Military Studies

The Development of Britain's Megaton Warheads

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Contents

Abstract

In 1946, the US Senate passed the McMahon Act, which prohibited the sharing of nuclear information with any other country. Prime Minister Churchill announced the intention to build a hydrogen bomb in February 1955, though development had started at AWRE Aldermaston the year before. In the summer of 1957, three large devices were exploded near Christmas Island in the Pacific Ocean; the series was code named *Grapple*. The official announcement stated that the devices were “in the megaton range”; the press was in no doubt that Britain had exploded an H-bomb. The following year, talks commenced with America and in June 1958 the McMahon Act was amended to allow exchange of nuclear information between the USA and UK. The result was that Britain had access to American thermonuclear weapon design; future British warheads were built largely to American designs.

At the time, very little information was released on the nature of the *Grapple* tests and this led to speculation that they were not thermonuclear devices at all, but large fission weapons. These suspicions were articulated in 1982 as the “Thermonuclear Bluff”. This proposed that the prime purpose of the tests was to deceive the Americans into believing that the UK had mastered the H-bomb and was therefore fit to be admitted into the thermonuclear club.

The gradual release of information in subsequent years allows the bluff theory to be examined. The central thesis, that the intention was to deceive the Americans, cannot be sustained. However, some of the secondary suppositions have proved to be correct, if not quite as the authors surmised. The British press did indeed collaborate in submitting eyewitness reports in advance of the event. The largest device was a uranium fission weapon and not an H-bomb; official announcements simply referred to it as being “in the megaton range”. The other two devices successfully achieved a radiation implosion of the secondary thermonuclear stage; this was the “secret” of the H-bomb. However, the yield was disappointing; this was because interaction between uranium and the light elements in the secondary had not been properly understood. Two redesigned bombs were tested and in May 1958 a true thermonuclear explosion was achieved.

The dissertation follows the development of British megaton devices during the period from 1954 to 1958, including the bomb that never was; code-named *Green Bamboo,* it was expected to provide the warhead for free fall bombs, the *Blue Steel* guided bomb and the *Blue Streak* missile. It was built and was ready to be tested at *Grapple*, but was outdated before being fired. British developments are followed in the context of Anglo-American relationships, tracing the gradual thaw during the 1950s until the 1958 amendment to the McMahon Act; Macmillan regarded this agreement as the “Great Prize”. Undoubtedly, the achievements of the Aldermaston weaponeers, culminating in *Grapple,* played an essential part in aiding Macmillan to achieve his goal.

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1 Introduction

At the end of the Second World War, the USA was the *de facto* sole possessor of the technology of the atomic bomb. Great Britain had made an invaluable contribution to the science of the bomb and had supplied a group of key workers, known as the British Mission, to work at Los Alamos, where the Manhattan Project successfully produced the two atomic bombs that destroyed Hiroshima and Nagasaki. At the end of the war, Britain was economically exhausted. However, it maintained what it considered to be its rightful membership of the Big Three powers and expected to maintain its atomic partnership with America.

It was not to be. After some abortive attempts to internationalise control of atomic energy, Congress passed the Atomic Energy Act in 1946. Popularly known as the McMahon Act, this made it illegal for the USA to share atomic information with other countries. Britain decided to go it alone, though the formal decision to make a bomb was not made until January 1947. However, the Atomic Energy Research Establishment (AERE) at Harwell was inaugurated in January 1946 and soon work began on reactors designed to produce plutonium. Following the 1947 decision, work on the bomb started at ARD Fort Halstead and was later transferred to Aldermaston, which became the Atomic Weapons Research Establishment (AWRE, later AWE). An atomic bomb was successfully exploded at Monte Bello off the north coast of Australia in 1952. Churchill, by then Prime Minister, hoped to use this success to re-establish the close working relationship with America that he had known during the war. However, just four weeks after *Hurricane*, as the test was named, America exploded a thermonuclear device. *Ivy Mike* was not a useable weapon, since it depended on a refrigeration plant to maintain its charge of liquid deuterium, but the yield of 10 megatons demonstrated that a new era of atomic weapons had been reached. The following year, the Soviet Union exploded *Joe 4*. Although at 400 kilotons it had a smaller yield than *Ivy Mike,* it was a ‘dry’ bomb using solid thermonuclear fuel and showed that the Russians were well on the way to a practical weapon.[1]

[1] The history of Britain’s development of the atomic bomb is covered in M. Gowing, *Independence and Deterrence: Britain and Atomic Energy 1945-1952. Vol 1 Policy Making*, and *Vol 2 Policy Execution* (London: Macmillan, 1974).

Britain found itself out of the race again, with no prospect of sharing in American developments. In February 1953, Lord Cherwell reported to Churchill that 'we think we know how to make an H-bomb'.[2] This was indeed optimistic, but it raised the question of whether Britain should commit itself to the inevitably expensive research and development program to develop a hydrogen bomb, with the subsequent cost and strategic implications.

A development and procurement programme for a major weapons system involves the weaponeers, the military and the political authority. After the first US thermonuclear test there was little immediate demand in the UK to follow suit. It was, after all, only weeks after Britain's *Operation Hurricane* and the UK had the task of producing a stockpile of operational atomic bombs. The initiative to force a decision on the H-bomb came from Sir Norman Brook; he was Cabinet Secretary and chaired the Home Defence Committee. Brook realised that the H-bomb made existing defence planning obsolete and he inaugurated a series of meetings with the Chiefs of Staff (COS), Sir William Penney and others. The outcome of these meetings was a considered report by the Working Party on the Operational Use of Atomic Weapons (OAW) entitled 'Hydrogen bomb research and production in the United Kingdom'.[3] The COS report was submitted to the Defence Policy Committee in June 1954, who recommended that a programme be initiated to develop a hydrogen bomb. The Prime Minister, Sir Winston Churchill, concurred and formal Cabinet approval was given on 27 July. They authorised the Lord President 'to proceed with his plans for the production of thermonuclear bombs in this country'.

Aldermaston set to work under the joint leadership of Penney and his deputy-director William Cook. New devices, employing both fission bombs and thermonuclear fusion were developed and three explosions 'in the megaton range' were fired during the summer of 1957 in the *Grapple* test series at Christmas Island in the Pacific Ocean. The following year Macmillan achieved the 'Great Prize' of nuclear co-operation with America. While the production of Britain's first atomic bomb employed the

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[2] L. Arnold, *Britain and the H-Bomb* (Basingstoke: Palgrave, 2001), p.37.
[3] TNA: DEFE 32/4 COS Committee Annex to COS(54) 66th meeting. 2 June 1954.

experience that the British Mission acquired during their work at Los Alamos, the development of the British hydrogen bomb was truly independent. This period of remarkable progress, both technical and political, is the subject of this dissertation.

Nearly 50 years later, it is still difficult to obtain authoritative information about the devices exploded at Christmas Island. As Clive Ponting observed: ‘Nowhere has the national obsession with secrecy been more evident and persistent than in the case of Britain's nuclear programme’.[4] Official pronouncements at the time referred simply to explosions ‘in the megaton range’ and allowed commentators to assume that the devices were H-bombs. There has been much speculation over the years as to the precise nature of the devices. The device with the highest yield, known as *Orange Herald* has variously been referred to as an H-bomb, a large fission bomb and a special type of boosted fission bomb known as a ‘layer cake’.

In 1992, Eric Grove tackled the apparent official obfuscation head on with an article entitled ‘Britain’s Thermonuclear Bluff’.[5] He argued that none of the devices tested at *Grapple* was a “true” thermonuclear bomb.[6] He surmised that the first and third, named *Short Granite* and *Purple Granite,* were layer cake boosted fission devices and that *Orange Herald* was a large fission bomb, as was *Grapple X*, tested in November 1957. According to Grove, it was not until *Grapple Y*, tested in April 1958, that Britain achieved a radiation implosion H-bomb. He considered that the *Grapple* test series was primarily political in intent, designed to reinforce Britain’s weakening position as a world power and to demonstrate to the Americans that Britain was a competent nuclear ally, ready to be admitted to full membership of a nuclear partnership. To emphasise the public relations aspect of the tests, Grove discusses the newspaper reports. Journalists were permitted to witness only the *Orange Herald* test, which was detonated on Friday morning, local time; this was Friday evening in

[4] C. Ponting, *Secrecy in Britain* (Oxford: Blackwell, 1990), cited in A.S.Burrows, R. Fieldhouse and R.S.Norris, *Nuclear Weapons Databook: British, French and Chinese Nuclear Weapons v. 5* (Boulder: Westview Press Inc, 1994), p.53.
[5] N. Dombey and E. Grove, ‘Britain's Thermonuclear Bluff’, *London Review of Books* (22 Oct 1992).
[6] The concept of a “true” hydrogen bomb appears frequently in nuclear history. While it has no strict definition, the term implies a thermonuclear weapon that employs radiation implosion to compress a fusion secondary. The bulk of the yield comes from thermonuclear fusion and does not rely on fission in U-238 to provide the yield. The use of a U-238 tamper is not excluded.

London. Eyewitness reports appeared in the Saturday morning London newspapers; as Grove points out, there was insufficient time for the reports to be written and to reach London in time for the morning editions. Grove's conclusion is that the 'apparent success' of *Grapple* played its part in the negotiations that led to the bilateral defence agreement of 1958, which opened the way to the sharing of design information for thermonuclear weapons, which opened the way to the sharing of information on the design of thermonuclear weapons.

Since publication of 'Britain's Thermonuclear Bluff', Lorna Arnold has published the official history of Britain's H-bomb development.[7] It was written with access to classified documents. The book confirms Grove's speculation that *Orange Herald* was a large fission bomb, but refutes his description of the other devices as layer cakes. However, Arnold does reveal that Britain had developed a layer cake bomb, which was termed a 'tamper boosted' weapon at AWRE. This became *Green Bamboo*, which was built but never tested. She doubts that the Americans were bluffed into amending the McMahon Act by *Grapple* and this is surely true, if 'bluff' implies outright deceit. However, Britain's development of megaton weapons undoubtedly played a part in the achievement of Macmillan's 'Great Prize' of nuclear co-operation with the USA. The preliminary discussions involved careful diplomacy, requiring the British delegation to demonstrate that they had information to contribute to their American counterparts, without revealing their hand in advance.

The core of this dissertation covers the period 1952 to 1958, from the first American thermonuclear test, through Britain's development of megaton weapons, to the amendment of the McMahon Act and the subsequent US-UK Mutual Defence Agreement. Britain's defence policy was strongly influenced by economic considerations, as well as by military planning and the strong political desire to maintain a strong international profile. The acquisition of megaton weapons and their associated delivery systems enabled new strategic policies to be developed, which were articulated in the 1957 Defence White Paper. Sufficient descriptions of earlier developments, technical, military and political, are given to show the background to the thermonuclear decisions. The *Grapple* series is examined from both technical and

[7] L. Arnold, *Britain and the H-Bomb.*

political points of view; there is an attempt to cover technical aspects that are not dealt with in other primarily historical treatments. The nature of the devices is examined, together with their relation to subsequent weapons that reached service in Britain's deterrent force. Special emphasis has been given to Britain's layer cake weapon, known as *Green Bamboo*. It was never tested, but for three years it formed the foundation of UK military planning for the thermonuclear era. The factors contributing to the rapid progress of negotiations leading to Mutual Defence Agreement of 1958 are analysed and it is shown that Britain's substantial progress in the thermonuclear field played an important part in the successful conclusion and subsequent nuclear co-operation. The often erroneous descriptions of Britain's megaton weapons that have appeared over the years are surveyed, since they contributed to the misunderstandings that led to the 'bluff' hypothesis. Recently released documents will be used to discuss in more detail the extent to which the word 'bluff' may be ascribed to the *Grapple* series.

2 British Nuclear Policy

The first atomic bombs were developed under control of the US Army in the Manhattan Project. Britain's contribution to the technology of the bomb was important, but small in comparison to that of America. The 'secret' of the atomic bomb consisted, not as a formula, but as a vast amount of technological experience and technical developments required to produce and handle the fissile materials, together with the intricacies of bomb design and construction. In 1945, Britain sought access to this knowledge, both for weaponry and the potential commercial exploitation of atomic energy. The Americans were, with some justification, suspicious of the British desire to be given full access to atomic information. This was partly reluctance to give away expensively obtained information and partly a feeling that American security would be compromised if atomic knowledge were spread abroad. During the immediate post-war period America parried British requests for information until the passing of the McMahon Act in August 1946, which put a stop to any possibility of information exchange.[8]

In 1945, Britain was one of the Big Three victors of the Second World War and head of a worldwide empire. There was a consensus among British politicians and military staff that Britain would require her own atomic capability to maintain her position as a world power. The Joint Technical Warfare Committee (JTWC) set up a scientific committee under the chairmanship of Sir Henry Tizard, which produced the Tizard Report of 3 July 1945. The report urged the Government to initiate research into atomic energy and concluded 'the only answer we can see to the atomic bomb is to be prepared to use it ourselves in retaliation. A knowledge that we were prepared, in the last resort, to do this might well deter an aggressive nation'.[9] The Chiefs of Staff expanded the Tizard report and produced the Report on Future Developments in Methods of Warfare, completed 1 July 1946. The report set out a clear vision of the future RAF deterrent force, based on high performance long-range bombers armed

[8] The progress of Anglo-American relations during the war is dealt with in more detail in Chapter 4.
[9] Cited in H. Wynn, *RAF Nuclear Deterrent Forces* (London: Stationery Office Books, 1994), p.2.

with atomic bombs.[10] Shortly afterwards, the Air Staff laid down the future shape of the RAF deterrent with Operational Requirements for both bomb and bomber.[11]

The Cabinet postponed any decision on atomic bomb development, but took some essential first steps. The Atomic Energy Research Establishment (AERE) was set up in January 1946 at Harwell and a government decision was made to proceed with the construction of nuclear reactors, which were designed to produce plutonium suitable for a Nagasaki type bomb. In October 1946 the GEN75 Cabinet Committee met to discuss authorising the expenditure of some £40 million for a gaseous diffusion plant for the production of U-235. Hugh Dalton and Stafford Cripps were opposed to expenditure on this scale, warning of 'an extremely serious economic and financial situation in two to three years' time'. The argument was settled by the much quoted outburst from the Foreign Secretary 'We've got to have this thing over here, whatever it costs [with] a bloody Union Jack flying on top of it'.[12]

The decision to build a bomb was formalised by a small cabinet group in January 1947.[13] The task of producing a bomb was given to William Penney, who was Chief Superintendent of Armament Research (CSAR) at the Armament Research Department (ARD), with headquarters at Fort Halstead; the establishment later became the Armament Research and Development Establishment (ARDE). A meeting in July 1948 attempted to partition manufacture of bomb components, particularly the plutonium core, among the existing atomic sites in Britain. None wished to do it and the responsibility was given to Penney. Fort Halstead was inadequate and a new site devoted to atomic weapons was needed. In February 1949 this was agreed and a few

[10] The complete report is given in Appendix 1, Wynn, *RAF Nuclear Deterrent Forces*.
[11] OR1001 described an air dropped fission weapon, with weight not exceeding 10,000lb, a diameter of 60in and all-up length of 11ft. OR229 specified 'a medium range bomber… capable of carrying one 10,000lb bomb to a target 1,500nm from a base which may be anywhere in the world'. Both requirements were successfully developed, as the *Blue Danube* bomb and the V-bomber aircraft. Both requirements were issued before the political decision to build an atomic bomb.
[12] TNA: CAB 130/2. GEN 75/15th meeting 25 October 1946 gives the formal minutes. Bevin's remarks are cited in A. Bullock, *Ernest Bevin, Foreign Secretary 1945-1951* (London: Heinemann, 1983), p.352.
[13] TNA: CAB 130/16. GEN 163/1st meeting 8 January 1947 'Confidential Annex Minute 1. Research in Atomic Weapons.

months later Aldermaston was selected as a suitable site, to open for business on 1 April 1950.[14]

The development of the British fission bomb will not be described here; the history has been fully documented by Margaret Gowing.[15] A target for a test explosion was set as 1952 and in 1950 the test site was chosen as the Monte Bello islands off the northwest coast of Australia; the entire programme was named *Operation Hurricane*. A single device was fired on 3 October 1952 and yielded an explosive power of 25 kilotons. The design was the prototype for the warhead of the RAF's first atomic bomb, the *Blue Danube*; the name refers to the entire weapon of warhead and casing.[16] Britain had produced an atomic bomb in a commendably short time, given the availability of industrial resources during the post-war period. The effort required should not be underestimated. Gowing estimates that the British bomb cost about half the equivalent parts of the Manhattan project. In 1953 some 15,000 people were directly employed in nuclear work.[17]

Within one month of *Hurricane*, the USA had exploded the world's first thermonuclear device with a yield 500 times greater than *Hurricane*. The American thermonuclear test was followed in 1953 by the Russian test of a fusion device. A decision was forced on Britain as to whether to stay in the race. The official history of the RAF Nuclear Deterrent Force quotes an American historian:

> The creation of the British nuclear deterrent force required almost 15 years of effort and the expenditure of £1000 million. It resulted from a conjunction of military, technological, political, economic and psychological currents in 1952 that persuaded the Churchill government, newly returned to power, to adopt the nuclear deterrent strategy and accept the consequences. The evolutionary span of 15 years falls into two periods of approximately equal length, with the year 1952 as the watershed between the two. During the first period – from 1945 to 1952 – the foundations of the nuclear deterrent force were laid and the basic decisions arrived at. The second period – from 1953 to 1960 – saw the production of nuclear and thermonuclear weapons and the V-bombers[18]

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[14] B. Cathcart, *Test of Greatness: Britain's Struggle for the Atom Bomb* (London: John Murray, 1994), p 91.

[15] M. Gowing, *Independence and Deterrence: Britain and Atomic Energy 1945-1952. Vol 1 Policy Making*, *Vol 2 Policy Execution* (London: Macmillan, 1974). The story is told in a very readable version by Cathcart, *Test of Greatness.*

[16] Wynn, *RAF Nuclear Deterrent Forces*, p. 87.It proved impossible to meet the strict requirement of OR1001 and the casing diameter was relaxed to 62 in, which fortunately could be accommodated in a V-bomber's bay.

[17] Gowing, *Independence and Deterrence* Vol II, pp 37 & 56.

[18] A. Goldberg, 'The Atomic Origins of the British Nuclear Deterrent', *International Affairs (Royal Institute of International Affairs 1944-)* 40 (1964), 409-429. Cited in Wynn, *RAF Nuclear Deterrent Forces*.

Goldberg's 'currents' all played their part in the development of Britain's thermonuclear weapons. Technical possibility itself may provide a driver for development. Lord Zuckerman, Chief Scientific Adviser to the British Government from 1964-71, stated this view directly, ascribing responsibility for weapon development to the men in white coats:

> Military chiefs…merely serve as the channel though which men in the laboratories transmit their views. …It is he, the technician, not the military commander in the field, who starts the process of formulating the so-called military need.[19]

Spinardi examined this thesis that technical push drove development of the H-bomb and came down against it. The Aldermaston weaponeers remained scientific civil servants, with no ambition to rule the world; there was no British Edward Teller.[20] The bulk of the work was administered by the civil service, whether, AWRE, AERE or the Ministry of Supply and, there was little direct involvement of big business in policy making. Private aerospace companies designed and built the V-bombers and much of the nuclear plant construction was sub-contracted to private contractors. The emergence of a powerful 'military - industrial complex' exercised Eisenhower at the close of his presidency:

> In the councils of government, we must guard against the acquisition of unwarranted influence, whether sought or unsought, by the military-industrial complex. The potential for the disastrous rise of misplaced power exists and will persist.'[21]

However, there is little discussion in the literature of the emergence of a British version of the complex nor is there evidence of a push for nuclear weapons driven by the prospect of industrial profit.[22]

Clark and Wheeler argue strongly for Britain's atomic programme as a rational response to the post-war world and reject the 'impressive consensus amongst historians…that the 1947 decision on the bomb was less a product of strategic reasoning than of a set of implicit assumptions: the need for a British bomb was taken to be self-evident'.[23] In a paraphrase of Aneurin Bevan, they add

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[19] S. Zuckerman, 'Science Advisers and Scientific Advisers', *Proceedings of the American Philosophical Society* 124 (1980),pp.241-255.
[20] G. Spinardi, 'Aldermaston and British Nuclear Weapons Development: Testing the 'Zuckerman Thesis'' *Social Studies of Science* 27(1997), pp.547-582.
[21] D. Eisenhower, Farewell Address to the Nation 17 January 1961. Available: http://en.wikipedia.org/wiki/Military-industrial_complex
[22] An exception is D. Edgerton, *Warfare State: Britain, 1920-1970* (Cambridge: CUP, 2005).
[23] I. Clark and N.J. Wheeler, *The British Origins of Nuclear Strategy* (Oxford: Clarendon Press, 1989), p.43.

> The idea of a once Great Power scuttling to hide its imperial nakedness with the fig leaf of an atomic bomb, whatever relevance it may have in the 1950s and beyond, is a wholly inadequate account of British perceptions in 1945.[24]

Until the shock of Sputnik in 1957, the American mainland was considered invulnerable to Soviet attack, while Britain was totally vulnerable. Eastern Europe was being absorbed behind the Iron Curtain, while Western Europe was weak and not yet able to defend itself. This situation supports Clark and Wheeler's contention that atomic development was a logical choice for Britain. America had withdrawn atomic co-operation, was invulnerable to Soviet attack and there was the strong possibility that it might revert to isolationist policies. For the US, nuclear weapons were a means of exerting influence on USSR, while for Britain they were a means of avoiding total defeat. The argument is supported by Freedman:

> In Britain – where because of the country's size and vulnerability to strike from Europe, the problem was seen as a defensive one from the start- an atomic stockpile was considered the only means of warding off aggressors. The United States Air Force, which was more interested in exploiting superiority than compensating for possible inferiority, tended to see the value of its bombers as a deterrent to all forms of aggression, atomic or otherwise.[25]

However, examination of the contemporary political and military archives lends strong support to the importance of Britain's self-perception as a world power in influencing the decision to become a nuclear power:

> …of more significance than the goal of British independence or the fear of Soviet capabilities was the need to retain a sufficient degree of international standing in order to influence the Americans to follow policies favourable to British interests and to take Britain more fully into account when it came to their strategic planning.[26]

Although the 1947 decision to embark on the nuclear course was made in secret, few people in Britain questioned the inevitability of the decision, which was 'based on an intuitive feeling that Britain must possess this climacteric weapon'.[27] Foreign Secretary Bevin made his famous demand for a bomb with a Union Jack on top of it to the Cabinet. In public, he could not divulge the development of an atomic bomb, but he continued the Great Power theme in the House of Commons. He did not agree:

> …that we have ceased to be a Great Power, or [with] the contention that we have ceased to play that role. We regard ourselves as one of the Powers most vital to the peace of the world and we still have our historic part to play.[28]

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[24] Clark and Wheeler, *The British Origins of Nuclear Strategy,* p.40.
[25] L. Freedman, *The Evolution of Nuclear Strategy* (London: Macmillan, 1989), p 41.
[26] M.S. Navias, *Nuclear Weapons and British Strategic Planning 1955-1958* (Oxford: Clarendon Press, 1991), p.21.
[27] L. Arnold, *A Very Special Relationship: British Atomic Weapon Trials in Australia* (London: HMSO, 1987), p.4.
[28] E. Bevin, *House of Commons* 437(1965), 16 May 1947.

Fear of relegation to the second division of nations was deep-seated, expressed by Lord Cherwell in the words 'if we have to rely entirely on the United States for this weapon, we shall sink to the rank of a second-class nation, only permitted to supply auxiliary troops, like the native levies who were allowed small arms but not artillery'.[29]. Sir Henry Tizard, chief scientific adviser to the Ministry of Defence, was more realistic. He observed in 1949 'we persist in regarding ourselves as a great power… we are *not* a great power and never will be again. We are a great nation but if we continue to behave like a great power we shall soon cease to be a great nation'.[30] However, Cherwell's views prevailed. Marshal of the Royal Air Force Sir John Slessor considered that a non-nuclear Great Britain could not even make the second division:

> If we were to leave to any ally…the monopoly of an instrument of such decisive importance...we should sooner or later sink to the level of a fourth-rate Power. In peace we should lose our great influence in Allied policy and planning; in war we should have little influence on the direction of Allied strategy.[31]

Britain successfully exploded her first atom bomb in *Operation Hurricane* in 1952, but within weeks America had exploded a thermonuclear device. While *Ivy Mike* was not a deliverable weapon, it signified that Britain was once again behind in the attempt to achieve great power status. With little idea of how to produce a hydrogen bomb, and with inadequate resources, Britain did not decide to embark on the thermonuclear road for another two years. Following the *Joe 4* Russian test in 1953 of a megaton weapon and information gleaned from sampling the airborne fallout, it became clearer to the British how a bomb might be developed. The hydrogen bomb promised to be relatively cheap to manufacture, as well as having enormous destructive power. This offered the chance of regaining parity with the two Super Powers. Julian Amery said in the House of Commons:

> The atom bomb rather put us out of the race because only big territorial expanses like the United States or the Soviet Union could stand up to atom bombing and hope to survive. We should have been obliterated very quickly. But the hydrogen bomb is a great leveller.[32]

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[29] Gowing, *Independence and Deterrence,* Vol 1, p.407.
[30]. Gowing, *Independence and Deterrence,* Vol 1, p.5.
[31] J.C. Slessor, *Strategy for the West*, (London: Cassell, 1954), p.104, cited in R. Gott, 'The Evolution of the Independent British Deterrent', *International Affairs (Royal Institute of International Affairs 1944-),* 39(1963), pp. 238-252.
[32] J. Amery, *Hansard*, 28 February 1956.

Time and again the major reason stated for going thermonuclear was to have influence in the world, and in particular on the United States. At a meeting of the Defence Policy Committee in 1954, Churchill said:

> that the difficulties of choice which lay before the Committee had been boldly put forward. The problem was to decide what practical steps could be taken to effect the saving of £200M per year, with the least risk of weakening our influence our influence in the world, or endangering our security. Influence depended on the possession of force….We must avoid any action which would weaken our power to influence United States policy.[33]

The Chiefs of Staff reinforced this view two weeks later '…we must maintain and strengthen our position as a world power so that HM Government can exercise a powerful influence in the counsels of the world'.[34] Edwin Plowden, recently appointed chair of the new UK Atomic Energy Authority, was asked to tell Churchill the cost and effort required to develop hydrogen bombs. Plowden later recalled, 'and when I'd explained what the effort necessary would be, he paused for a time...and said, "We must do it. It's the price we pay to sit at the top table"'.[35] Churchill expressed the same view in a modified form when proposing the development in Cabinet 'we could not expect to maintain our influence as a world power unless we possessed the most up to date nuclear weapons'. This view was reinforced by Lord Salisbury, who insisted that 'the Americans would feel more respect for our views' if the thermonuclear deterrent were not left as an exclusively United States responsibility.[36] Churchill anticipated Cabinet approval and started discussions with Canada for a supply of tritium. The Cabinet was indignant at this decision being taken without their knowledge. The matter was raised and the formal Cabinet approval given on 26 July. They authorised the Lord President 'to proceed with his plans for the production of thermonuclear bombs in this country'.[37] As recounted by Arnold, this was an exemplary piece of decision-making:

> It had been a fraught five months since the Sterling Cole speech and the *Bravo* shot in February. Norman Brook, at the centre of Whitehall, had initiated a quick and effective response and had guided the decision-making process with a firm hand. Penney and Cockcroft had given their scientific opinions, the Chiefs of Staff and their experts had supplied wide-ranging military advice, ministers had considered the questions and a momentous decision had been reached.[38]

[33] TNA: CAB 134/808. Defence Policy Committee, 19 May 1954. Cited in Hennessey, *The Secret State: Whitehall and the Cold War* (London: Penguin Books, 2003), p.54.
[34] Hennessey, *The Secret State*, p.55.
[35] Cited in Hennessy, *The Secret State,* p.52.
[36] TNA: CAB 128/27. W.S. Churchill, CC 48(54). 7 July 1954.
[37] TNA: CAB 128/27, CC (54) 26 July 1954. Cited in Hennessey, *The Secret State*, p.58.
[38] Arnold, *Britain and the H-Bomb*, p.56.

The two major decisions, by Attlee to develop the atomic bomb and by Churchill the H-bomb, showed the politicians to be in control. The 1954 H-bomb decision was made by Churchill following recommendations from the Defence Policy Committee and was subsequently confirmed by the Cabinet. However, neither decision was later questioned by Parliament. The view that political control of nuclear policy was maintained is reinforced by Simpson:

> Development programmes for British nuclear weapons have always been initiated by the high policy decision of political leaders…There is no overt evidence to suggest that nuclear decision have ever escaped from political control by the Prime Minister of the day and selected members of his cabinet…Any argument that those activities represent a case of sectorial policy or low politics is undermined by the initial higher-level political decisions and choices.[39]

An important question, not explored in detail in this dissertation, is the extent to which Britain had any realistic degree of independence in nuclear matters. American nuclear weapons were regarded as an integral part of the V-bomber force, yet a degree of independence was to be maintained, presumably with British-sourced weapons. In discussing the size of the British V-force, Stephenson, the ACAS (P), wrote to the Chief of the Air Staff:

> The size of the UK deterrent force should not be related to the size of the probable UK nuclear weapons stocks. American nuclear weapons will be available for every weapon carrier....We must be prepared to 'go it alone' in defence of purely British interests...Not only do we have to convince Russia that we have a worthwhile [independent] deterrent force: we also have to convince our allies.[40]

Stephenson wrote a few months later ‘The first purpose of Britain's independent nuclear deterrent is to increase British political influence with other countries and, in particular, with the United States’.[41]

The documents held in the archives cover military and political requirements for nuclear weapons. There is little, if any, indication of ethical or spiritual concerns. The implication is that those decisions were made in 1945 and need not be reconsidered. However, the 1950s saw the birth of the nuclear disarmament movement. Bertrand Russell was of sufficient standing for the Prime Minister to send him a personal letter, setting out the case for the nuclear deterrent. Eden had shown a draft to Selwyn Lloyd, then Minister of Defence. Lloyd’s comments are revealing:

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[39] J. Simpson, *The Independent Nuclear State: the United States, Britain and the Military Atom* (London: Macmillan, 1986), p.232.
[40] TNA: AIR 8/2400. J.N.T. Stephenson, ‘Arguments in support of minimum size of V-bomber force’. ACAS(P)/2805,24 May 1957.
[41] TNA: AIR 8/2400. CAS2583 dated 3 October 1958.

> the purely materialist argument which seems to suggest that the survival of the species is more important than any spiritual values and that an earthly paradise is the ultimate objective seems contrary to our whole Christian conception of the purpose for which we are put on earth.[42]

These sentiments became official policy in the 1955 Defence White paper, which included the statement

> Nevertheless, in the last resort, most of us must feel that physical devastation, even on the immense scale which must now be foreseen, is manifestly preferable to the national humiliation and the individual moral and spiritual degradation which would result from subservience or subjection to militant communism.[43]

This hints at deeper feelings, which may have been as important as the overt rationalisations in shaping defence policy.

From 1952 to 1957, British defence policy moved steadily in the direction of a reliance on nuclear deterrence. In 1952 the Chiefs of Staff were asked to review defence strategy ‘with due regard to the economic difficulties of the country’.[44] The result was the Global Strategy Paper regarded by Wheeler as ‘one of the most important documents of post-war British defence policy’.[45] This was written on the eve of Britain’s first atomic test and after the first Valiant test flights, and the COS were confident of the imminent availability of a British bomb. The central thrust of their argument was that by relying on a nuclear deterrent, Britain could reduce future defence expenditure.[46] The acceptance of a policy of deterrence was a necessary precursor to the decision to commence development of thermonuclear weapons in 1954.

In the mid 1950s, the defence budget was a great burden on the British economy. Following the failure of the Suez intervention. Macmillan replaced Eden as Prime Minister. On the day he took office, he demanded that the Minister of Defence, Anthony Head, agree to major defence cuts by that afternoon. Head failed to do so and was immediately replaced by Duncan Sandys. On 18 January 1957 Macmillan issued a directive to the COS and service ministers. This asserted the authority of the

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[42] TNA: DEFE 13/71, Selwyn Lloyd on disarmament, 12 July 1955.
[43] Cmnd 9391, *Statement on Defence: 1955 Defence White Paper*, (London: HMSO, 1955).
[44] TNA: CAB 131/12, D(52) 45, 31 Oct 1952.
[45] N.J. Wheeler, ‘British Nuclear Weapons and Anglo-American Relations 1945-1954’, *International Affairs* 62 (1985), pp. 71-86.
[46] W.J. Slim,, R.McGrigor and J.C. Slessor, *Defence Policy and Global Strategy*, (London: HMSO, 1952). A copy is held at TNA: AIR 20/11154.The Paper is fully discussed by Clark and Wheeler, *The British Origins of Nuclear Strategy*.

new Minster, who would be required to draw up a plan to reduce the armed forces to the extent necessary to achieve the needed economies. It was explained that the service ministers would now report to the Minster of Defence and not directly to Cabinet. Sandys set about his task, which resulted in the renowned 1957 Defence White Paper.[47] It is remembered for its emphasis on the British nuclear deterrent as the main strand of defence policy. At the time, it was the substantial reduction in manpower in the Army and Navy, coupled with the ending of National Service, that produced most disagreement. Neither the press nor the military strategists were happy. *The Times* commented:

> As the nuclear stalemate between east and west approaches, the balance of power is likely to shift back towards conventional forces. In general, therefore, there is not time to make large reductions in our conventional strength…[48]

The Vice-Chief of Naval Staff was forthright, stating that the new Minister of Defence did not have 'any strategical concept beyond the factor that in his opinion the atomic weapon was all important'.[49] The COS fought the White Paper to the end, culminating in last ditch attempts to distance themselves from any implication that they had agreed to meet Britain's defence commitments, as they saw them, with such reduced forces. Sandys countered by inserting a paragraph in the White Paper that asserted the indissolubility of prosperity and defence:

> Britain's influence in the world depends first and foremost on the health of her internal economy and the success of her export trade. Without these, military power cannot in the long run be supported. It is therefore in the true interests of defence that the claims of military expenditure should be considered in conjunction with the need to maintain the country's financial and economic strength.[50]

The White Paper is commonly viewed as strengthening Britain's nuclear deterrent forces. This is not so. There was no absolute increase in expenditure on nuclear weapons, only a relative rise when compared with conventional expenditure. Indeed, while emphasising the primacy of the nuclear deterrent, it proposed restricting funds for further development. This drew a protest from the Minister of Supply, Aubrey Jones, who again emphasised the primacy of prestige and influence:

> The reason for our continuing with the nuclear deterrent is to enable us to wield some diplomatic pull over the USA when events threaten a part of the world of particular interest to ourselves....is it not essential to our diplomatic influence to be able to threaten localised war

[47] Cmnd 124, *Defence: Outline of Future Policy* (London: HMSO, 1957).
[48] *The Times*, 11 Dec 1957.
[49] Cited in Navias, *Nuclear Weapons and British Strategic Planning*, p.140.
[50] Cmnd 124, 1957 Defence White Paper, para 6.

> through possession of up to date tactical weapons? Is our ability...nullified if we become reliant on the USA for the newest tactical weapons?[51]

The White Paper appeared to reject the idea of a totally independent deterrent and stated 'it is generally agreed that [Britain] should possess an appreciable element of nuclear deterrent power of her own'. At a Defence Committee meeting in February 1957, Macmillan hinted at the possibility of independent use: 'We should, however, have within our control sufficient weapons to provide a deterrent independent of the United States'.[52]

According to Navias, the 1957 White Paper marked a 'major discontinuity in British strategic planning – even though the pressures for such changes had long been existent'.[53] With the substantial cut in conventional forces and the ending of National Service, the effectiveness of Britain's nuclear deterrent force became paramount. Yet there was remarkably little discussion about the nuclear weapons themselves. At the time of drafting the White Paper, Britain was committed to its first thermonuclear tests in the summer of 1957. The success of the tests could not be guaranteed, and the practical problems of developing deliverable and reliable megaton weapons could only be guessed at. While the White Paper was being drafted, the Air Staff were perusing the quarterly report on progress in nuclear weapons. Only *Blue Danube* was completed, though noted as 'unreliable'. The planned warhead for *Blue Steel* had not been fired. It was considered that it might be replaced by the as yet untested and speculative thermonuclear *Green Granite*.[54] Sandys was implying considerable confidence in the Aldermaston weaponeers to produce the weapons that underpinned his entire defence strategy.

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[51] TNA: AIR 8/2157. Letter from Aubrey Jones to Duncan Sandys. 15 March 1957.
[52] TNA: CAB 131/18, D2 (57) 1, 27 Feb 1957, cited Navias, *Nuclear Weapons and British Strategic Planning,* p.142.
[53] R.S. Norris and H.M. Kristensen, 'Global nuclear stockpiles, 1945-2006', *Bulletin of the Atomic Scientists*, 62 (2006), pp.64-66.
[54] TNA: AIR 2/13733. DCAS Progress Report on New Weapons. Quarter ended 31 March 1957.Air Council AC(57)37.

3 Development of thermonuclear warheads

While the formal decision to develop a hydrogen bomb was taken in 1954, studies had started earlier at AWRE. That a hydrogen bomb was theoretically possible had been known for some years; Klaus Fuchs, employed at Harwell until his arrest in 1950, had attend the 1946 Los Alamos conference on the "Super" and had actually taken out a patent with von Neumann on the possibility of igniting a deuterium reaction by an implosion process.[55] Aldermaston inaugurated a New Weapons Committee, which met for the first time in October 1951. At first, the committee considered the benefits of very large fission weapons; Penney considered them more economical in terms of area destroyed per unit cost. However, the RAF expressed a wish for more rather than bigger bombs so that they could attack more targets.[56] At an OAW meeting in August 1953, Penney mentioned the possibility of a 'very large weapon' and the meeting confirmed Penney's calculation that large bombs were more economical when used against large cities, in term of use of fissile material. However, in associated correspondence, AVM Tuttle (ACAS OR) expresses some irritation with Penney for anticipating bombs that 'don't exist'.[57]

In April 1953, Churchill's adviser on atomic policy, Lord Cherwell, reported to the prime Minister optimistically 'We think we know how to make an H-bomb'. In November of that year, Cherwell followed up with an even more positive view:

> Discussions with Penney, Cockcroft and Hinton have shown that exchange of information with the United States on the production of fissile material and the design of bombs is no longer of great importance to us. Today we are convinced that we know practically as much as the Americans do.[58]

At the beginning of 1954, Penney's ideas were beginning to clarify. American and British scientists had collaborated over the analysis of debris from the 1952 *Ivy Mike* and 1953 *Joe 4* tests. He realised that they were two different types of bomb, which he later termed Type A and Type B. The Russian bomb was Type A. It was a hybrid, using a fission bomb to initiate a fusion reaction in lithium deuteride; this in turn produced fast fission in a natural uranium jacket; it had a maximum yield of 1 or 2

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[55] R.Rhodes, *Dark Sun* (New York: Simon and Schuster, 1996), p.255.
[56] Arnold, *Britain and the H-Bomb*, p.39.
[57] TNA: DEFE 32/3 'Operational use of Atomic Weapons'. Report by OAW. COS(53) 359, 5 June 1953.
[58] Arnold, *Britain and the H-Bomb,* p.39.

megatons. Penney referred to a 'true' hydrogen bomb as Type B. This is a two-stage weapon, using a fission primary to ignite a secondary stage of thermonuclear fuel.

In February 1954, the United States detonated the notorious *Castle Bravo* shot; the 15 megaton yield was unexpectedly high and produced extensive fallout. Penney was in Washington and gathered whatever information he could. In March he reported to a COS meeting that the USAF would deploy hybrid Type A bombs by the end of 1954. America was moving to the production of true hydrogen bombs, which would use liquid deuterium as thermonuclear fuel. The USAF had several plants on both the east and west coasts of the USA where bombers, already carrying an H-bomb, could pick up liquid hydrogen to arm the bomb. At the subsequent COS meting Sir Norman Brook queried the validity of this information. Penney replied the information was unofficial but he had little doubt of its accuracy. He added that there would be no Russian ICBM for 10-20 years. Penney was mistaken on all accounts.[59]

The Cabinet's H-bomb decision made a decisive difference, driving expansion at AWRE. Penney himself had hoped to return to an academic career but 'with a heavy heart' decided he should stay at Aldermaston. Just before the H-bomb decision he wrote 'The plain fact is that weapons work is unpopular and nobody wants to do it'. W R J Cook, then Chief of the Royal Naval Scientific Service, was persuaded to move to AWRE and arrived in September 1954. Cook's organisational ability complemented Penney's inspirational leadership qualities. They set about building up staff, in particular creating a strong nuclear physics division and together led the team, that succeeded in testing thermonuclear weapons in a remarkably short time scale.[60]

Although Penney had stated that the USA had developed a Type B bomb, and that it would be lighter and cheaper when developed, the military favoured the apparently more practical Type A. A COS meeting in April 1955 recommended high priority for Type A development, with only theoretical work on Type B.[61] The Type A device was to be developed under the name *Green Bamboo*. This device was completed in time for *Grapple*, but not tested. A large boosted fission bomb, the second device to be tested at *Grapple,* was named *Orange Herald*. Design elements of both *Orange*

[59] TNA: CAB 130/101. Meeting in Cabinet Office, 12 March 1954.
[60] Arnold, *Britain and the H-Bomb*, pp.76-79.
[61] TNA: DEFE 32/4. COS(55) 24th meeting, 6 April 1955.

Herald and *Green Bamboo* were subsequently incorporated in *Green Grass*, a pure fission device that formed the physics package of the *Violet Club* free-fall bomb delivered to the RAF. These three bombs had a similar yield, of about half a megaton, used a similar U-235 fission core and shared some components.

Green Bamboo was a layer cake device. The principle had been proposed by Edward Teller and Robert Richtmeyer during the summer of 1946. In Teller's words:

> Bob insisted on calling that design the Alarm Clock. Given its simple and feasible nature, it should wake people up to the idea that work on a thermonuclear explosive ought not to be delayed. Unfortunately, it did not rouse anyone.[62]

There was little enthusiasm for the design and Teller himself continued with his obsession with the multi-megaton Super. Interest in the Alarm Clock was revived in 1950 when it was realised that lithium deuteride could be used to make a practical weapon. However, by then the USA could make fission weapons with a yield of several hundred kilotons. The Alarm Clock could not produce a yield of much more than 1 megaton, at a cost of making the bomb larger and heavier, and work was discontinued.[63]

The Soviet scientists had received substantial information via Klaus Fuchs on the early American ideas about the Super. However, their invention of the layer-cake bomb in 1948 was independent of the American ideas.[64] The explosion of RDS-6s, known in the West as *Joe 4*, in August 1953 was a remarkable triumph for the Soviet Union, as it represented a practical weapon, unlike the enormous *Ivy Mike,* with its refrigeration plant.[65] However, when the American scientists had deduced the nature of *Joe 4* from fallout analysis, they were dismissive of a device that had produced a lower yield than the fission *Ivy King* and was incapable of further development: 'We never tried the Alarm Clock, because it was a dead end'.[66]

All this was unknown to the British. Two concepts had to be understood before Penney's Type A bomb could be realised. One was the use of lithium deuteride, both

[62] E. Teller and J.L. Shoolery, *Memoirs. A twentieth century journey in science and politics* (Oxford: Perseus Press, 2001), p.242.
[63] Rhodes, *Dark Sun*, p.418.
[64] G.A. Goncharov, 'American and Soviet H-bomb Development Programmes', *Physics-Uspekhi* 39(1996), pp.1033-1044.
[65] The US did weaponise the design to produce a practical 'wet' H-bomb, the EC-16. C.A. Hansen, 'A Hindenburg in the Bomb Bay: The Transition from Liquid to Solid Fueled Thermonuclear Weapons, 1951-1954'. Available: http://www.uscoldwar.com/hindenburg.htm
[66] Rhodes, *Dark Sun*, p.524.

to produce tritium under neutron bombardment and to provide a source of deuterium for the D-T reaction; the second was the possibility of producing fission in natural uranium with fast neutrons. Both developments were mentioned in an open 1955 paper by Joseph Rotblat, who, incidentally, was the only scientist to leave the Manhattan project on conscientious grounds.[67]

The early stages of development of AWRE thinking on thermonuclear reactions are hard to follow. Technical documents remain classified and in Lorna Arnold's words, 'for the historian it is a somewhat impenetrable period'. Keith Roberts, one of the major talents at Aldermaston, wrote his thoughts on single-stage bombs in October 1955. He envisaged two types of boosting: core boosting and tamper boosting. Core boosting would be achieved by placing a mixture of lithium deuteride and lithium tritide at the centre of the core. Tamper boosting he considered more suitable for larger weapons, using a layer of lithium deuteride between the fissile core and a thick tamper of natural uranium. The uranium would 'catch neutrons as they came out of the core, convert them into 14 MeV neutrons, and burn up the tamper'.[68]

There was a two-way interaction between the military and Aldermaston in the development of bombs and warheads. Defence requirements, delivery systems and nuclear 'physics packages' had to be anticipated ten years ahead to ensure that both budgets and technical developments would come together to provide an operational weapons system. During the necessarily lengthy development period, continuous interaction and feedback between the parties was essential to update specifications.

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[67] J. Rotblat, 'The Hydrogen-Uranium Bomb'. *Bulletin of the Atomic Scientists* 11 (1995), pp. 171-172, 177.

[68] Arnold, *Britain and the H-Bomb,* p.86. The tamper-boosted concept is the layer cake under another name. The efficiency of a simple implosion fission weapon of the *Fat Man* variety is low; only a small fraction of the core fissions before it is blown apart. A core-boosted fission weapon incorporates a small quantity of thermonuclear material, typically a D-T mixture, in the centre of the core. The implosion is sufficient to ignite a thermonuclear reaction, which produces a large quantity of neutrons. These greatly increase the amount of core material undergoing fission. The result is a larger yield, or the use of less fissile material for the same yield; the direct contribution of the thermonuclear reaction to the yield is small. In contrast, the yield of a layer cake device is shared between the fission core, the thermonuclear layer and the outer uranium shell. Estimates given by Khariton give the total yield of the Soviet Joe-4 layer cake as 400 kilotons. A 40 kiloton fission core was employed, so that the thermonuclear contribution can be said to be 90%. Of this, about 20% was due directly to the thermonuclear reaction, the remainder being contributed by the increased fission in both core and tamper caused by large neutron flux. Y. Khariton and Y.N. Smirnov, 'The Khariton Version', *Bulletin of the Atomic Scientists* 49 (4) (1993), pp.20-31.

During the period of interest, the Air Staff, through its Operational Requirements Committee, set out requirements for new weapons. Each requirement had an extended life, passing though several drafts and versions before being finalised. A list of relevant ORs is shown in Table 1. An OR was a performance specification, not a design. Over the life of an OR, the device expected to meet it might be modified radically or changed for a different one.

In December 1955, the state of progress was summarised by Cook in a letter to the Director General of Atomic Weapons in the Ministry of Supply. By that time, there was an expectation of producing an experimental two-stage thermonuclear device *(Green Granite)*. The layer cake device, which Cook termed ‘a megaton boosted fission assembly’, i.e. *Green Bamboo*, was intended for free falling bombs and the powered guided bomb, i.e. what were to become *Yellow Sun* and *Blue Steel*. He went on ‘the essential basis of the long-range ballistic missile programme … is the development of a small lightweight megaton warhead [*Orange Herald (Small*]. In all the above experiments there is a risk of failure. Since our initial aim is the successful demonstration of our ability to achieve a megaton explosion, we must have an assembly based on the most certain method we know [*Orange Herald (Large)*].[69]

Both the Type A layer cake bomb and the projected Type B depended on Li-6 deuteride as the thermonuclear fuel. Natural lithium consists of two isotopes with atomic weights of 6 and 7, with the lighter isotope constituting about 8% of natural lithium. Li-6 is required for thermonuclear reactions and must be separated. Little was known at the time about working with lithium and methods had to be developed in Britain to separate the isotopes and gain experience with production and fabrication of the hydride. An enrichment plant to produce the Li-6 isotope was commissioned at Capenhurst in the mid-1950s; fabrication of the solid deuteride was carried out at Aldermaston.[70] The production of a thin LiD shell to surround the uranium core of *Green Bamboo* must have been a most difficult operation. Before proceeding with the

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[69] Cited by Arnold, *Britain and the H-Bomb*, p.88.

[70] UKAEA Fourth Annual Report (1957-58), p.10, cited by Simpson, *The Independent Nuclear State*, p.105. Little information has been released. TNA: AB 6/1084 ‘Separation of lithium isotopes: Project Crystal’ (1955) would appear to be a major source. It was due to be released in Jan 2006, but has been retained. Lithium hydride, and the similar lithium deuteride, is a crystalline solid. It reacts violently with water. It can be fabricated into solid shapes by pressing and subsequent machining; all operations must be carried out in a dry (RH<2%) atmosphere.

full scale Type A bomb, it was necessary to confirm the predicted behaviour of lithium deuteride when subjected to the compression of a fission explosion. This could not be done in the laboratory and required a full-scale atomic test: 'one way or the other experience in the use of lithium deuteride must be obtained in 1956, since upon this experience depends in very great manner the detail of the 1957 trials'.[71] Britain had started in 1955 to construct a permanent test site at Maralinga in South Eastern Australia. However, this would not be ready in time to conduct a test and the decision was made to return to the Monte Bello islands, the site of the original *Hurricane* test. The British government had categorically stated that no thermonuclear tests would be carried out on the Australian mainland. In asking for permission to conduct the *Mosaic* tests, Prime Minister Eden had to explain the inclusion of light elements:

> Our people here…suggested that your agreement be sought to a programme of two firings in the Monte Bello islands in April 1956. The experiments would consist of atomic explosions with the inclusion of light elements as a boost. It would of course be made clear in any public pronouncement that the explosions were atomic and not thermonuclear…The smaller of the two shots would be fired first and if this was completely successful the second and slightly larger shot would not then be fired. Neither would give a yield more than 2½ times greater than the *Hurricane* operation.[72]

Menzies promised full co-operation, but noted that the expected yield was much greater than *Hurricane* and the two *Totem* tests at Emu Field. He asked that 'the most meticulous care' be exercised and requested further information. He was reassured in August 1955 that the fission weapons would be used as vehicles for 'certain diagnostic and experimental tests'. The explanation went on:

> The smaller yield weapon is a fission weapon which in order to get scientific data contains small quantities of the light elements used in thermonuclear bombs. The light elements are expected to react but the quantities are so small that the effect on the yield is small. The larger yield weapon is a fission weapon containing somewhat larger quantities of the light elements, but containing no uranium with which the light elements can react.[73]

Preparations went ahead and the first test, *Mosaic G1* was fired on a tower on 16 May 1956. It was a successful test, in that good quality measurements were obtained. However, the effects of the small quantity of lithium hydride had been slight and the second shot would be necessary. The original intention had been to use a lead tamper surrounding the G2 device, to ensure that there was no risk of neutron induced fast

[71] TNA: DEFE 7/915. CAW to Defence Research Policty Committee, 6 Dec 1955. Cited in L. Arnold and M. Smith, *British Atomic Weapons Trials in Australia* (London: Palgrave, 2006).
[72] Cable Eden to Menzies, 16 May 1956. Cited by L. Arnold, *A Very Special Relationship, p.110.*
[73] Arnold, *A Very Special Relationship,* p.115.

fission in a uranium tamper; the British had given an assurance to Australia that no test yields would exceed 80 kilotons. The result of G1 convinced the Aldermaston staff that there was no risk, and natural uranium tamper was fitted to the G2 device, in spite of the assurance given by Eden. G2 was detonated successfully on 19th June. The yield was officially released as 60 kiloton, just under the anticipated 2½ times the 25 kiloton yield of *Hurricane*. In 1985 documents were released in response to the Australian Royal Commission that quoted the yield at 98 kilotons and this is the figure normally quoted by writers critical of nuclear testing.[74] There seems little reason to doubt the 60 kiloton figure.[75] Arnold quotes Penney as saying that *Mosaic* had confirmed that 'we have not made a dreadful mistake' in the understanding of LiD reactions and that the trials were crucial to the plans for next year's *Grapple* tests.[76]

The clearest, and most authoritative, statement on the nature of the *Mosaic* devices and their relation to the layer cake is to be found in a document from the AWRE archives, dated September 1958. It is reproduced by Arnold, who states it was most likely prepared for submission to the American representatives at the UK-US Sandia meeting that month.[77] The following paragraph is reproduced in its entirety:

> Meanwhile two possible routes to a megaton airburst weapon were being followed. The first of these was merely a large fission weapon with a very thin HE layer. The control of scabbing in this weapon took up a large part of our effort, but otherwise did not contribute to our thermonuclear work.[78] The second route was the scheme of using a Li-6D layer just outside the U-235 of a big fissile bomb. The first deliveries of Li-6D were made early in 1956 and it was planned to do two tests on kiloton weapons to check the boosting of this material in such a position. As it happened, by the end of 1955 AWRE opinion had already come to the conclusion that no really worthwhile boost could be obtained in this way. This was verified by the first test [*Mosaic G1*] and, in view of the importance of the conclusion, a second test was fired [*Mosaic G2*] giving an even higher temperature and compression in the Li-6D layer, but again without producing more than a few percent change in the yield. Thus it became clear by

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[74] S. Connor, 'The Nuclear Blast that Britain Kept Secret', *New Scientist* (24 May 1984), S Connor and A. Thomas, 'Minister Withheld Data on A-Tests', *New Scientist* (18 April 1985).

[75]. TNA: DEFE 16/234. R. Pilgrim, 'Mosaic Yield', 1957. Much of the discrepancy arises from the inherent uncertainties of yield measurement. The higher figure was obtained by pressure wave measurements, which were made less accurate by a 'precursor wave', which distorted the wave front. The lower figure was based on the 'far better method' of radiochemical analysis. Arnold's summary of the lessons learned from *Mosaic* include 'a salutary re-examination of basic questions about yield – its meaning and its measurement by a variety of methods (radiochemical analysis of debris, ultra high speed photography, and gamma flash and blast measurements)'

[76] Arnold, *A Very Special Relationship*, p.132.

[77] Arnold, *A Very Special Relationship,* Appendix 3.

[78] This weapon is clearly *Orange Herald*. This is supported by the titles of still classified documents, e.g. TNA: ES10/217 'Scabbing in Orange Herald'. Scabbing is the tendency for fragments of an inside surface to break off when the material is subjected to an explosion on the outer side.

> mid-1956 that we had really only two routes to the megaton airdrop weapon, these being a straightforward fission weapon in which we had confidence and the problematical double bomb [*Granite*], which we doubted if we would have sufficient time to develop before nuclear tests were stopped by international agreement.

Thus the Mosaic tests took place after AWRE had concluded that LiD boosting was unlikely to be viable. However, with the growing likelihood of a ban on nuclear testing it was considered essential to confirm the calculations. Arnold considers *Mosaic* as an example of ‘negative testing’, i.e. to confirm that the boosting would not work.[79] However, even if AWRE had lost confidence in the principle of the layer cake by the end of 1955, it did not stop development of *Green Bamboo*, nor diminish the expectations of the military. It had been expected to fulfil several roles: OR1136, the warhead for the freefall *Yellow Sun*, OR1141, the warhead for *Blue Steel* and OR1142, the warhead for what was to become *Blue Streak*. The estimated weight of *Green Bamboo* was about 4500 lb. Design studies of the Medium Range Ballistic Missile (MRBM) showed that a warhead weight of no more than 2000 lb was very desirable; the use of *Green Bamboo* would require two rocket motors instead of one.[80] AWRE submitted that it would be possible to build a lighter warhead using an unboosted fission bomb with a high fissile content. This warhead was given the code name *Orange Herald* in August 1955. At this stage it was a private AWRE project. Steps were taken to amend OR1142 so that it would refer to the fission bomb rather than the layer cake. The amendment was accepted in November 1955.

In August 1956 a query was raised by Reginald Maudling, Minister of Supply, about the necessity and associated cost of simultaneously developing two different megaton warheads. In his reply, the DGAW Jackson explained the difference between the two. The reduced weight of *Orange Herald* was achieved by increasing the amount of fissile material, at a cost of £750,000 per bomb. He went on to say that the amount of fissile material in *Green Bamboo* had been increased as a result of the *Mosaic* trials.[81] The reply must have been convincing and in 1956 the Ministry of Supply placed an order for *Orange Herald* at £3.2M and *Green Bamboo* at £1.9M. At this stage, the

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[79] Arnold, *British Atomic Weapons Trials in Australia*.

[80] TNA: AVIA 65/1193. W.H. Stephens, ‘Notes on the performance of a MRBM with various warhead weights’, RAE Tech Note GW375. July 1955.

[81] This information is taken from several documents incorporated in TNA: AVIA 65/1193, ‘OR1142 Warhead for a medium range ballistic missile’ 1955.

Granite double bomb was classed as a research project, paid for out of the AWRE budget.[82]

While AWRE was now committed to building *Green Bamboo*, there are signs that the doubts expressed by Corner as to its viability were beginning to spread. AWRE was gaining confidence in the *Granite* double bomb. In January 1957 the DDAArm N Coles says it is hoped that *Green Granite (Small*) may be used in place of *Green Bamboo*. The hope has moved up to an expectation by March. The March 1957 CAS Report on New Weapons expected *Green Bamboo* to be replaced by the 'more economical' *Green Granite*.[83]

This is indeed what happened. During the preparations for *Grapple* in the first part of 1957, Arnold reports that *Green Bamboo* suffered from 'persistent assembly difficulties' and it was decided that, though it would be sent to Christmas Island, it would not be fired if the first *Granite* shot gave a satisfactory result. However, a letter dated 25 May shows that, following the first *Grapple test,* Penny and Brundrett decided to cancel the *Green Bamboo* test and the device was retained at AWRE.[84] From being Britain's megaton warhead of choice, expected to arm *Yellow Sun, Blue Steel* and *Blue Streak*, *Green Bamboo* never left the workshop.

Orange Herald was a boosted uranium fission warhead, which produced the highest yield of the first *Grapple* series of tests. *Orange Herald* resulted from the interaction between military requirement for a missile warhead and the political requirement to demonstrate an explosion in the megaton range during the Christmas Island test series. In the early 1950s it was seen that developments in missile technology would make manned bombers vulnerable to defensive guided missiles. However, missile technology also offered the opportunity of developing long-range offensive missiles. The improvement in Anglo-American relations in 1954 led to the agreement in August between Secretary of Defense Charles Wilson and Duncan Sandys. The Wilson-Sandys agreement agreed that the USA would develop Intercontinental Ballistic Missiles (ICBM) while the United Kingdom would develop a Medium

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[82] TNA: AB 16/1888. 'Grapple 1 and Green Bamboo weapons tests; finance', 1956.
[83] TNA: AIR 2/13733. 'DCAS Progress Report on New Weapons. Quarter ended 31 March 1957'. Air Council AC(57)37.
[84] TNA: AVIA 65/1211. DGAW Jackson to PS/PM, 25 May 57. 'Operation Grapple: Correspondence'.

Range Ballistic Missile (MRBM) with a range of about 4000 km; America would provide technology transfer to Britain.[85] The American ICBM was to become the *Atlas* missile. In July 1955 the Air Staff issued OR1139, the requirement for a MRBM.[86] This was immediately followed by OR 1142, Warhead for a Medium Range Ballistic Missile.[87] The expectation was that the OR would be filled by the Type A (layer cake) warhead currently under development to meet OR 1141 (warhead for the powered guided bomb OR1132).[88] This device became known as *Green Bamboo*. The MRBM was then at a preliminary stage of design. A Royal Aircraft Establishment (RAE) design study of July 1955 showed that the range of the missile was critically dependent on warhead weight. Although *Green Bamboo* existed only on paper, it was clear that its total weight would be over 4000 lb; with this payload the MRBM would require twin rocket motors if the missile was to achieve the required range.[89] Penney suggested that it would be possible to maintain the required yield and reduce the weight to 1800lb with an 'unboosted fission' warhead by using double the amount of fissile material. The code name *Orange Herald* was assigned to this proposal in August 1955.[90] At this stage, *Orange Herald* was still an AWRE venture. OR1142 was formally rewritten in November 1955 to incorporate *Orange Herald*. At this time, the wording was revised from 'thermonuclear' to 'megaton'.

During 1955 and 1956 ideas, both military and nuclear, were in a state of rapid flux. The result is some inevitable inconsistencies in the record. About the time that Penney was proposing an unboosted fission warhead, Roberts at AWRE was drawing up proposals for both core boosted and tamper boosted single stage fission weapons. In December 1955, drawings of two core-boosted devices - *Orange Herald (Large) and Orange Herald (Small)* - had been drawn up. The small version had a target weight of 2000 lb and was designed to fulfil OR 1142. The large version had a larger HE

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[85] B. Cole, 'Soft Technology and Technology Transfer: Lessons from British Missile Development', *The Nonproliferation Review* (Fall, 1998), pp. 56-69.
[86] TNA: AIR 2/13211. 'Medium range ballistic missile OR 1139', 1954.
[87] TNA: AVIA 65/1193.. OR1142 Warhead for a medium range ballistic missile. Air Ministry: 1955'. This specified a thermonuclear warhead with a yield of 1 megaton and a weight of 1 ton. Other requirements were a failure probability of less than 1% and the ability to be made ready in less than 2 hours and to maintain readiness for at least 6 hours.
[88] TNA: AVIA 65/1193. Memo CA/3/5/9 from CA to CGWL dated 29 July 1955.
[89] TNA: AVIA 65/1193. W.H. Stephens, 'Notes on the performance of a MRBM with various warhead weights', RAE Tech note GW375,July 1955.
[90] TNA: AVIA 65/1193. Note GEN/1/17, 'Security' dated 23 August 1955.

supercharge; this increased the weight of the warhead, but increased confidence in achieving a successful explosion. Further, by increasing the compression of the fissile core it would increase the yield over *Orange Herald (Small)*. The priority given to achieving a large and successful explosion is demonstrated by a report from AWRE to the COS in December 1955:

> …the most certain way we know of producing a trial megaton explosion in 1957 and thus achieving our initial aim is to use a large pure fission assembly in a Mk1 case with enough fissile material to ensure a megaton yield. Such a device will be big, heavy and extravagant in fissile material and its military application could only be as a free-falling bomb…. The essential basis of the long-range ballistic missile programme…is the development of a small lightweight megaton warhead (*Orange Herald*). This will have to be a pure fission assembly. Because of the limitation in size it would not have the same chance of success at the first trial as the pure fission assembly in the Mk1 case….Since our initial aim is the successful demonstration of our ability to achieve a megaton explosion, we must have an assembly based on the most certain method we know…There will be no need to fire this [*Orange Herald (Large)*] assembly if *Green Bamboo* is fired successfully.[91]

This passage clearly demonstrates the political aspect of the *Grapple* trial. There was no intention to proceed with development of *Orange Herald (Large)* as a weapon; it was there to demonstrate a British megaton test if the other devices did not achieve the expected results. A few weeks later, in January 1956, Penney described the device as the 'special assembly'.[92] In the event, *Orange Herald (Small*) achieved a satisfactory yield of 700 kilotons and the (*Large*) was never fired.

Orange Herald (from now on the *Small* will be understood) was designed from the start as a core boosted device. In Roberts' original scheme, lithium deutero-tritide would be placed at the centre of the core. There would be sufficient compression as the core assembled to produce a thermonuclear reaction. The resultant fast neutron flux would increase the efficiency of the uranium fission by ensuring a higher burn up. The resultant increase in yield would be produced by the increased fraction of the core undergoing fission; the direct contribution of the thermonuclear reaction would be small. Arnold consistently refers to *Orange Herald* as a boosted fission weapon and there is no reason to doubt that this was the intention. However, in the COS papers it is usually referred to as 'pure fission'. Perhaps AWRE wished to avoid introducing a potentially confusing topic, or pure fission was considered sufficiently descriptive term for the basically non-technical discussions.

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[91] Cited in Arnold, *Britain and the H-Bomb,* p.89.
[92] Letter from Penney to Plowden, 17 January 1956. Cited in Arnold, *Britain and the H-Bomb,* p.133.

A large fission bomb necessarily employs uranium as the fissile material.[93] A mass of highly enriched uranium equivalent to several critical masses must be held in a safe configuration until assembled and compressed by the explosive lenses and supercharge. The core is in the form of a hollow sphere, which is collapsed by the surrounding explosive. It is necessary to initiate the chain reaction as the core reaches maximum density by providing a burst of neutrons. *Orange Herald* was the first British weapon to use an external neutron initiator (ENI).[94]

The large quantity of fissile material in the bomb raised difficult questions of safety. As an experimental device, it did not have to meet the rugged safety requirements appropriate to a service weapon. However, it had to be 'one point safe', i.e. detonation of just one of the 32 explosive lenses should be insufficient to cause a nuclear explosion. In addition, fire or impact, as might occur following a crash on take-off, should not cause detonation.[95] In January 1957, Cook wrote to Jackson 'The safety source being introduced for Grapple is 'internal' and will not give complete safety – it reduces yield of an accidental explosion'. This refers to the placement of a continuous neutron emitter.[96] In the event of an accidental approach to criticality, the continuous neutron flux would initiate early fission, which would disassemble the core before a major explosion could take place. The neutron emitter was removed as part of the arming sequence when airborne. However, as late as March 1957, safety of *Orange Herald* was described as a 'major difficulty'.[97] Arnold states that the design was revised 'because of concern about criticality in a resting state'; the context indicates

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[93] Plutonium has a low but appreciable rate of spontaneous fission, which would be sufficient to cause premature initiation of the chain reaction during the implosion assembly of a large core.

[94] This is an electronic device, mounted externally, which is triggered electronically to provide a burst of neutrons at the exact moment required. Earlier bombs used a device termed the 'urchin' at the centre of the core, which was activated by the collapsing core. The ENI provided much more precise timing and the additional advantage of leaving the centre of the core free for any boosting device.

[95] . The danger was real enough. During practice flights in the UK, a dummy *Blue Danube* had refused to release from the bomb rack of a *Valiant*. During return to base with the bomb doors closed, the bomb released itself from the rack into the bomb bay. After landing, the bomb doors were opened, whereupon the bomb fell to the ground. W.E. Oulton, *Christmas Island Cracker: an Account of the Planning and Execution of British Thermonuclear Bomb Tests 1957* (London: Thomas Harmsworth, 1987), p.136.

[96] http://nuclearweaponarchive.org/Nwfaq/Nfaq4-2.html

[97] TNA: AIR 2/13733. DCAS Progress Report on New Weapons. Quarter ended 31 March 1957.Air Council AC(57)37.

that this was about April, before the bomb was flown to Christmas Island at the end of May.

Orange Herald was fired successfully on the morning of 31 May 1957. The yield was estimated at about 700 kilotons; this was large enough to demonstrate that the UK now had a bomb 'in the megaton range'. If there was any contribution to the yield from the core boosting, it was very small. The designers at AWRE put the failure down to Taylor instability and decided to abandon this form of boosting.[98] The device is now recognised as holding the record for yield of a single stage device.[99]

The first *Grapple* test series consisted of the successful *Orange Herald* test and the two disappointing *Granite* double bombs. However, the *Granite* firings were sufficient to demonstrate that the principle of radiation implosion was understood in principle and that Britain was on track to produce a successful thermonuclear weapon. In the meantime, the RAF required a megaton weapon. Planning for the introduction of an interim weapon had started in 1956, when four possibilities were mooted: a *Granite* type weapon, *Green Bamboo*, and two derivatives of *Orange Herald*, varying in the amounts of uranium and explosive. The production of four interim weapons based on *Orange Herald* by August 1958 would use all the available supply of HEU, which, however, was 'lying idle in considerable quantities'. According to Wynn, there was no other use for it.[100]

After *Grapple*, the position was clearer. The design of the megaton bomb was under development as OR1136, named *Yellow Sun.* However, the bomb casing was still not finalised and the intended *Green Bamboo* warhead had by this time been abandoned. An interim weapon was devised with a fission warhead named *Green Grass*. It combined a uranium fission core similar in concept to that of *Orange Herald* with the larger 72 lens implosion system of *Green Bamboo*; the ineffective core boosting was

[98] Arnold, *Britain and the H-Bomb*, p.147. Taylor instability would result in asymmetric implosion and ineffective compression of the LiDT booster.
[99] In 1952, the US exploded the 500 kT *Ivy King*, also a pure fission uranium bomb. This employed 60kg of HEU and saw service with the USAF as the Mk 18 bomb. http://en.wikipedia.org/wiki/Ivy_King
[100] TNA: AIR 2/13680. H.V. Satterly, 'Notes on DGAW's suggestion for producing an interim Red Beard and an Interim Megaton bomb'.Cited in Wynn, *RAF Nuclear Deterrent Forces*, p.242.

abandoned. This physics package was then incorporated in a *Blue Danube* casing, to become the interim weapon *Violet Club*. Since the warhead no longer had to meet the limitations imposed by the MRBM, size and weight considerations were relaxed. The greater compression provided by the implosion system allowed the weight of the HEU fissile core to be reduced from 120 kg to 75 kg, and still give a yield 'in the megaton range'. The Air Staff settled on a 0.5 megaton yield to economise on fissile material.[101]

The development of *Violet Club* as a practical weapon of war required the solution of difficult design problems to ensure reliability and safety. The hand-over of the *Blue Danube* bomb to the RAF had been plagued by reliability problems and it was only in July 1957 that it received its CA certificate, implying that it was then a usable weapon. The fissile core of *Blue Danube* was a compact sphere of plutonium, weighing about 8 kg and about 100 mm diameter.[102] In production models it was possible to arm the weapon in flight.[103] This safety procedure was not possible for *Green Grass,* since the fissile core was in the form of a hollow spherical shell; it was not possible to remove and replace it routinely during the arming process. The core consisted of several critical masses of HEU and there was a real risk of a criticality explosion if the weapon were subjected to physical shock or fire. The safety solution adopted was to fill the hollow centre of the core with steel ball bearings, which physically prevented any collapse of the core.[104] Unsurprisingly, the weapon was not popular with the RAF. A memo from AWRE to the Air Ministry admitted '*Violet*

[101] TNA: AIR 2/13733. Progress Report on the Development of New Weapons, 30 Sep 1957.

[102] *Blue Danube* was supplied to the RAF with a variety of yields and cores; both plutonium and plutonium/uranium composite cores were used. The *Blue Danube* drawings at TNA give a figure of 7.7 kg. See M. Smith, 'Why Britain had to make its own A-bomb' *Daily Telegraph,* 15 April 2002. A 1953 report mentions 4 to 6 kg. TNA: DEFE 32/3 'Operational use of Atomic Weapons'. Report by OAW. COS(53) June 1953.

[103] The core and a cylindrical section of the tamper and explosive layers were inserted in flight to arm the bomb. The removable section was termed the *Gauntlet.* The *Valiant* bomber incorporated a vertical space to incorporate the loading mechanism, termed the chimney.

[104] TNA: AVIA 65/1218. Violet Club: Correspondence. The balls were contained in a rubber bag, which fitted inside the core. Before take-off the balls were removed by draining them through a rubber hose into a bin, followed by removal of the bag; the 2" diameter hole was then closed with a plug containing a section of the explosive lens. Once the balls had been removed, there was a serious risk of a nuclear explosion if the aircraft crashed or the bomb was jettisoned. In the event of the bombing mission being aborted and the *Valiant* returning safely, the operation was reversed; the bomb was lowered from the bomb bay, rotated so that the drain hole was uppermost, the bag inserted and inflated, and the core refilled with ball bearings.

Club is basically an experimental weapon. It will have to prepared for use under guidance of AWRE personnel'.[105]

Few *Violet Clubs* were produced. The first was delivered to RAF Wittering in February 1958 and the second in August. A letter of April 1959 complains of late delivery and records three as having been delivered.[106] As the first *Yellow Suns* became available, the *Green Grass* warheads were transferred to the new casing, which was smaller and lighter than the *Blue Danube* casing. However, the same 'last minute safety' procedure was retained. The projected *Yellow Sun Mk1 Stage 2* bomb, which never materialised, allowed the steel balls to be drained in flight.

Thus by the end of 1958, the RAF had a nuclear armoury of *Blue Danubes* and a small number of *Violet Clubs*. The actual numbers remain classified. Norris states a total figure of 22 bombs, while Simpson produced a gross figure of 40, basing his estimate on production of fissile material.[107] All contemporary records indicate that the promised supply of weapons consequent on the1958 US-UK Mutual Defence Agreement was eagerly awaited.

From 1955 onwards, priority had been given at Aldermaston to development of the Type A layer cake bomb. However, Penney and the weaponeers were aware that the Type B 'true' hydrogen bomb offered the substantial advantages of lower weight, economy in the use of fissile material and the possibility of unlimited yields. There was enough knowledge of nuclear physics at that time to show that a reaction between deuterium and tritium should be the easiest fusion reaction to ignite; it was also the reaction with the greatest release of energy. Penny had picked up enough information in America to know that the *Castle* H-bomb had a primary and secondary stage and that lithium hydride (or deuteride) was involved. In September 1955, Penney called a meeting at AWRE where he outlined his thoughts on the Type B bomb. He envisaged

[105] TNA: AIR 2/13718. Violet Club Policy.
[106] TNA: AVIA 55/1166. G.W.P. Myers, 'Bomb delivery', 23 April 1959.
[107] The actual numbers remain classified. There is also an inevitable discrepancy between the total amount of fissile material available, the number of fabricated warheads and the number of bombs in service. Norris states a total figure of 22 bombs, while Simpson produced a gross figure of 40, basing his estimate on production of fissile material. R.S. Norris and H.M. Kristensen 'Global nuclear stockpiles 1945-2006', *Bulletin of the Atomic Scientists,* 62 (2006), pp. 64-66. Simpson, *The Independent Nuclear State*, p.92.

a three-stage bomb and christened the three stages Tom, Dick and Harry. The first stage would be a straightforward fission bomb; this would be used to compress and detonate a second fission bomb. By using the energy flux from Tom, very high compression could be achieved in the fission core of Dick, giving a more efficient explosion and higher yield than would be obtained by using high explosive. The energy of the first two stages would be used to ignite a fusion reaction in the third stage. Although this three-stage design was soon abandoned, the names Tom and Dick survived for the first two stages.[108] The development of ideas moved rapidly and at the end of 1955 Cook wrote to the DGAW in the Ministry of Supply:

> We have now come to the conclusion that there is a strong incentive to test at *Grapple* a variation of *Green Granite* sufficiently light to be capable of adaptation to …the powered guided bomb. …We can have such a weapon ready by 26 June 1957 for air transport to Christmas Island.[109]

In spite of the confident tone of this letter, Arnold's account makes clear that the principles of the fusion bomb, especially that of radiation compression of the secondary, were not yet settled. The first few months of 1956 saw investigations of several different designs. The conclusion was that a large fraction of the yield of a fusion bomb came from fast fission of the natural uranium in the secondary and that the thermonuclear fuel would be provided by solid lithium-6 deuteride:

> …by April 1956, an authoritative engineering drawing for G*reen Granite* was in existence. …The basic features of H-bomb design – Tom, the fission primary; Dick, the secondary with its solid thermonuclear fuel; radiation implosion; and the exploitation of the lithium-6/uranium cycle – all seem to have fallen into place by mid-April.[110]

While Penney led the initial theoretical work on H-bomb design, the challenging task of constructing a workable device in time for *Grapple* fell to W J R Cook. Cook arrived at Aldermaston in September 1954 as deputy director. He was 'a superb organiser, and a decisive project manager, with a powerful grasp of detail and an infallible eye for essentials'.[111] As the H-bomb project developed, Cook set about recruiting talented staff and transforming the organisation of Aldermaston. About the time that the design of *Green Granite* was settled in April 1956, Cook set up the Weapon Development Policy Committee (WDPC). It directed the entire range of

[108] The meeting was not recorded and this account was produced from information given to Lorna Arnold by Drs Corner, Pike and Allen. The idea of radiation implosion had not yet been incorporated. Arnold, *Britain and the H-Bomb*, p.85.
[109] Cited in Arnold, *Britain and the H-Bomb,* p.88. *Granite* implies a staged thermonuclear device; the origination of the name is unclear.
[110] Arnold, *Britain and the H-Bomb,* p.93.
[111] Arnold, *Britain and the H-Bomb,* p.78.

Aldermaston's weapon development; the general feeling at AWRE was that the H-bomb could not have been achieved without Cook's direction.

There is an obligation under the Non-Proliferation Treaty that the signatories should not release information that would assist the spread of nuclear weapons. Consequently, little information has been released about the design of the *Granite* series.[112] They were two-stage devices. The fission primary was based on the *Red Beard* warhead. This was a spherical fission device, with size and weight substantially less than the earlier *Blue Danube*.[113] The secondary, Dick, was also spherical and the two stages were contained in a common casing. The nature of the radiation implosion produces an isotropic pressure on the secondary, so that shape is not critical. A spherical shape was chosen to simplify calculations of the effects of the implosion on the multi-layer Dick. Subsequent bombs based on American designs would use a cylindrical secondary; this had the advantage of reducing the cross section of a weapon.

The design of *Green Granite* was discussed throughout the remainder of 1956. In September, the WDPC approved the construction of a close-coupled double bomb, to be named *Short Granite*. Tom and Dick were moved closer together, making the bomb shorter and lighter. The design of Dick involved no less than 14 concentric shells of 'various exotic materials'.[114] At least one shell consisted of Li-6 deuteride. The design was finalised in February 1957 and the bomb was ready for transport to Christmas Island in April.

In the meantime, the Task Force under command of Air Vice Marshal Oulton had prepared the test site at Christmas Island and had carried out practice drops with dummy bombs. All of the devices tested at *Grapple* were incorporated into *Blue Danube* casings and air dropped over the ocean; this reduced the amount of fall out.[115]

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[112] This treatment of the development of fusion weapons at Aldermaston is heavily dependent on Arnold, *Britain and the H-Bomb*, which is the source of information unless otherwise attributed.
[113] Using air or an inert material to replace the slower explosive component reduced the size and weight of the high explosive wave shaper.
[114] A speculative drawing is given in Appendix C.
[115] The planning, preparation and execution of the *Grapple* series was a substantial achievement, not covered in this dissertation. An entertaining, non-technical, personal account is given by Oulton, *Christmas Island Cracker.* The aviation side is covered in K.

Short Granite was dropped from a *Valiant* on 15th May 1957. The test went well and good recordings were obtained. However, it soon became clear that the yield was below expectation; it was to be estimated at 300 kilotons. Penney promptly wrote to Brundrett and, while expressing disappointment with the yield, emphasised that the principle of achieving a radiative explosion had been confirmed. The AWRE scientists realised that they had made 'one stupid mistake', which would have the effect of yield reduction. Since the close-coupled *Short Granite* had worked, there was no need to pursue the longer *Green Granite* and the shot was cancelled. A modified *Short Granite,* named *Purple Granite,* was quickly designed and produced. The secondary stage was modified by 'increasing the amount of U-235 and replacing the outer layer by aluminium'.[116] The device was produced remarkably rapidly and fired on 19th June. The modifications had not had the desired effect and the yield was a disappointing 200 kilotons. That evening, Cook confessed to Oulton 'We haven't got it quite right and we shall have to do it all again'.[117]

Arnold implies that, following the *Grapple* results, the double bomb concept was in danger of being cancelled 'After much discussion…it was agreed that this type of warhead should not be abandoned'.[118] Planning started for a further megaton test at Christmas Island, to be known as *Grapple X*. There was a great sense of urgency since there was an international movement towards a ban on atmospheric nuclear testing; the UK would not risk the ignominy of breaking a ban.[119] Cook and his team set about improving the design. The first requirement was an improved primary. This was to be a modified *Red Beard* fission warhead, with a composite core, beryllium tamper and improved yield of 45 kilotons. Improvements were also required for the secondary. Here, the decision had to be made between a cautious, step by step approach, requiring several test firings, but providing sound information, or whether to try and jump to the final design in one go, to anticipate the looming test ban. It was decided to build a simplified secondary (Round A) with just three layers, in contrast to the 14 layers of *Short Granite*. If this were successful, it would be followed by a five-layer Round B; if not, by a diagnostic Round C, which would check the yield of the U-235

Hubbard and M. Simmons, *Operation Grapple: Testing Britain's First H-Bomb* (London: Guild Publishing, 1985).

[116] Arnold, *Britain and the H-Bomb,* p.146. The original composition of the layer is not stated.

[117] Oulton, *Christmas Island Cracker,* p.356.

[118] Arnold, *Britain and the H-Bomb*, p.148.

[119] Arnold, *Britain and the H-Bomb*, Chapter 9.

core of Dick. In short time, Round A of *Grapple X* was readied for firing at Christmas Island by 5th November and fired successfully on 8th November. It was a notable success, with a yield of 1.8 megatons, against a predicted figure of 1 megaton.[120] It was within safety limits, however, and produced no significant contamination. Given this success, there was no point in proceeding with Round C, which was cancelled. *Grapple X* was over.

However, it did not provide the practical weapon required to meet the one ton/one megaton requirement. Analysis of the American and Soviet H-bomb debris had shown that a high proportion of the yield came from fast fission of natural uranium The thinking at AWRE behind the three thermonuclear devices tested so far envisaged the U-238 component of the secondary as an integral part of the thermonuclear explosion; this is reinforced by the frequent references to 'the Li-6 uranium cycle'.[121] At one stage, it was considered making the secondary largely from a composite material consisting of an intimate mixture of U-235, U-238 and lithium deuteride.[122] However, a 'true' thermonuclear bomb does not require U-238 in the secondary. Eventually, a proposal due to Ken Allen was adopted. Superficially, the arrangement was similar to *Grapple X*, with a three layer Dick and a primary based on *Red Beard*. However, by increasing the yield of the primary the compression in the secondary was increased. The U-235 core of the secondary was made smaller and the thickness of the deuteride layer increased. It is not clear if thorium was used in place of natural uranium for the tamper; this was suggested to enable a more discriminatory analysis of the fission products. The proportion of the Li-6 isotope in the lithium deuteride was also reduced.[123]

It had been hoped to fire *Grapple Y* during February 1958. There were strong reasons for minimum delay. As well as the possibility of a test ban, negotiations had by now started between Eisenhower and Macmillan, which offered hope of Anglo-US co-

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[120] Arnold, *Britain and the H-Bomb* ,p.160, gives a graphic description of the progression of the nuclear explosion. This has been incorporated into the analysis in Appendix C.
[121] The implication here is that neutrons arising from fast fission of U-238 interact with Li-6 to produce more tritium; the result is a pseudo chain reaction.
[122] Arnold, *Britain and the H-Bomb,* p.166. Supported by the title of the still classified TNA: ES 2/43 'Preparation and properties of uranium: lithium deuteride shapes', 1955.
[123] Presumably this was done because of the difficulty of producing sufficient supplies of Li-6; there seems little advantage in using Li-7. See Appendix A.

operation in nuclear matters. The demonstration of a successful thermonuclear explosion would strengthen the hand of the British negotiators. However, building works at Christmas Island forced a delay. *Grapple Y* was fired on 28th April and delivered a yield of 3 megatons. This was the highest yield of any British device and was undoubtedly a “true” hydrogen bomb, where a substantial proportion of the yield came from thermonuclear fusion reactions. The Aldermaston weaponeers had independently succeeded in developing a thermonuclear device, as well as the large interim fission bomb. One further series, *Grapple Z*, was to take place at Christmas Island in September 1958, which would be the last British atmospheric test. In 1958, the success of *Grapple* was influential during the discussions with America that would lead to an exchange of nuclear secrets.

4 Anglo American Relations

The concept of the atomic bomb was first set out in Britain by Otto Frisch and Rudolf Peierls. In February 1940, Frisch had the insight to realise that an explosive chain reaction might be produced by fast-neutron fission in U-235[124]. He and Peierls rapidly calculated the critical mass, which they estimated to be 'a pound or two'.[125] An atomic bomb was possible. The British government set up an organisation to develop the bomb, under the code name Tube Alloys. As early as the summer of 1940, Churchill offered to exchange military information with America, including the potential atomic bomb. However, it was only after America entered the war that Roosevelt approved the necessary budget for development. In September 1942, General Leslie R Groves was appointed in charge of the Manhattan Engineering District. He proved an able leader; the story of the Manhattan Project is well known and has been told in a number of books, notably *The Making of the Atomic Bomb.*[126] He took charge immediately and within a week of his appointment, Groves brought up the subject of sharing information with the British. Groves and his colleagues decided to cease any information exchange; 'we felt no pangs of conscience when we decided that information on the Manhattan Project would not assist British military participation in the current war'.[127] James Chadwick, discoverer of the neutron, was responsible for technical cooperation with America. It was clear to him that Britain did not have the resources to produce an atomic bomb and he soon came to the conclusion that the best course was to assist the Americans by sending a team of British scientists to work in the USA, where they were known collectively as the British Mission.[128] Rhodes described the Mission as:

> Churchill's flying wedge. The bomb had been theirs to begin with as much as anybody's, but more immediate urgencies had demanded their attention and now they were couriers sent along to help build it and then bring it home. America was giving the bomb away to another state, proliferating.[129]

Rhodes' observation that America was 'giving the bomb away' is echoed by Edward Teller's ungracious comment. 'The British were firmly convinced, then and

[124] Technical aspects of nuclear weapons are covered in Appendix A.
[125] Cited by Rhodes, *The Making of the Atomic Bomb*, p.323.
[126] Rhodes, *The Making of the Atomic Bomb*.
[127] L.R. Groves, *Now it can be Told* (London: Andre Deutsch, 1963), p.129.
[128] D.C. Fakley, 'The British Mission', *Los Alamos Science* (1983), pp.186-189.
[129] Rhodes, *The Making of the Atomic Bomb,* p.523.

afterwards, that they had started the atomic bomb project with their Tube Alloys program'.[130] Groves' more measured view was that without the British, there would probably have been no bomb to drop on Hiroshima; he paid tribute to the influence of Churchill in maintaining American purpose.[131]

After the war, the British were anxious to establish a new understanding with the Americans that would enable them to profit from the shared wartime experience and use the knowledge as the foundation of a post-war British atomic energy industry. Given the grossly disparate effort expended by the two nations, the Americans were understandably reluctant to provide full and free exchange of commercial information. In September 1944, a conversation between Roosevelt and Churchill had produced the Hyde Park *aide-mémoire*. The two leaders agreed that full collaboration should continue between America and Britain in developing Tube Alloys for both military and commercial purposes after the war. However, the agreement proved of no account. When the British tried to revive collaboration in 1945, Roosevelt was dead and Churchill out of office. Not only that, the Americans professed no knowledge at all of the Hyde Park *aide-mémoire*; it turned out that it had been misfiled and was not discovered until years later.[132] Prime Minister Attlee visited the USA in November 1945, together with Sir John Anderson, who had been asked to continue as a government advisor on atomic energy. The meeting produced the Truman-Attlee-King Declaration of 15 November 1945. This said, in effect, that while free exchange of nuclear information would be desirable, it must be controlled and limited to peaceful purposes; to that end the three powers would restrict such exchanges until adequate controls were established by the United Nations. [133] This optimistic but vague document did not answer Britain's desire for agreement on scientific and technical information. Anderson and Groves together drew up the Groves-Anderson memorandum. This was a confidential document intended to form the basis for a future formal agreement on the sharing of information and material, above all

[130] E.Teller and J.L. Shoolery, *Memoirs. A twentieth century journey in science and politics* (Oxford: Perseus Press, 2001), p.184.
[131] Groves, *Now it can be Told*, p.408.
[132] Gowing, p.341; Groves, *Now it can be told,* p.402.
[133] Groves, *Now it can be told,* p.403. Full text of the declaration is available from the web site of the Nuclear Age Peace Foundation www.nuclearfiles.org/menu/key-issues/nuclear-energy/history/dec-truma-atlee-king_1945-11-15.htm

uranium. It recognised the desirability 'in principle' of future co-operation. In this, it contradicted the previous day's Declaration, which postponed co-operation until the United Nations had deliberated.[134] A short public statement to this effect, known as the Truman-Attlee-King Statement was issued on the 16 November 1945; this is distinct from the Declaration of the previous day.[135] The full text of the Statement read:

> We desire that there should be full and effective co-operation in the field of atomic energy between the United States, the United Kingdom and Canada
> We agree that the Combined Policy Committee and the Combined Development Trust should be continued in a suitable form.
> We request the Combined Policy Committee to consider and recommend to us appropriate arrangements for this purpose.

Things then ground to a halt. The promised co-operation did not materialise in spite of specific requests by Clement Attlee.[136] However, there was a more absolute bar to exchange of information on its way. The first draft of the McMahon Bill was introduced in December 1945. It proposed the setting up of a civilian Atomic Energy Commission (AEC) to oversee all atomic work. Very stringent clauses were incorporated that restricted dissemination of information. The final version said that as far as interchange of information with foreign countries was concerned, that until Congress declared by joint resolution that effective and enforceable international safeguards against the use of atomic energy for destructive purposes had been established, there must be no exchange of information with other nations with respect to the use of atomic energy. The penalties for transmitting such information could, in some circumstances, be life imprisonment or death. The bill ignored the letter and the spirit of previous agreements: the Quebec agreement of 1943, the Hyde Park Memorandum of 1944 and the Truman-Attlee-King understanding of 1945. These agreements had not been made public and Senator McMahon was apparently unaware of them. He told Churchill in 1952 'if we had seen this [Hyde Park] agreement there would have been no McMahon Act'.[137] This is supported by Edmonds:

> After 12 May 1947, when [Secretary of State] Acheson at last gave the Joint Congressional Committee, in secret, an oral summary of the Quebec and Hyde Park Agreements, the terms of

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[134] Full text in Gowing, *Independence and Deterrence,* Vol 1, p.85.
[135] Groves, *Now it can be told,* p.404. The discussions surrounding the documents are described in: *Interim Committee Log Memorandum for the Record 17 Oct. 1945 through 16 Nov. 1945*,. Nuclear Age Peace Foundation, 1945. http://www.nuclearfiles.org/menu/key-issues/nuclear-weapons/history/pre-cold-war/interim-committee/interim-committee-log-october-november_1945.htm.
[136] Gowing, *Independence and Deterrence,* Vol 1, p.124.
[137] Cited in R. Gott 'The Evolution of the Independent British Deterrent', *International Affairs (Royal Institute of International Affairs 1944-),* 39(1963), pp.238-252.

> reference of the Combined Development Trust, the membership of the Combined Policy Committee, and the outline of Anglo-American agreements on raw materials; the Committee's initial expression [was one of] shock.[138]

However, Margaret Gowing dismisses the Senator's apparent recantation as 'poppycock'.[139] The Bill passed into law as the Atomic Energy Act of 1946. From then on, sharing information with Britain would be illegal.

There was to be a slight thaw the following year. By the end of 1947, relationships in the atomic field had improved and the Americans wished to reach a new understanding. There were a number of reasons for this. The existing wartime agreements had been made available to the CPC and were obviously unsatisfactory. Their interpretation was unclear and they gave Britain and Canada a veto over any American use of atomic weapons; this was unacceptable to the USA. Relationships with the Soviet Union were rapidly worsening and it was seen that America and Britain had common security interests. More importantly, Britain had control over large stocks of uranium ore, which they were not in a position to use and which were needed by the USA to fulfil its targets for bomb production. In a remarkably short period of one month, which in those days required several transatlantic sea passages, a new agreement was negotiated and completed on New Year's Day, 1948. The agreement took the form of a *modus vivendi*. It was not signed, but at a meeting of the CPC, representatives from America, Canada and Britain solemnly declared their intention to proceed on the basis of the document.[140] In Margaret Gowing's words:

> In the long history of strange atomic energy agreements, the *modus vivendi* emerges as the strangest of them all….In the New Year of 1948 no one seriously doubted that the egg was a good one. Only later did the British find that it was addled after all. [141]

Some useful exchanges were indeed made as a result of the agreement, though the British were disappointed not to get any useful information on plutonium metallurgy. However, the Americans did not want Britain to make bombs for a variety of reasons ' varying from old fashioned isolationism and a feeling that the atomic bomb was God's sacred trust to the American people, to the merits of using resources with

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[138] R. Edmonds, *Setting the Mould: The United States and Britain 1945-1950*, (Oxford: OUP, 1986), p.86.
[139] Cited in I. Clark, *Nuclear Diplomacy and the Special Relationship: Britain's deterrent and America. 1957-1962*, (Oxford: Clarendon Press, 1994), p.25.
[140] *Modus Vivendi (Anglo-American Agreement 1 Jan 1948).* Reproduced in Appendix 9, Gowing, *Independence and Deterrence* Vol 1.
[141] Gowing, *Independence and Deterrence* Vol 1, p.254. Full text of the agreement on p.266.

maximum efficiency and avoiding proliferation of weapons'.[142] It was made clear that America would not share information related to weapons. Britain was still on its own.

The cold war deepened and resulted in the formation of the North Atlantic Treaty Organisation (NATO) in April 1949. The paradox of closer co-operation in all defence matters except the most important of all was more apparent than ever. The *modus vivendi* was increasingly seen as unsatisfactory and unproductive and in the autumn of 1949 yet another attempt was made to integrate the atomic activities of the three atomic countries. Although started enthusiastically, the talks faded as each side contemplated the consequences for loss of independence. Any possibility of agreement was killed by the arrest of Klaus Fuchs in February 1950; in addition, the American decision to develop an H-bomb inhibited further sharing of information.

A fully independent British bomb was exploded in *Operation Hurricane* at Monte Bello off the north west coast of Australia on 3 October 1952. It was a plutonium implosion weapon, similar to the bomb that had devastated Nagasaki. Churchill had taken office as Prime Minister in October 1951 and hoped to resume the close wartime relations with America that he had enjoyed during the war. He expected that the British A-bomb test would earn respect from America and ensure Britain's full acceptance into the nuclear club. However, by the time *Hurricane* took place, America's first thermonuclear device was being assembled. The 10 megaton *Ivy Mike* was exploded on 1 November 1952 at Eniwetok. Congress felt there was little, if anything, to be gained by co-operation. Matters eased with the election of Eisenhower as President in 1953. He personally disagreed with the 1946 McMahon Act, which he regarded as 'one of the most deplorable incidents in American history, of which he personally felt ashamed'.[143] However, America continued to refuse to divulge any technical information on the design and manufacture of atomic bombs. Churchill tried again to renew atomic co-operation at the three-power (with Canada) Bermuda Conference in December 1953, and again in Washington in June 1954. Eisenhower assured Churchill that steps were being taken to amend the McMahon Act and the

[142] Gowing, *Independence and Deterrence,* Vol 1, p.265.
[143] H.Macmillan, *Riding the Storm* (London: Macmillan, 1971), p.324.

amended United States Atomic Energy Act passed into law on 30 August 1954.[144] In principle, the Act allowed information to be shared among allies on the yield and effects of weapons as well as their dimension; details of design and fabrication were excluded. Preferential treatment was provided for Britain and details of the permissible exchanges were agreed as the bilateral Agreement for Co-operation Regarding Atomic Information for Mutual Defence Purpose, signed in June 1955.[145] Unfortunately for Britain, opposition from the JCAE, as well as from the AEC, restricted the exchange. An arrangement to transfer nuclear submarine propulsion was suppressed and the agreement was of 'limited practical use'.[146]

The V-force became a reality in January 1955 with the first *Valiant* squadron, but its effectiveness was limited by the very small number of atomic bombs in the hands of the RAF. In September that year, the Chief of the Air Staff visited the USA with the aim of instigating a dialogue with the USAF on the co-ordination of strategic air operations between the two countries. His brief read 'we should achieve closer association with the United States worldwide in the field of defence strategy. This is particularly important in strategic air operations, where Bomber Command and the Strategic Air Command will be attacking components of the same vast target complex'.[147] According to Wynn, the talks led to a meeting between senior officers of the two air forces, which took place in London during August 1956, and it was at this meeting that co-operation on target planning and the supply of atomic weapons to the RAF was initiated. However, Ball argues that there was *de facto* co-operation between the military that anticipated formal governmental agreements. Ball quotes a 1951 document, referring to the long-held belief of the US military establishment that:

> With respect to the field of disclosure of atomic weapons information, particularly the military aspects of atomic weapons or military employment of such weapons…the Department of Defense should be the sole judge of what is disclosed and …may be militarily advantageous to the United States.[148]

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[144] Full text http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr0980/ml022200075-vol1.pdf#pagemode=bookmarks&page=14
[145] Cmnd 9555. Text cited in Bottti, *The Long Wait,* Chapter 15.
[146] Arnold, *Britain and the H-Bomb*, p.197.
[147] Wynn, *RAF Nuclear Deterrent Forces*, p.254.
[148] Report by the joint strategic survey committee to the Joint Chiefs of Staff on amendment to the Atomic Energy Act. Washington:(JCS 2208/2), 1951. GUL.25 October 1951, cited in S.J. Ball, 'Military Nuclear Relations between the United States and Great Britain under the Terms of the McMahon Act, 1946-1958', *Historical Journal* 38 (1995), pp.439-454.

The military of both countries moved ahead to create a scheme for the provision of American nuclear weapons to the RAF; this became known as Project E. This had two phases: the conversion of RAF *Canberras* and V-bombers to carry American nuclear weapons, and the supply to the RAF of the weapons themselves. The early stages of the Project were highly sensitive and there is still no complete record in the archives. Wynn dates the first step towards the Project to a meeting held on 15/16 August 1956 in London, which set out the agreed principles of a co-ordinated strategic target policy.[149] The supply of American bombs was discussed between the RAF and USAF on 5 March 1957, which, according to Wynn, marked the inauguration of Project E.[150] However, Ball notes a document dated December 1955 as containing the first recorded reference to Project E by name.[151] Two types of bomb were agreed.[152] The expected supply of American bombs was essential to all planning for the British deterrent carried out during the second half of the decade. Without the bombs 'it is clear that on any hypothesis about detailed requirements there will be insufficient British weapons to match the build up of the V force'.[153] Project E weapons became of less significance as the supply of British weapons increased. The Project E weapons were withdrawn in 1965, when the last *Valiant* was withdrawn from service. RAF *Phantoms* based in Germany on Quick Reaction Alert duty carried American nuclear weapons until 1970.

Eden succeeded Churchill in April 1955 and showed scant interest in pursuing closer nuclear co-operation with America. There were strong divisions within America over the wisdom of sharing information with Britain. To simplify, the President and the AEC were more relaxed in their view, compared with the JCAE, which was a

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[149] Wynn, *RAF Nuclear Deterrent Forces,* p.255.
[150] Wynn, *RAF Nuclear Deterrent Forces, p.*258.
[151] TNA: T225/645. R.T.Armstrong, 'Project E', 5 December 1955, cited in Ball, 'Military Nuclear Relations between the United States and Great Britain'.
[152] TNA: AIR 2/13697. 'Project E. V-bomber Policy', 1956. The US Mark 7 bomb was a light (1630 lb) tactical bomb. This was given the RAF name of *Target Marker E* and was to be fitted to the *Canberra*, which would employ the Low Altitude Bombing System (LABS), otherwise known as loft and toss bombing. The US Mark 5 bomb was the standard American fission weapon and was to be carried by V-bombers; it was given the RAF designation Bomb HE (HC).
TNA: AIR 2/13698. In 1957, AM Tuttle was offered Mark 15/39 thermonuclear weapons by Major General Moore; he seems to have been taken aback by the offer of an H-bomb and asked for confirmation. E. Moore, 'Study. Feasibility of Equipping British V-bombers for Combat Delivery of Mk 15/39 weapons', 31 Dec 57.
[153] TNA: AIR 2/13789. R.C. Kent, 'Project E for the V-bomber force', AC(58)14.4 Mar 1958.

Congressional body.[154] Britain did, in fact, have some information the Americans would have liked. Calder Hall was a gas-cooled reactor, of a type the United States had not developed. It is famed for being the world's first power reactor to feed electricity into the National Grid.[155]. Eight such reactors were built, four at Chapel Cross and four at Dumfries. Eden refused to share its design with America on the grounds that it was a military plant, designed to produce weapons grade plutonium. Any hope of better relations was disrupted by the Suez incident in October 1956.

1956 saw the start of a movement in America towards greater sharing of information with Britain. However, this received a substantial setback when in October 1956 Britain and France invaded Egypt and seized the Suez Canal. The action was condemned by the international community and, in particular, enraged Eisenhower. Eden's act of lying both to Eisenhower and the House of Commons compounded the disaster; Lord Owen considers this behaviour uncharacteristic and attributes it to Eden's serious kidney problems.[156] Under strong American pressure, Britain was forced to withdraw from Egypt. The Eden government fell in January 1957 and Harold Macmillan became Prime Minister. Paradoxically, the consequence of Suez in promoting Macmillan to Prime Minister was crucial to the improvement of Anglo-American nuclear relations. Botti considers the Suez crisis and its aftermath to be of key importance:

> The real turning point in Anglo-American nuclear relations occurred ironically in late October 1956 with the falling-out of the United States and Britain over the Suez crisis and the subsequent decision by Eisenhower to use improved nuclear ties as a way to compensate the British for their deep political and international embarrassment over Suez.[157]

Macmillan had been British liaison officer to Eisenhower in North Africa and personal relations were good. Both leaders were keen to repair the Atlantic relationship. Eisenhower invited Macmillan to a conference in Bermuda during March

[154] American politics are outside the scope of this dissertation. A detailed political view of Anglo-American negotiations is given in T.J. Botti, *The Long Wait: The Forging of the Anglo-American Nuclear Alliance 1945-1958* (New York: Greenwood Press, 1987).
[155] A more realistic description is that it was a reactor designed to produce weapons grade Pu239, with some electricity as a by-product to use up the excess heat generated. Operation was sub-optimum for electricity generation, since the fuel rods had to be changed frequently to avoid the build up of unwanted Pu240. In military files the design is referred to as PIPPA (Pile for Producing Power and Plutonium) See, for instance, TNA: DEFE 13/452, 'Development of Fissile Materials and Nuclear Weapons'.
[156] Lord Owen, 'The effect of Prime Minister Anthony Eden's illness on his decision-making during the Suez crisis', *Quarterly Journal of Medicine* 98(2005), pp.387-402.
[157] Botti, *The Long Wait,* p.171.

1957. Preliminary talks took place in Washington between the newly appointed Defence Minister Duncan Sandys and his American counterpart Charles Wilson, covering the deployment of Thor missiles in Europe. This dovetailed with Sandys' proposals to reduce British defence spending by an increased reliance on nuclear deterrence.[158] The Bermuda meeting was successful in its main objective of restoring Anglo-American relations. Eisenhower later described the encounter as the most successful international conference that he had attended since the close of World War II.[159] There was, however, little progress on the exchange of information. The British Ambassador, Harold Caccia, was pessimistic about the prospects: 'however much the President may wish it, I can see no prospect whatever of this Congress amending…legislation in our favour'.[160] During the summer of 1957, Britain carried out the *Grapple* series of tests, which at the time excited little interest in Washington. The situation changed with the launch of *Sputnik* on 4th October. America's unquestioned assumption of technological superiority had been challenged; there was also the realisation that mainland America was no longer invulnerable to direct Soviet attack. Caccia sensed an opportunity: 'with luck and judgement, we should be able to turn this…to our special advantage'.[161] Macmillan wrote to Eisenhower on 10 October, proposing that the two countries should co-operate in the atomic field to meet the new Soviet threat. British scientists could do the job alone; but without an amendment to the McMahon Act allowing co-operation the cost would be great.[162] Macmillan set out for Washington for three days of talks over 23-25 October. When Eisenhower produced a directive setting up two study groups to deal with nuclear collaboration, Macmillan 'could scarcely believe his ears' that such rapid progress had been made.[163] Within two days a Declaration of Common Purpose had been issued. This contained the clause:

> The President of the United States will request the Congress to amend the Atomic Energy Act as may be necessary and desirable to permit of close and fruitful collaboration of scientists and engineers of Great Britain, the United States, and other friendly countries[164]

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158 Macmillan, *Riding the Storm*, p.260.
159 Baylis, *Ambiguity and Deterrence*, p.90.
160 Cited in Clark, *Nuclear Diplomacy*, p.82.
161 TNA: PREM 11/2554. Caccia to FO, 6 Oct 1957. Cited in Clark, *Nuclear Diplomacy*, p.80.
162 Macmillan, *Riding the Storm*, p.315.
163 A. Horne, *Macmillan 1891-1956* (London: Macmillan, 1988), p.56.
164 *Declaration of Common Purpose by the President and the Prime Minister of the United Kingdom. 25 October 1957.* Available: http://www.presidency.ucsb.edu/ws/print.php?pid=10941

The amendment to the Atomic Energy Act came into law in June 1958. During the congressional hearings, a clause had been inserted that only nations that had made 'substantial progress' in nuclear weapons could be given information.[165] The follow-up bilateral agreement was rapidly drafted and was signed on 3 July; it prepared the way for detailed talks on the exchange of information.[166]

By the end of August, Penney, Cook and a small team were on their way to Washington for the first technical exchange. Both sides were initially cautious; it was necessary to demonstrate some degree of progress in a field before expecting to receive detailed information. The American side had a complex authorisation procedure, involving the AEC, JCAE and the President, before approval was given for disclosure of any specific information. However, relations were friendly and progress was rapid. An immediate benefit was that the Americans provided information that contributed to the organisation of the imminent *Grapple Z* series, which took place in early September.[167]

The research and development carried out by the scientists and engineers at AWRE could now be evaluated by their American peers. Macmillan wrote later that he was particularly glad to be told that 'somewhat to the surprise of our friends, it was found that the specialist information was not all on one side'.[168] A direct tribute came from the AEC in a report on the meeting:

> During the first meeting it became obvious that the United Kingdom has achieved an advanced state of weapon research and development in both the fission and thermonuclear fields. Moreover, it appeared that certain advances made by the United Kingdom would be of benefit to the United States.[169]

The next month, Cook led a team for a meeting at the Sandia Laboratories, New Mexico. The American team was led by General Starbird, Director of Military Application at the AEC. The meeting went extremely well and led, among other

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165 The Atomic Energy Act (1954) is the primary document, which by now incorporates several amendments. The entire document is available: http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr0980/
166 1958 US-UK Mutual Defence Agreement. Text available: http://www.basicint.org/nuclear/1958MDA.htm
167 A detailed description of the talks is given by Arnold, *Britain and the H-Bomb*, pp.203-206.
168 Macmillan, *Riding the Storm*, p.563.
169 USDOE: Quarterly Progress Report, Part III. Weapons: Jul-Sep, 1958. Cited in Arnold, *Britain and the H-Bomb*, p.206.

things, to the adoption of the American Mark 28 thermonuclear warhead design by the British. Cook reported back:

> No doubt that our technical achievements in thermonuclear warheads…with our resources and timescales have considerably impressed the US delegates and have been reason for a more forthcoming attitude than formal procedures would dictate. Starbird has been very co-operative and is genuinely anxious that exchange should be increased.[170]

This meeting represented the actualisation of Macmillan's Great Prize. General Starbird and Sir William Cook signed a joint agreement. The implementation of the agreement is dealt with by Arnold.[171] It set the pattern for co-operation that continues to this day. The first practical result was that the American W28 warhead design was adapted for British production and became *Red Snow,* the warhead for the *Yellow Sun MkII* free-fall bomb and the *Blue Steel* stand-off bomb.

[170] Cited in Arnold, *Britain and the H-Bomb,* p.208.
[171] Arnold, *Britain and the H-Bomb*, p.211.

5 Thermonuclear Bluff?

This dissertation concentrates on the circumstances of the first *Grapple* series of tests. For some 35 years they were uncritically referred to as 'thermonuclear'. From the start, this produced some misgivings. In 1954, Britain had committed itself to development of thermonuclear weapons, but at that stage development was concentrated on the 'Type A' bomb, i.e. a layer cake. AVM Satterly wrote of the Type A weapon:

> It is a boosted atomic (thermonuclear) bomb and not in the strictest sense an H-bomb. The Minister of Defence… spoke about our future defence policy; he used the words hydrogen bomb and thermonuclear weapon and implied we should proceed with development…The Press have all stated that we are going to develop the H-bomb…We should stop using the expression hydrogen bomb.[172]

In 1992 Norman Dombey, a professor of physics, and Eric Grove, a military historian, published an article entitled 'Britain's Thermonuclear Bluff'.[173] They argued forcefully that the prime purpose of the *Grapple* series was political rather than military: 'prestige and a US-UK special nuclear relationship were the objectives'. Writing at a time when very little information had been released about Britain's nuclear weapons, they went on to argue that the two *Granite* devices were 'thermonuclear boosted fission weapons'; the context makes clear that they imply a layer-cake design. *Orange Herald* was a 'fallback high yield fission device', designed to produce a large explosion with high certainty of success. Dombey and Grove finish by stating:

> The thermonuclear bluff achieved its purpose; it helped Britain to delay acknowledging its loss of power and to resist the European logic of the post-war settlement by clinging on to the skirts of its transatlantic partner for another 40 years.

Since then, more information has become available on the nature of the devices and Dombey and Grove's original thesis must be reassessed. However, Grove maintains a modified position. He acted as advisor for Channel 4 documentary 'Britain's Cold War Super Weapons', transmitted in May 2005. The accompanying website includes the unattributed, but challenging, phrase 'While the world had been duped into

[172] TNA: AIR 2/13679. H.V. Satterly, 'Thermonuclear Bomb Programme'.1 March 1955.
[173] N. Dombey and E. Grove, 'Britain's Thermonuclear Bluff', *London Review of Books*, 22 Oct 1992.

thinking Britain had a thermonuclear device, the scientists were busy trying to make one that actually worked'.[174]

Britain was anxious to be regarded by the USA as a potential partner in matters nuclear. It was therefore in Britain's interest that the 1957 tests should be successful and be seen to be successful. Planning for the *Grapple* trials started with the selection of Christmas and Malden Islands as the site in October 1955. Files that have now been released demonstrate both a desire to impress the world with British power and a simultaneous fear that our weakness would be exposed. Brundrett and Penney were against inviting US observers. This was not for fear of revealing secrets, since the Americans were clearly well ahead in thermonuclear development, but for concern that they would realise our limitations. Brundrett reported to a COS meeting 'We knew Americans were anxious to find out extent of our knowledge and we should lose a strong bargaining counter if they should do so. Once observers were landed on Christmas Island it would be impossible to prevent them from obtaining the information'.[175] It was not only the Americans who were to be impressed, but also the home public. Elkington wrote 'Perhaps the main aim of *Operation Grapple* is the political one to demonstrate that we can produce a successful megaton weapon. This political aim will best be served by full and favourable publicity.'[176] He goes on to argue for inviting the British Press, which was done.

Full technical details of the three devices exploded during the first *Grapple* series have still not been released. The following summary is the best description of the nature of the devices that may be inferred from published information. The first and third devices exploded, named respectively *Short Granite* and *Purple Granite*, were prototype two-stage thermonuclear weapons. Both employed a spherical fusion secondary containing lithium deuteride as the fusion fuel; the thermonuclear reaction was initiated by radiation implosion from the fission primary, and so worked on the same principle as the American Teller-Ulam bombs. The second device, *Orange Herald*, was a large uranium fission bomb, with perhaps some boosting. The nature of

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174 [Online] http://www.channel4.com/history/microsites/B/britains_cold_war_super_weapons/nuclear.html see also T. Royle, 'How we lied our way into the nuclear club', *Sunday Herald,* 24 April 2005.
175 TNA: AVIA 65/1216. 'Grapple Trials: Attendance of US observers'. 1957.
176 TNA: AVIA 65/1216.

the devices is considered in more detail in Appendix C, but it is helpful to bear this description in mind when evaluating the various conflicting reports.

By 1955 both the USA and the USSR had exploded hydrogen bombs and the public was familiar with the general concept of a thermonuclear fusion weapon. Following the British tradition of secrecy in atomic matters, Eden was reluctant to announce the proposed British trials until his hand was forced by Chapman Pincher, who revealed in the *Daily Express* during April 1956 that Britain would drop an H-bomb in the Pacific during 1957. On 7 June 1956 Eden made a short statement to the House that a megaton weapon would be tested in the first half of 1957, using Christmas Island as a base. [177] Pincher's version of the story is that he learnt about the proposed test 'through my close friendship with the late Sir Frederick Brundrett, then the government's chief defence scientist'. Believing his telephone to be tapped, Pincher went to a call box and telephoned a 'senior Defence Ministry friend' and asked 'If I were to wish you a Happy Christmas instead of a Happy Easter would it make sense to you?'. He replied 'It would indeed' and Pincher had his story.[178]

The official announcements of the successive tests were brief. The first explosion on 15 May was tersely described as a 'nuclear device' exploded at a high altitude. The *Valiant* crew were named, but no more information on the bomb was given. However, an article published the following day, entitled '"Device" a Hydrogen Bomb' by *The Times* Science Correspondent, attempted to deduce the nature of the test. The article speculated that the device, which we now know as *Short Granite*, was a two stage thermonuclear weapon based on lithium deuteride without an outer fissionable tamper. Two weeks later, *The Times* simply announced the *Orange Herald* test as 'Second British Nuclear test in the Pacific: Bigger Explosion than the First'; there was no further information, nor any speculation. Both *The Times* and the *Manchester Guardian* carried a report on 1 June, credited to Reuters, which referred to 'Britain's second hydrogen bomb test'. The report of the third test was similarly brief and, perhaps surprisingly, there was no leader comment on the series in *The Times*.[179]

[177] Arnold, *Britain and the H-Bomb*, p.102.
[178] C. Pincher, *Inside Story* (London: Sidgwick and Jackson, 1978), p.142.
[179] The Times 16 May, 17 May, 1 June and 20 June, 1957.

The press were invited only to the second test, *Orange Herald*. Enthusiastic eyewitness reports appeared in the Saturday editions of the London daily papers. In his 1992 paper on the thermonuclear bluff, Groves points out the impossibility of the reports reaching London in time.[180] Oulton gives a description of the press arrangements, but carefully avoids details of the timing. The day before the test, the reporters were accommodated on the spectator ship *Alert* and were given information packs by the Chief Information Officer Brigadier Ivor Jehu. 'Arrangements had been made for the press photographs and copy to be flown to Christmas Island… and a Canberra would take these on to Honolulu where the Staging Post would express them on to London for the earliest possible publication'.[181] *Orange Herald* was detonated at 1041 local time, corresponding to1941 GMT on Friday 31 May. The time calculation is confused by later political events. In 1979 the Gilbert Islands were granted full independence as the Republic of Kiribati, incorporating Christmas Island under its new name of Kiritimati. Kiribati extends some 3000 km from east to west, straddling the International Date Line. In 1995, the republic shifted the International Date Line to circumvent Kiritimati to the east, so that Kiribati should have the same date over its entire territory.[182] The new Christmas Island thus exists a day apart from Hawaii, although it lies on the same longitude. However, it is clear that in 1957 it was not possible for an eyewitness report of the test to be flown in two legs to Honolulu and arrive in time for the London Saturday papers. Grove speculated correctly, but in fact Chapman Pincher had already described the deception in his 1978 book *Inside Story*. The day before the test, Brigadier Jehu briefed the journalists on what the test would look like; they wrote their descriptions there and then, which were taken to Christmas Island and held in anticipation of a successful test. The moment *Orange Herald* exploded, the reports were flown to Honolulu for onward transmission to London. Pincher went one better. He wrote his report even before the press briefing and lodged it at Honolulu, where it was transmitted to London on first news of the test. The *Daily Express* had its scoop.[183] The story is confirmed by Jehu's letter to Oulton dated 13 May 1957.[184] He states that publicity will be organised for the second test, *Orange Herald*, and names the 7-strong press party of British journalists. He reiterates the

[180] Dombey, 'Britain's Thermonuclear Bluff'.
[181] Oulton, *Christmas Island Cracker,* p.342.
[182] M. Rosenberg, 'Kiribati Moves International Date Line'. Available: http://geography.about.com/od/physicalgeography/a/kiribatiidl.htm.
[183] Pincher, *Inside Story*, p.178.
[184] TNA: AVIA 65/1211. 'Operation Grapple: Correspondence', 1957.

'desire to make most of publicity opportunities with film and photographs of hot news'. Jehu issued the press with an information pack, which included the Ministry of Supply's own account of the first test, to 'enable them to prepare preliminary despatches on the bang itself'. He goes on 'It has not been found possible to provide signalling facilities. Pre-explosion despatches, prepared by the correspondents, will be flown to Christmas Island for immediate despatch when the bang is made … to reach London for the morning papers'.

The press, with one exception, co-operated fully in the deception; William Connor, better known as Cassandra of the *Daily Mirror* filed his report after he had seen the test. 'I see H-bomb blast' headlined the *News Chronicle*. Chapman Pincher estimated the yield of 'Britain's No 2 Hydrogen bomb, which I saw explode this morning' as equal to 5 million doodle bugs. All correspondents gave the estimated yield as 5 megatons, and the *Mail* described this as 'the world's most powerful'. The *Daily Telegraph* correspondent limited himself to a near impersonal 'we watched'. Most added some inaccurate details. The *Daily Mail* had the bomb exploding at 'twelve noon precisely', while Pincher had the *Valiant* release the bomb in 'over-your-shoulder style as the aircraft made a climbing turn'. All illustrated the articles with pictures, identified correctly, of the first *Grapple* test. All described the fireball in similar terms, as red/brown, orange/red or red/copper.[185]

Simpson, writing in 1986, then had little information to go on. He described *Grapple* as a 'Thermonuclear Demonstration Programme', implying that there was a political as well as technical agenda. He goes on:

> It seems likely that the British test programme there consisted of work on at least three designs, a large yield fission bomb, a boosted device that could also be used as an H-bomb trigger and a true H-bomb. It is also possible that the British were working on a variant of the intermediate design used by the USSR as a half way house to its full H-bomb design.

The last is of course a reference to the layer cake design. In discussing the June 1956 *Mosaic G2* test, Simpson says 'One stimulus was a rumour from the United States that by placing fusion material in the core of a weapon and surrounding the core with a natural uranium...tamper, the resulting fissions in the tamper would increase the

[185] C. Pincher, 'Our BIG bomb', London: *Daily Express*, 1 June1957.
L. Bertin, 'Britain Explodes Second H-Bomb', London: *The Daily Telegraph* :1 June 1957.
H.I. McLeave, 'I See H-Bomb Blast', London: *News Chronicle* :1 June 1957.
J, Starr, 'Our Mighty Bang', London: *Daily Mail* :1 June 1957.

yield of the device'. This again is a description of a layer cake, except for the misplacing of the lithium deuteride layer within the fissile core instead of surrounding it. Nowhere in the book does Simpson use the terms layer cake or alarm clock.[186]

Misunderstanding of the nature of the *Grapple* devices is, understandably, widespread. The *Nuclear Weapons Databook* is an authoritative series providing comprehensive information on the world's nuclear weapons. Volume V, which dealt with British weapons, was published in 1994 and even then could only speculate, it turns out incorrectly, on the nature of the Grapple trials.

> It is doubtful if any of the four 1957 *Grapple* tests [i.e. including Grapple X] were two-stage radiation implosion designs. At least one of the four was the Penney "fall back" device, and the other three were probably single-stage designs, either simple boosted fission devices or something similar to Sakharov's layer cake device. …The chief candidate for the first test of a British thermonuclear device using the Teller-Ulam concept appears to be *Grapple Y* on 28 April 1958.[187]

The Nuclear Weapons Archive is a major web based resource on the design and practice of nuclear weapons. It describes itself as 'from public sources, plus a bit of inference'. In the lead up to *Grapple*, the Archive states ' Britain had developed … two boosted fission designs using U-235 surrounded by lithium deuteride: *Green Bamboo* and a smaller and lighter (but less efficient) device called *Orange Herald*'. However, Arnold clearly states *Orange Herald* to be core boosted, i.e. the lithium deuteride resides within the uranium pit, not outside it.[188] The Archive continues 'They also had a large two-stage thermonuclear weapon design called *Green Granite* expected to produce multi-megaton yields (1-4 megaton)'.[189] The verdict on the first *Grapple* series was 'All in all, this first phase was a mixed success. The rediscovered Teller-Ulam design, and a deployable megaton-class weapon design had both been proven. On the other hand, the H-bomb yields were far below those predicted'. *Mosiac G2* is referred to unequivocally as a layer cake.

Richard Moore, writing as late as 2001, said of *Grapple* 'Historians still do not know whether British scientists discovered independently how to create a two stage hydrogen bomb, although it is now clear that the 1957 tests included at least one

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186 Simpson, *Independent Nuclear State*, p.xxiv.
187 A.S. Burrows, R. Fieldhouse and R.S. Norris, *Nuclear Weapons Databook: British, French and Chinese Nuclear Weapons V. 5* (Boulder: Westview Press Inc, 1994), p.40.
188 Arnold, *Britain and the H-Bomb*, p.131.
189 http://nuclearweaponarchive.org/Uk/UKTesting.html

failed attempt'.[190] It is now clear that they did make the independent discovery and that *Grapple* contained two disappointing yields, rather than a failure. Baylis, in 1995, was more prescient 'In fact, it is now known that *Short Granite* and *Purple Granite* were thermonuclear devices while *Orange Herald* was a fall back fission device'.[191]

Nuclear Weapons Frequently Asked Questions is a major web based resource on the design and technology of nuclear weapons. A section dated 1998 describes the principle of the layer cake in some detail and classes *Orange Herald* as a device of this type:

> The first test of this concept was a device designated RDS-6s, (known as Joe 4 to the U.S.) on 12 August 1953. By using tritium doping it achieved a 10-fold boost over the size of the trigger, for a total yield of 400 kilotons. The UK *Orange Herald Small* device tested in Grapple 2 (31 May 1957) was similar but used a much larger fission trigger (300 kiloton range) apparently without tritium for a total yield of 720 kilotons, a boost in the order of 2.5-fold. This is probably the largest test of this design.[192]

Channel 4 broadcast a programme entitled *Britain's Cold War Super Weapons* on 25 April 2005; this employed Eric Grove, author of 'Britain's Thermonuclear Bluff' as advisor. The supporting website for the programme acknowledges the two *Granite* tests as experimental H-bombs and refers to *Orange Herald* as an A-bomb in disguise and 'the world was duped into thinking that Britain had a thermonuclear device'. An article published that day previewing the programme described *Orange Herald* as 'basically a monster atomic bomb cobbled together from existing stocks in much the same way that a child might put elastic bands round a bunch of bangers'.[193] The following day, the *Western Mail* reported 'Professor John Baylis, head of politics and international relations at the University of Wales, Swansea, said, "I would not go as far as to say we lied our way into the nuclear club. But we were certainly economical with the truth about what happened."'[194] It does seem that care was taken to avoid any precise description of the devices fired at *Grapple*; official sources were careful to stick to the term 'megaton'. A background memo on *Short Granite* makes it clear that

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[190] R. Moore, 'Where Her Majesty's weapons were', *Bulletin of the Atomic Scientists* 57(2001), pp.58-64.
[191] Baylis, *Ambiguity and Deterrence*, p.262.
[192] C. Sublette, *Nuclear Weapons Frequently Asked Questions*, Section 1 1998. Available http://nuclearweaponarchive.org/Nwfaq/Nfaq1.html
[193] *Britain's Cold War Super Weapons* broadcast 25 Apr 05 on Channel 4. See http://www.channel4.com/history/microsites/B/britains_cold_war_super_weapons/nuclear.html T.Royle, 'How we lied our way into the nuclear club', Sunday Herald, 24 April 2005. Since this article was written after much information was available on the nature of *Orange Herald*, it would be charitable to describe it as inaccurate.
[194] R.Turner, 'I wouldn't say we lied', *Western Mail,* 26 Apr 2005.

information was not to be offered to inquirers: ‘The motive lying behind this question may be to discover whether our megaton bomb is a large fission weapon or a hydrogen bomb’.[195]

The conclusion must be that here was no bluff, in the sense that there was no deliberate attempt to deceive. Most importantly, there was no attempt to deceive the Americans. There would be no point; the Americans were invited to take airborne samples and could deduce for themselves what was going on, and if the goal of close co-operation were to be achieved, any bluff would immediately be revealed once information started to be exchanged across the Atlantic. However, great political import was given to the achievement of a megaton explosion. For this purpose, *Orange Herald (Large)* was taken to Christmas Island. This bomb did not fulfil any of the service requirements, but was regarded as a safe insurance policy to provide a megaton if the other devices disappointed. Official statements were usually careful to describe *Orange Herald* as a megaton device and did not use the term hydrogen bomb. On the other hand, no clarifications were issued when others did so.

[195] TNA: DEFE 7/896. UK Hydrogen bomb tests, 1958.

6 Conclusions

Even though the two initial *Granite* firings produced disappointing yields, the *Grapple* series was a technical success. The *Granite* tests demonstrated that the principle of radiation compression required to produce a true thermonuclear explosion had been understood; the Aldermaston weaponeers had independently reproduced the Teller-Ulam technique. The role of U-238 in the secondary reaction had not yet been properly understood. They went on to perfect the design with the 3 megaton Grapple Z firing in 1958. The initial *Granite* test was considered successful enough to abandon the layer cake *Green Bamboo* and to plan to use a *Granite* type device as the warhead for the *Blue Steel* stand off bomb. Although the core boosting produced little benefit, *Orange Herald* performed well, reliably producing a large 700 kilotons yield to confirm Britain's membership of the megaton club.

Grapple had little direct effect on development of nuclear weapons for the British armed forces. The fissile core of *Orange Herald* was fitted with the explosive lens system of *Green Bamboo* to produce the large pure fission warhead *Green Grass*. This was fitted in a *Blue Danube* case to produce the interim weapon *Violet Club*, and later transferred to *Yellow Sun.* It was expensive in fissile material and had to be maintained by AWRE technicians. A complex arming procedure restricted flexibility in use and the weapon was deeply disliked by the RAF and very few were delivered. Following the 1958 US-UK Mutual Defence Agreement, it was possible to draw on American design experience. The US W28 thermonuclear warhead was modified for British manufacture and became the *Red Snow* warhead, deployed in the *Yellow Sun Mark II* free fall bomb, the *Blue Steel* guided bomb and, potentially, *Blue Streak*.

Grapple did fulfil its other, and perhaps primary, goal of demonstrating to the world, and particularly to the USA, that Britain had a thermonuclear capability. Post-Suez and post-Sputnik, President Eisenhower was well disposed to sharing nuclear information with the United Kingdom. Congress required convincing and the wording of the 1958 Amendment to the Atomic Energy Act included the words "nations that have made substantial progress". Britain was able to demonstrate that she had fulfilled this criterion. By this time Britain had established a substantial nuclear engineering capability, both civil and military. Without this, the information shared with the USA could not have been put to practical use. As it was, Britain was able to manufacture its own version of the American B28 hydrogen bomb with little delay.

Britain, more than the USA or USSR, has maintained a high level of secrecy over nuclear weapons. It was against this background that Dombey and Grove wrote their paper on 'Britain's Thermonuclear Bluff'. With the advantage of the information that has been released over the ten years since the paper, it is possible evaluate the article: the Government was happy for the press to describe the all tests as thermonuclear: Grove was correct in his deduction that the press eyewitness accounts of *Orange Herald* were written the day before, at the instigation of the official PRO: it was not correct to describe the *Granite* tests as failures and Grove misunderstood the nature of the devices. His most serious error was to consider that the tests were designed to deceive the Americans. Their participation in airborne sampling would have told them the nature of the devices and any subsequent revelation of deceit would have destroyed the prospects of future co-operation.

The development of Britain's megaton weapons, undertaken during a period of economic difficulty and carried out under the pressure of an imminent test ban, was a remarkable achievement. It enabled Macmillan to achieve his 'Great Prize' of nuclear co-operation with America and within a short time Britain had a good stock of thermonuclear weapons. To Grove, the Great Prize 'helped Britain to delay acknowledging its loss of power and to resist the European logic of the post-war settlement by clinging on to the skirts of its transatlantic protector for another 40 years'. To Macmillan it was the foundation of Britain's position in the world and fully justified the substantial effort that had been expended:

> Our primary purpose in maintaining an independent nuclear capability is to gain the opportunity of exercising our influence in world affairs by membership of the nuclear club. It is for this reason that we decided to make the A-bomb and, later, the H-bomb. These decisions have so far paid a good dividend; had we not taken them we should not have achieved the special relationship with the US Government which we now enjoy.

OR	Relevant code name(s)	Description	First issue	Requirements		Note
				Yield	Weight (lb)	
OR229		Medium range bomber	17Dec46			No action. Withdrawn
OR1001	Blue Danube	Free fall bomb	Aug 46	16kT	10,000	First service issue. Pu implosion
OR1127	Red Beard	Free fall bomb	Nov 53	15kT	2,000	Pu implosion. In service 1960 – early 70s
OR1132	Blue Steel	Powered guided bomb	1954			Warhead OR 1141. In service 1964-70
OR1141	Green Bamboo	MT warhead for Blue Steel	1954			Never fired. Blue Steel eventually fitted with Red Snow
	Green Grass			MT		Substituted for Green Bamboo in 1957
OR1136	Yellow Sun Mk I	Free fall bomb	Jul 54	MT	7000 lb	Warhead originally to be Green Bamboo, then Green Granite, then in practice Green Grass. In service 1959-63.
	Yellow Sun Mk II					Used Red Snow warhead. In service 1961-66
OR1139	Blue Streak	MRBM	July 1955			Cancelled
OR1142	Orange Herald	Warhead for Blue Streak	22 Jul 55	MT	2000	Tested. Developed as Green Grass. OR1142 cancelled 1959
Interim Weapon	Violet Club	Free fall bomb		MT	9000	Green Grass warhead in Blue Danube case. Only 5 delivered in 1958
OR1140		Warhead for SAGW	Jun 55			Warhead for Blue Envoy. Cancelled 1957
OR1153		Multi MT warhead				
OR1171	Red Snow	H-warhead	1959	1MT		Common MT warhead, developed from US Mk28

Table 1. Operational Requirements.
The relation between an OR and the equipment to meet it could change over time.

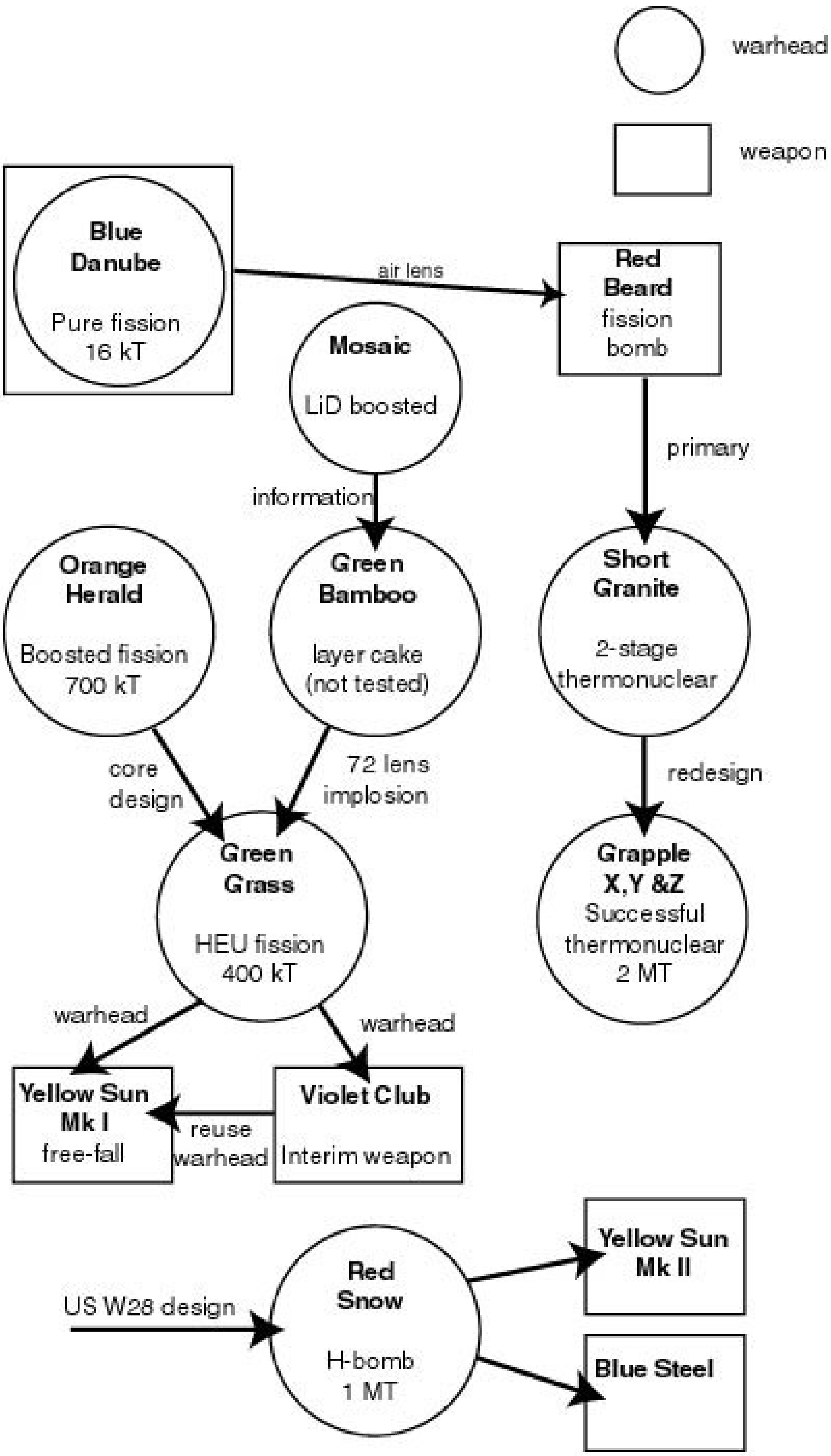

Figure 1. The Megaton Family

FigureMegaton.ai

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References to individual documents are given as footnotes throughout the text and are not repeated here. The documents were drawn from the following TNA Departmental classifications:

AB	UK Atomic Energy Authority
AIR	Air Ministry
AVIA	Ministry of Supply
CAB	Cabinet Office
DEFE	Ministry of Defence
ES	AWRE
FO	Foreign Office
PREM	Prime Minister's Office
T	Treasury

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7 Appendix A. Nuclear Weapons

The term nuclear weapons covers all those explosive devices where the energy release comes from some rearrangement of atomic nuclei. Energy is released when the nuclei of some heavy atoms split into two parts; this is nuclear fission At the other end of the periodic table, if some of the lightest nuclei can be persuaded to combine to form a heavier nucleus, energy is released; this is nuclear fusion and is the source of the sun's energy. The range of nuclear weapons that have been developed since 1945 is large and some combine several types of nuclear reaction to achieve the design target of yield, weight or cost. This appendix summarises the nuclear reactions involved in nuclear weapons and classifies the major types of weapon design. It is not intended as a primer in nuclear physics, but scientific terminology is used where necessary for clarity.

7.1 Nuclear Reactions

7.1.1 Fission

Nuclear fission takes place when the nuclei of certain isotopes of some heavy elements become unstable after capturing a neutron. The nucleus splits into two roughly equal pieces with the release of a great deal of energy. In addition, several neutrons are emitted, which in the right circumstances will go on to produce a chain reaction.

While several heavy elements can be persuaded to fission, only three reactions are of importance in weapon design. Uranium-235 and plutonium-239 are said to be fissile. If a uranium-235 nucleus absorbs a neutron it becomes unstable and spontaneously undergoes fission. The nucleus splits into two lighter nuclei plus two or more energetic neutrons.

$$^{235}U_{92} + n \rightarrow {}^{89}Kr_{36} + {}^{141}Ba_{56} + 2n + \gamma + 170\ MeV \qquad \text{Equation 1}$$

This is a typical reaction. Up to 5 neutrons may be produced and a range of fission fragments is found. The energy spectrum of the emitted neutrons has a median value of about 1 MeV. A uranium nucleus can undergo fission when it absorbs a neutron of any energy, including low energy or 'thermal' neutrons. Plutonium fissions in a similar manner to uranium-235. These two nuclei are said to be fissile, i.e. they undergo spontaneous fission after absorbing a slow neutron; no additional energy is required. The number of neutrons produced in fission increases with the energy of the incident neutron.

Naturally occurring uranium consists largely of the $^{238}U_{92}$ isotope. Uranium-238 can fission if it absorbs a neutron with a kinetic energy above 1 MeV; this is termed fast fission and the nucleus is said to be fissionable, as opposed to fissile. However, for this energy of incident neutrons, most are absorbed by inelastic scattering without producing fission. It is only for neutrons above 10Mev energy that fission of U238 becomes a practical possibility.

7.1.2 Fusion

At the other end of the periodic table, energy is released if light nuclei can be persuaded to fuse together and create a heavier nucleus. The fusion of hydrogen into helium provides the energy of stars. However, it is not possible to transmute hydrogen nuclei directly into helium. There are a few possible fusion reactions involving isotopes of hydrogen that can be considered for fusion weapons.

$$^{2}D_{1} + {}^{3}T_{1} \rightarrow {}^{4}He_{2} + n + 17.6\ \text{MeV} \qquad \text{Equation 2}$$

$$^{2}D_{1} + {}^{2}D_{1} \rightarrow {}^{3}He_{2} + n + 3.3\ \text{MeV} \qquad \text{Equation 3}$$

$$^{2}D_{1} + {}^{2}D_{1} \rightarrow {}^{3}T_{1} + p + 4.0\ \text{MeV} \qquad \text{Equation 4}$$

$$^{2}D_{1} + {}^{3}He_{2} \rightarrow {}^{4}He_{2} + p + 18.3\ \text{MeV} \qquad \text{Equation 5}$$

The reaction in Equation 2 is relatively easy to ignite and can be initiated using a fission bomb to produce the required temperature and compression. It is possible to initiate the reaction using high explosive alone. This will not produce a thermonuclear explosion, but is used to provide additional neutron for boosting a fission reaction. . The emitted neutron has energy of 14 MeV. This is sufficient to cause fast fission in U238, allowing the possibility of the fission-fusion-fission bomb. The other reactions require radiation implosion to achieve the necessary temperature.

Deuterium occurs naturally and is a stable isotope with an indefinite life; natural hydrogen contains 0.015% deuterium. Deuterium may be produced by electrolysis of water in a process that concentrates the heavier atoms. Tritium, however, is radioactive and decays with a half-life of 12 years; the atmosphere contains only minuscule amounts, produced by cosmic rays. Tritium must be manufactured using a nuclear reactor. The process is expensive and long-term storage of tritium is limited by its natural decay. Several types of nuclear weapon utilise the D-T reaction of equation 2. Rather than attempt to employ elemental tritium, it is more practical to generate it on the spot. In a "dry" thermonuclear weapon, neutrons generated by a fission explosion are used to generate tritium by bombarding lithium nuclei:

$$^{6}Li_{3} + n \rightarrow {}^{4}He_{2} + {}^{3}T_{1} + 4.7\ \text{MeV} \qquad \text{Equation 6}$$

$$^{7}Li_{3} + n \rightarrow {}^{4}He_{2} + {}^{3}T_{1} + n - 2.5\ \text{MeV} \qquad \text{Equation 7}$$

Thus, a mass containing lithium deuteride provides a supply of both tritium and deuterium to supply the components for the reaction in Equation 2. This is employed in a number of designs, which will be described below. Lithium-6 is an essential component of thermonuclear fuel and the isotope must be enriched from naturally occurring lithium. The reaction in Equation 7 requires an incident neutron with energy greater than 4 MeV and can be significant in the later stages of an explosion.

7.2 Chain reaction

When a nucleus of a fissile material fissions, it emits some neutrons. The number varies from zero to six or more, but is typically 2 or 3, each with an energy of around 1 MeV. In a mass of fissile material, these neutrons can go on to produce further fissions. In a small or impure lump of material, neutrons will escape from the surface or be absorbed by impurities without causing further fission; the reaction will die away. If however, the lump is large and pure enough, each fission will cause more than one subsequent fission and a chain reaction will take place. The energy release develops exponentially and a nuclear explosion occurs. The mass of material required for a chain reaction to take place is termed the critical mass. The mass is affected by the geometry of the mass, whether it is surrounded by a neutron reflector and by its density. For a bare sphere, typical critical masses are 52 kg for U-235 and 10 kg for Pu-239. Critical mass is inversely proportional to the square of the density of the material. Increasing the density of the core by implosion techniques is the basis of most fission bomb designs. U238 cannot sustain a chain reaction. Even if some nuclei of U238 could be persuaded to fission, most of the emitted neutrons would be absorbed without causing fission. The few fissions that result would produce a reduced second generation of neutrons and the reactions rapidly dies away.

8 Fission weapon design

8.1 The atomic bomb

The term atomic bomb is normally reserved for a weapon deriving its energy from the fission of a core of U-235 or Pu-239. There are several variations, designed to improve yield or to reduce size or cost.
The basic design requirements for a fission weapon are:

- Keeping the fissile material in a sub-critical state before detonation, avoiding any possibility of predetonation
- Rapidly assembling the material into a super critical mass
- When the desired critical configuration has been reached, introducing neutrons to initiate the chain reaction.
- Ensuring that as high a proportion as possible of the core fissions before it blows itself apart

The degree of criticality of a mass of fissile material may be indicated by the multiplication factor k. This is simply the number of neutrons per fission that go on to cause further fissions. When $k<1$, the mass is sub-critical and no chain reaction will occur. A nuclear reactor controls $k=1$ to ensure steady state reaction. For a bomb, k must be as high as possible, usually about 2, at the start of the chain reaction.

8.1.1 Gun assembly

Perhaps the most obvious assembly method is to divide the critical mass into two parts and then fire one part at the other using a conventional gun mechanism. This was used in the Little Boy bomb dropped over Hiroshima and there was sufficient confidence in the method to use it without prior testing. The core of the bomb was a sphere of U-235, equivalent to about three critical masses. An axial cylinder was removed from the sphere in the manner of an apple core. The diameter was chosen to give rather less than a critical mass to the cylinder, which formed the bullet of the gun assembly. The geometry of the remaining sphere with cylinder removed gave a critical mass of less than one. The two sub-critical pieces were brought together by firing the cylinder down a gun barrel into the centre of the hollowed out sphere. Gun assembly method is inefficient compared with implosion. No compression of the fissile material take place, so there is no reduction in the mass of material required for criticality. The relatively slow assembly makes it unsuitable for plutonium because of the risk of pre-detonation and the gun mechanism makes the weapon large.

8.1.2 Implosion

Implosion is the basis for most atomic weapons and for the fission primary of thermonuclear weapons. A sub-critical sphere, which may be solid or hollow, of fissile material is compressed rapidly using conventional high explosives. Since critical mass is inversely proportional to the square of the density of the material, doubling the density of the sphere will produce a mass four times critical. Conventional high explosives are capable of producing very high temperatures and pressures, sufficient to turn a solid metal sphere into a hot compressible liquid. To achieve an efficient explosion, the spherical fissile core must be compressed symmetrically. This requires the production of a spherical implosive shock wave travelling inwards. Deviations from symmetry will squeeze the fissile core outwards and substantially reduce the fission yield. Production of the spherical wave involves the design and production of a set of explosive lenses which shape the wave, which then detonates a spherical shell of pure explosive known as the supercharge. The lens system involves using carefully shaped lenses of two explosives with different detonation velocities. The first British bomb used 32 lenses, which had to be detonated simultaneously to within microseconds. The design of the explosive lens system and its detonation turned out to be a demanding aspect of early bomb design. The explosive system represents a substantial proportion of the size and weight of a nuclear weapon and considerable improvements have been made in their design. One major development is to use an air lens, where the slower explosive is replaced with inert foam.

8.1.3 Initiation

A supercritical mass of fissile material will spontaneously start a chain reaction if a stray neutron entering the mass triggers a fission. This could be produced by a cosmic ray traversing the material or an occasional spontaneous fission. However, with an implosion design of bomb the compressed supercritical core stays at maximum density for a period of less than a microsecond and to achieve maximum yield it is essential that the reaction be initiated at this moment. This is done by generating a burst of neutrons at exactly the right moment. Three methods have been developed:

- A beryllium-polonium urchin. Beryllium-9 emits a neutron when struck by an alpha particle. The reaction is very inefficient, so a strong alpha emitter is needed to produce a neutron flux sufficient to initiate the required chain reaction. Polonium-210 is commonly used. The initiator consists of small quantity of beryllium held close to a suitable mass of polonium. Careful design is required so that no alpha particles reach the beryllium, to avoid neutron production and pre-detonation of the core, but arranged so that when assembly of the core occurs, the two components are mixed rapidly to initiate the fission reaction at the required instant. The initiator was referred to as the Urchin and housed in a dimple moulded in the centre of each of the two plutonium hemispheres. Polonium-210 has a half-life of 140 days, so there are maintenance problems for a weapon stockpile.

- A somewhat similar method uses a fusion reaction between deuterium and tritium to produce the required neutrons. The temperature and pressure reached at the centre of the imploding core is sufficient to produce thermonuclear fusion in the D-T mixture. By the standards of a thermonuclear weapon, the reaction is slow and inefficient and it is not possible to construct a weapon using explosive compression only. However, the reaction produces sufficient neutron flux to initiate fission of the imploding plutonium core. Careful engineering is needed to produce the high precision implosion necessary to produce the high temperature required for fusion. However, the 12-year half-life of tritium reduces the maintenance requirement compared with the polonium initiator.
- ENI. External Neutron Initiator. Most modern weapons use a device termed a pulse neutron tube. A short high voltage pulse is used to accelerate D or T ions into a metal hydride target. An intense pulse of neutrons is produced, whose timing can be accurately controlled. The initiator can be placed external to the implosion assembly, allowing simple maintenance.

8.1.4 Efficiency and Disassembly

As the fission process proceeds, the core expands and the chain reaction ceases. This limits the efficiency of a fission weapon, since much of the fissile material remains unused. The Fat Man bomb was about 17% efficient, while Little Boy was only 1.4%. The efficiency is improved by confining the core in a layer of dense material called the tamper. This has the effect of delaying the expansion of the core, allowing further stages of the chain reaction to proceed. The critical mass of fissile material is reduced if the fissile core is surrounded with a neutron reflector. Neutrons that would otherwise escape are reflected back into the core and contribute to the ongoing chain reaction. Suitable materials are beryllium, tungsten carbide or tungsten. As the chain reaction proceeds, the core expands rapidly, terminating the reaction. This may be delayed, by surrounding the core with a tamper made of dense material. The functions of reflector and tamper are distinct. However, U-238 is often used to combine the functions, since it is both dense and a good reflector of neutrons. An additional advantage is that the neutrons from the chain reaction are sufficiently energetic to cause fast fission in the U238. The proportion that cause fission is small. However, the contribution from fast fission in the uranium tamper was sufficient to add about 20% to the yield of FatMan.

8.1.5 Boosted fission

Incorporating a few grams of deuterium tritium mixture in the fission core may substantially increase the efficiency of a fission bomb. The early stage of the fission chain reaction in the core initiates a fusion reaction. This produces energetic neutrons, which cause additional fission in the surrounding core. The fusion neutrons are much more energetic than those produced by fission, resulting in a greater production of neutrons from the core fission. There is a rapid increase in the rate of fission and release of energy. In practical bomb design, the boosting gas mixture is held externally to the core and injected just before detonation; it is thought that all practical weapons are boosted designs. The very large neutron flux ensures a very rapid rate of fission, which happens so fast that a massive tamper is not always required to contain the disassembly. Although a thermonuclear fusion takes place, its contribution to the yield is small. Fusion boosting differs from the use of fusion for initiation, in that the fusion is initiated by the fission reaction and then boosts it further. With fusion initiation, the fusion reaction is started by the explosive driven implosion and takes place before fission; the fusion reaction has no effect on the yield, other than ensuring the explosion take place as planned.

8.1.6 Large fission weapons

Pure fission weapons have been tested up to a yield of 500 kT or more. It is necessary to use highly enriched uranium as the fissile material. Plutonium is unsuitable since spontaneous neutron emission of plutonium would cause predetonation in the large fissile mass. Safety is a serious problem with high yield fission bombs. A total mass several times the critical size is used, in the form of a hollow sphere. Simply mechanical collapse of the hollow space inside the core could render it highly supercritical. Any accidental detonation of the explosive layer would squash a hollow core and could lead to a very powerful explosion (in the tens of kilotons). Much milder accidents could also create serious criticality events. *Green Grass* used ball bearings to fill the hollow core and prevent accidental implosion; they were drained out as part of the arming process. Equivalent American warheads used a length of chain to fill the hollow core.

8.2 Fission weapon design

There are many variation s on fission weapon design, too numerous to detail. The spherical high explosive layer is required to produce an accurately spherical implosion wave. The number of explosive lenses has ranged fro 32 to 92. A relatively recent design has used a carefully shaped ovoid of explosive, shaped like a rugby football. It is possible to create a spherical wave at the centre by using only two-point detonation, one at each end. This makes the weapon more reliable and of smaller cross section. As well as the tamper and reflector shells surrounding the core, it is common to use a pusher of low-density material such as aluminium. This may be combined with the use of a levitated core, where the fissile core is held in the centre of the hollow pusher shell; this results in more effective compression. Another variation is to use a layered core, using both U-235 and Pu-239; the partition between the two materials may be optimised in several ways, including cost.

8.3 Neutron bomb

Enhanced radiation weapons, also known as neutron bombs, are low yield battlefield weapons designed to produce a very high lethal level of neutrons. The neutrons are able to penetrate steel armour of a tank and incapacitate the crew. Weapons were produced by the USA that could be incorporated in an artillery shell, with a total yield of about 1-kiloton. The design appeared to be a miniature staged radiation implosion fusion bomb, with three-quarters of the yield coming from the fusion reaction.

8.4 Layer cake design

This design was first conceived by Teller, who termed it the ‘alarm clock’. It was independently reinvented by Sakharov, who named it a *sloika* or layer cake.. It was invented again, but anonymously, by the British at Aldermaston, where it was built as *Green Bamboo*, but never tested. It is a concentric three-stage design, using a fission core explosion to initiate fusion in a surrounding layer of lithium-6 deuteride, via the production of tritium. This in turn emits neutrons and produces fast fission in a surrounding layer of U-238. The lithium deuteride layer has been heated and compressed by the assembly implosion and is further heated by the energy released during the formation of tritium. The layer reaches sufficient temperature to start a fusion reaction, equation 2. The third layer is a fission tamper of natural uranium. This constrains the fission and fusion layers, enhancing compression and increasing yield. In addition, the neutrons emitted by the fusion reaction cause the U-238 to undergo fast fission. The fast fission in the natural uranium layer releases far more energy than the fusion reaction; for this reason the Alarm Clock design is not generally classed as a "true" thermonuclear bomb.

There are two major variations on the design. In the "once through" approach the neutrons emitted by the fission in the core produce tritium in the lithium deuteride layer, which then reacts with the deuterium to undergo fusion. A layer at least 120 mm thickness is required to catch most of the emerging neutrons.[196] The neutrons emitted by this process in turn produce fission in the natural uranium tamper. Each fission in the fission trigger produces about one excess neutron. This transmutes one lithium nucleus, in turn causing one fusion reaction. This produces a fast neutron, which causes fast fission in the surrounding uranium. The reaction, and hence yield, in the tamper thus balances that of the fissile core. The result is to approximately double the yield of the fission core. Since each of the outer layers matches the layer beneath, there is little scope for increase in yield; the overall yield is about double that of the central fission core.

It is possible to increase the yield by using a thicker lithium deuteride blanket and thicker tamper, or perhaps by arranging them as intimate layers. Enough of the secondary neutrons produced by fast fission in the outer tamper end up back in the middle fusion layer to produce additional fusion reactions, which produce more neutrons to cause further fast fusion. In this way, a chain reaction is produced, with the chain: fast fission → tritium breeding → fusion→ fast fission. Another way of looking at this is that the fusion layer enables a chain reaction to take place in U-238. The reaction ceases as the explosion disperses the material. Joe 4 used a nominal 40 kT plutonium fission primary. The total yield was 400 kT, of which 15 to20% was from the thermonuclear reaction. The remainder came from fission in the tamper and core caused by the excess neutron flux.

9 Thermonuclear weapons

Several of the weapon types described above utilise the fusion reaction between deuterium and tritium. However, these reactions are there to provide neutrons for further fission; the fusion reaction contributes only a small fraction of the explosive yield and these weapons are not normally classified as hydrogen bombs. Only one design has been developed for a practical thermonuclear weapon.

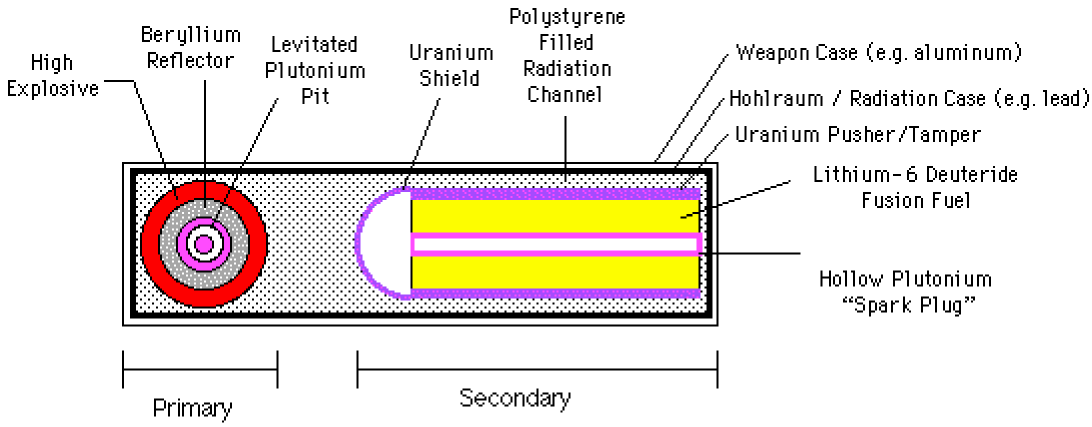
Although it was realised in principle from an early stage that a fission explosion might be used to create the pressure and temperature necessary to initiate a fusion reaction, it proved impossible to ignite a deuterium fuel charge using a fission explosion alone. A major design breakthrough was required before a thermonuclear weapon could be realised in practice. A fission explosion releases a large part of its energy in the form of gamma rays and Edward Teller realised that this radiation could be used to compress the fusion charge very rapidly, before the shock wave arrived to blow it apart. Stanislaw Ulam contributed a mathematical analysis of the process and it is

[196] www.milnet.com/nukeweap/Nfaq4-3.html This is the only alarm clock dimension found.

termed the Teller-Ulam design. It is otherwise known as a staged radiation implosion design and has subsequently been independently invented in Russia, the UK and other countries. The first thermonuclear explosion was achieved by the USA using the Teller-Ulam principle and a fusion stage consisting of liquid deuterium. Although first steps were made toward weaponising a liquid deuterium weapon, practical hydrogen bombs only became possible with the use of solid lithium deuteride; see equations 6 and 7. This enabled the so-called "dry" bomb.

A thermonuclear bomb thus consists of a fission primary, which acts as the trigger, and a fusion secondary. The secondary consists of lithium deuteride and has to be compressed to an extremely high temperature and pressure, as well as being subjected to a neutron flux, to produce a thermonuclear explosion.

Figure A1. Schematic of a Teller-Ulam radiation implosion weapon



When the primary trigger explodes, it emits a high flux of X-rays, which fill the radiation channel with energy. The uranium radiation shield protects the fusion fuel from the radiation to prevent it from being heated prematurely and asymmetrically. The physics of the system produces a very uniform cylindrical implosion, which compresses the fuel and the plutonium spark plug, which itself goes supercritical and explodes. The temperature of the lithium deuteride fuel is now sufficient for fusion to take place; all reactions in equations 2 to 5 occur. Where a uranium-238 tamper is used, the bomb is described as fission-fusion-fission. Very energetic neutrons are produced and cause fission in the uranium-238 tamper. The energy released by the fast fission in the tamper may account for up to 85% of the total energy released in a large bomb. This results in a dirty weapon with a high level of fall-out. Replacement of the uranium tamper with a material such as tungsten gives a so-called clean bomb.