157 TNA AIR 2/17331, Introduction of WE117 Weapon System into Service Meeting, 19 February 1964.

158 TNA DEFE 72/312, Nuclear Weapons: allocations of scrambled serial numbers to WE 177, 1973 -1975.

159 TNA ES 12/226, Explosive ordnance disposal procedure for bomb, aircraft, high explosive (HE) 950 lb, MC RAF reference 76D/02 and bomb, aircraft, HE, surveillance, 950 lb, MC RAF reference 76D/13, 1970; and TNA ES 12/227, Explosive ordnance disposal procedure for bomb, aircraft, high explosive (HE) 600 lb, MC RAF reference 76D/01 and bomb, aircraft, HE, surveillance, 600 lb, MC RAF reference 76D/12, 1971. Both are closed files, but open descriptions.

160 TNA DEFE 19/195, Warhead for Bomb aircraft HE 950 lb MC No.2, V.H.B. Macklen, DC (PN), Atomic Warhead Approval No 12 Issue 2, 7 October 1977.

161 TNA AIR 2/18456, Air Vice Marshall S.H. Bonser, D.C.Q., Ministry of Aviation to ACAS (O.R.) and ACAS (Ops), MOD (Air), Amalgamation of R.N. and R.A.F. Bombs Aircraft H.E. 600lb M.C. into a Common Stockpile, 8 September 1969.

162 TNA AIR 2/18456, B.G. Dickinson (Air Commodore) to DCQ, Common RN/RAF Stockpile of HE LB MC Bomb, 26 March 1970.

163 TNA AIR 2/18456, Air Vice Marshal A. McK. S. Steadman, ACAS (Pol) to DCQ, Common RN/RAF Stockpile of HE 600lb MC Bombs, 26 March 1970.

164 TNA DEFE 58/200, Wg Cdr W. Bradley, Plans 2 RAF to Grp Cpt P & P et al, WE 177 Stocks, 4 June 1970.

165 107 WE 177 As in total were eventually ordered. Another source noted that that 120 WE117As were to be built by April 1975 2-3 per month –– aim for Plan R (an RAF aircraft and squadron deployment plan for each year) was 230; 53 WE 177 Bs were be retained in service as an insurance throughout the LTC September 1970 – September 1979 30 a year of WE 177 A.

166 Kristan Stoddart, *Losing an Empire and Finding a Role, Britain, the USA, NATO and Nuclear Weapons, 1964–70*, Palgrave Macmillan, Basingstoke, 2012, page 221.

167 TNA AIR 2/18150, WDC (NS) 4.69 Atomic Energy Authority (Weapons Group) – Expenditures on Nuclear Defence Research, Air Commodore J.W. Allan DOR3 (RAF) to PS to VCAS/DCAS (RAF), 14 November 1969.

168 C.N. Hill, *An Atomic Empire A Technical History of the Rise and Fall of the British Atomic Energy Programme*, Imperial College Press, 2013, electronic copy location 2003.
169 TNA AIR 2/18147, Annex B to draft Nuclear Policy Committee paper, Tactical Nuclear Weapons for the RAF, Note by the Secretary of State for Defence, 1972.
170 TNA AIR 2/18147, PS to CAS to Sec COS, RAF Nuclear Weapons in the Tactical Role, 8 November 1971.
171 TNA DEFE 24/1175, VCAS to CSA, RAF Nuclear Weapons, 9 July 1971.
172 TNA AIR 2/18147, PS to CAS to Sec COS, RAF Nuclear Weapons in the Tactical Role, 8 November 1971; see also TNA AIR 2/18147, P. de L. Le Cheminant, Air Vice-Marshall, ACAS (Pol) to PS CAS, Tactical Nuclear Weapons, 17 November 1971.
173 TNA DEFE 19/195, DCA (PN) Atomic Warhead Approval No.7 – Issue 9, Warhead SW641 for use in Bomb, Aircraft, HE, 950 lb MC No.2 under cover of minute from V.H.B. Macklen, DCA (PN), WE 177 Warheads for Bomb, Aircraft, HE, 950 lb MC and 950 lb MC No.2 to CA et al, 7 October 1977.
174 TNA AIR 2/18147, first draft Air Staff Requirement ASR 1223, An Intermediate Yield Nuclear Bomb, 22 February 1972. See TNA CAB 134/4431, Item 4. The Nuclear Weapons and Propulsion Programme - Fissile Material Supply Problems, Cabinet Ministerial Committee on Nuclear Policy, PN (67)1st Meeting, Minutes of a Meeting held on 9 January, 1967.
175 TNA PREM 16/1557, Fred Mulley, Secretary of State for Defence to Prime Minister, Defence Requirements for Future Supplies of Plutonium, 19 September 1978.
176 TNA DEFE 19/191, Polaris Improvement Programme: Weapons Safety Coordinating Committee Minutes, 1975. TNA DEFE 19/19, Draft Paper to KH 793 Project Review Board, Chevaline 1974, Development Cost Plan, Note by DAWD dated 16 June 1975. See also John R. Walker, *British Nuclear Weapons and the Test Ban 1954-1973, Britain, the United States, Weapons Policies and Nuclear Testing: Tensions and Contradictions*, Ashgate, Farnham, 2010, p 326.
177 TNA DEFE 19/191, Polaris improvement programme: Weapons Safety Co-ordinating Committee Minutes. 1975; TNA DEFE 19/208 Ad hoc committees on Polaris improvements: Weapons Safety Co-ordinating Committee minutes, 1974-1975.
178 TNA DEFE 24/1175, RAF Future Nuclear Weapons Programme, J.H. Nelson Head of DS 3 to DUS (E), 22 July 1971.
179 TNA DEFE 24/1175, V.H.B. Macklen DCA (PN) to VCAS, 1 October 1971.
180 TNA AIR 2/18147, D.C. Love (Air Vice-Marshal) ACAS (OR) and P.de L. Le Cheminant, Air Marshall A/Vice Chief of the Air Staff to various, Air Staff Requirement No 1223, An Intermediate Yield Nuclear Bomb, 5 July 1972.
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188 TNA AIR 2/18147, Annex B to draft NPC paper, Tactical Nuclear Weapons for the RAF, 1972; and Group Captain W.J. Herrington, DD Ops (s) RAF to DD Ops (S) RAF, Nuclear Weapons for MRCA, 28 November 1972. There are other references to 111 additional weapons spread over three years for the RAF, but this figure dates from October 1971 - see TNA DEFE 11/470, E. Broadbent, AUS (OR) to CSA, Tactical Nuclear Weapons, 28 October 1971. If this figure excludes the 15 spares for maintenance, then the figure increases to 126.
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192 TNA DEFE 24/1036, Nuclear costings 1973 and estimates 1974-1975, including POLARIS improvement assumptions.

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194 TNA DEFE 19/195, F.H.Panton, ACSA (N) to DCA (PN), Nuclear Weapons – Production and Refurbishment, 22 January 1974.

195 TNA SUPP 5/1402, Royal Ordnance Factory Burghfield, Report for Year Ending 31 March 1975.

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197 TNA PREM 15/1363, Lord Carrington to Foreign Secretary, Deployment of British Nuclear Weapons in Germany, 5 April 1973.

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201 TNA DEFE 70/783, WE 177 Studies, Brief for DMO to represent VCGS on 7 October 1977, C.A. Ewing GSO1 MO1, 3 October 1977.

202 Statement on the Defence Estimates 1981 Vol 1, London, HMSO, paragraph 223 page 16.

203 TNA AIR 2/13755, Ministry of Defence Operational Requirements Committee, RN-Ikara Requirement for the nuclear payload, Note by the Navy Department, The Nuclear Depth Bomb (WE 177 A), undated.

204 TNA DEFE 69/464, Annex A to DN Plans SF 17 Assistant Director of Naval Plans (Polaris) to CFS Co-ord et al Defence Review – Nuclear matters. Annex shows DN plans understanding of present and planned future policy relating to the 600 lb bomb, 3 April 1974.

205 Operation CORPORATE 1982: the carriage of nuclear weapons by the Task Force assembled for the campaign, Produced by CBRN Policy, MOD http://www.rna-10-area.co.uk/files/corporate-nuclear.pdf See also Lawrence Freedman, *The Official History of the Falklands Campaign: War and Diplomacy: Volume. 2 (Government Official History Series)*, Routledge, 2005 pages 48-50.

206 TNA AIR 20/12199, DUS (P) to Secretary of State, Deployment of RAF Nuclear Weapons in Germany draft, June 1970.

207 TNA AIR 20/12198, Secretary of State to Prime Minister, Nuclear Weapons, May 1969; Humphrey Wynn, RAF Nuclear Deterrent Forces, London, HMSO, 1994 pages 549 and 567; see also Kristan Stoddart, *The Sword and The Shield Britain, America, NATO, and Nuclear Weapons, 1970-1976*, Palgrave Macmillan, 2014 page 130. It is likely that WE 177 Bs continued to be stored at Akrotiri to arm any Vulcan aircraft deployed as 'detached squadrons'; four B2s from 50 Sqn arrived on 20 January as a Strike Command detachment – Wynn op. cit. page 549. There were plans for continued nuclear targeting possibly until as late as January 1977 - there is a closed file at TNA, which suggests this: TNA DEFE 58/196 Near Eastern Air Force (NEAF) Nuclear Targeting and Planning 01 November 1974 – 31 January 1977. The Vulcan squadrons IX and 35 returned from Akrotiri to Waddington and Scampton respectively in January 1975 as a direct result of the Greek-Turkish conflict over Cyprus – see Tony Blackman and Anthony Wright, *V-Force Boys*, Grub Street, 2017 electronic version location 1263.

208 TNA DEFE 58/200, Deployment of WE 177 B Weapons to NEAF, B.B.T.Horsley, Air Vice-Marshall, Assistant Chief of the Air Staff (Operations), 15 July 1968.

209 TNA DEFE 13/545, E.Broadbent to D.J.D.Maitland, Movement of Nuclear Weapon Assemblies, 1 November 1968.

210 TNA DEFE 58/200, Group Captain J.G. Matthews, Deputy Director Operations (Strike), RAF to Group Captain A.H. Mawer, Headquarters Strike Command, Refurbishment of Bomb Aircraft HE 950 LB MC – Proposed

Programme, 18 April 1969.

211 TNA DEFE 58/200, G. Bryan, Wing Commander for Deputy Director of Operations (Strike) (RAF) to Headquarters Strike Command (Attn: Wg Cdr M.G. Bradley, Plans 2), WE 177 Weapons, 12 May 1970; D.L.Hawkins, Strike Command HQ to Air Vice Marshall, R.L. Wade, Headquarters No.1 Group (B), Phase Out of Blue Steel, 25 November 1970.

212 TNA DEFE 58/200, B. Rejder Sqn Ldr for Deputy Director of Operations (Strike) (RAF) to Headquarters Strike Command (Wing Commander Bradley), WE 177 Production and Refurbishment, 19 March 1970; and TNA DEFE 58/200, Wg Cdr W. Bradley, Plans 2 RAF to Grp Cpt P & P et al, WE 177 Stocks, 4 June 1970.

213 TNA DEFE 13/545, PSO/CDS to APS/SoS, Withdrawal of Nuclear Weapons from the Far East, 24 July 1969.

214 TNA DEFE 13/545, D.C. Humphreys, Head of DS 9 to PS/Secretary of State, 16 June 1969.

215 TNA AIR 20/12198, Secretary of State to Prime Minister, Nuclear Weapons, May 1969. See Ken Young, *The American Bomb in Britain US Air Forces' Strategic Presence, 1946–65*, Manchester University Press, 2016 pages 205–208 for details on origins of, and agreement on, Project E.

216 TNA AIR 2/18000, Annex to Brief for DOR1 (RAF)'s Monthly Meeting, Buccaneer Mk2 Development on 29 January 1969, DDOR4 (RAF), 27 January 1968.

217 TNA AIR 2/18000, Brief for CAS, from OR29 (RAF), CAS's Conference with AOCs-in-Chief, Buccaneer S Mk2a and 2B, 6 March 1970.

218 TNA AIR 2/18000, Brief for DOR1 (RAF), Visit to A & AEE 12 Sep 69, OR29, RAF. A & AEE Buccaneer Flight Test Programme, 11 September 1969.

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222 TNA DEFE 58/200, G. Bryan, Wg Cdr for Deputy Director of Operations (Strike) (RAF) to HQ Strike Command, WE 177 Stocks and Deployment, 4 June 1970.

223 TNA AIR 20/12198, Draft minute Secretary of State for Defence to Prime Minister, Nuclear Weapons, 12 May 1968.

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226 TNA DEFE 58/200, Wg Cdr G. Bryan Deputy Director Operations (Strike (RAF) to Wg Cdr Bradley, HQ Strike, RAF, 4 June 1970.

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234 TNA DEFE 11/470, Secretary of State for Defence to Prime Minister, Control of British Nuclear Weapons Based In Germany, 18 January 1972.
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