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Questions on the British H-Bomb

by

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Developing Fusion Weapons, 1954-1958[1]

We know very little about the development of the British H-bomb. For example, we do not know which scientists should be credited with the crucial discoveries, the counterparts of Teller and Ulam in the U.S. and Sakharov, Zeldovich, and Khariton in the Soviet Union. We do not know when those conceptual advances occurred, or what the sequence of events were that led up to them.

In the aftermath of the first Soviet explosion in August 1949, there was an intense, largely secret, discussion among U.S. scientists, politicians, and the military about whether to proceed with an H-bomb. The debate had a moral dimension -- whether an H-bomb *should* be built -- and a theoretical dimension whether it *could* be built. In late 1949 and early 1950, when these issues were being deliberated, the American scientists did not know how to make an H-bomb. All agreed the effort would take a great amount of resources and money. After the decision was announced to develop an H-bomb by President Truman on 31 January 1950, it would be almost a year before Teller and Ulam figured out the conceptual solution, and another twenty-two months before it was tested.

We have no sense of these dynamics in the British case. Were there similar discussions and differences of opinion? The British benefited of course, as did the Soviets, in knowing that an H-bomb was possible after the American success on 31 October 1952. We know little about the factors that went into the British decision. For the most part the H-bomb probably appeared as the next logical step for an aspiring, albeit medium-sized, world power. What follows is an attempt to fill in some of that history and raise some issues, while we await the release of an official account.

Prime Minister Winston Churchill and a small subcommittee of the Cabinet decided on 16 June 1954 that Britain should develop and manufacture the H-bomb.[2] Churchill had been impressed by the magnitude and implications of the H-bomb, especially after reading a February 17 speech by the Chairman of the Joint Committee on Atomic Energy of the U.S. Congress, Sterling Cole. Soon after Churchill gave a major speech about its potential impact to the House of Commons on April 5. Shortly thereafter during a trip to North America Churchill informed his allies of the H-bomb decision; President Eisenhower on June 26, and Canadian Prime Minister Louis St. Laurent three days later. Upon returning to Great Britain Churchill discussed the decision with the Cabinet on July 7, 8, and 26, saying, "we could not expect to maintain our influence as a world Power unless we possessed the most up-to-date nuclear weapons." Among the British there were strong feelings at the time that U.K. possession could exert a restraining influence on U.S. policy. There was less concern about Soviet aggression at the time than there was with American adventurism.[3] With the release of the annual Defence White Paper (Cmd. 9391)

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[1] This short working paper in an excerpt from Volume V of the *Nuclear Weapons Databook* series, *British, French and Chinese Nuclear Weapons* (forthcoming: Westview Press). Readers' corrections and additions are welcomed and appreciated.

[2] Martin Gilbert, *'Never Despair,' Winston S. Churchill 1945-1965* (London: Heinemann, 1988), p. 993; Ian Clark and Nicholas J. Wheeler, *The British Origins of Nuclear Strategy 1945-1955* (Oxford: Clarendon Press, 1989), pp. 210-229. The Cabinet papers that revealed the decision to develop and produce an H-bomb were only released in January 1985 to the Public Record Office at Kew, London. The precise date was not known before that. Sir Frederick Brundrett, Chief Scientific Adviser to the Ministry of Defence and Chairman of the Defence Research Policy Committee, had originally recommended to the Government the development of a thermonuclear weapon and its urgent testing; Wilfrid Oulton, *Christmas Island Cracker: An Account of the Planning and Execution of the British Thermo-Nuclear Bomb Tests 1957* (London: Thomas Harmsworth Publishing, 1987) p. 363.

[3] Clark and Wheeler, *British Origins*, pp. 214-215.

on 17 February 1955 and Churchill's speech to the House of Commons on March 1, Britain publicly announced that it planned to develop, test, and produce H-bombs.[4]

The added challenge of also developing an H-bomb put a great strain on resources, and William Penney asked that William R.J. Cook be given special responsibility for managing the thermonuclear research, development, and testing program.[5] Cook began work at Aldermaston on 1 September 1954 having served under Brundrett, then Chief Scientific Adviser in the Ministry of Defense. Cook chose members of a Weapons Development Committee, which he would chair, to plan the work and the necessary tests.

Sometime over the next three years the British discovered how to make a workable two-stage thermonuclear bomb, using what has become known as the Teller-Ulam configuration based on the principle of radiation implosion.[6] Early clues may have come from the British participation in the U.S. *Castle* series conducted from the end of February until mid-May 1954.

The United States, in return for being allowed to participate in the British *Totem* test series in Australia, permitted RAF Canberra aircraft to conduct cloud sampling operations during U.S. Operation *Castle* in 1954 (see Table 1). This was a crucial series of tests for the American thermonuclear program. Various configurations were tested in the six *Castle* tests. The successful series proved the feasibility of lightweight, solid-fuel, deliverable thermonuclear weapons. British scientists no doubt quickly analyzed the U.S. fallout debris throughout March, April and May 1954. This analysis may have provided British scientists with certain clues and short cuts to solving their H-bomb puzzle.[7] It may be a coincidence but the formal political decision to proceed with an H-bomb was made on 16 June 1954.

Since the history of the British thermonuclear program remains classified, we must turn first to (limited and sometimes contradictory) descriptions of its nuclear tests to gain some understanding of the chronology of events. Following the H-bomb decision two years earlier, the first series of thermonuclear

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[4] Gilbert, *'Never Despair,'* pp. 1000, 1019, 1021-1022, 1098-1100. In the March 1st speech Churchill encapsulated the predicament: "it may well be that we shall, by a process of sublime irony, have reached a stage where safety will be the sturdy shield of terror, and survival the twin brother of annihilation."

[5] Lord Penney and V.H.B. Macklen, "William Richard Joseph Cook," *Biographical Memoirs of Fellows of the Royal Society (BMFRS)* (London: The Royal Society, 1988), Volume 34, pp. 49-52; Sir William Cook, Obituary, *The Times*, 19 September 1987, p. 12. See also Lorna Arnold, *A Very Special Relationship: British Atomic Weapon Trials in Australia* (London: HMSO, 1987), pp. 16, 120; Oulton, *Christmas Island Cracker*, p. 54.

[6] In a letter to President Eisenhower on 12 January 1955 Churchill mentions the progress being made. "I visited some of our secret establishments last week, and was struck by their progress and prospects, both in the atomic and in the hydrogen sphere ('sphere' is apposite in more senses than one). We are making atomic bombs on a steadily increasing scale, and we and *our experts are confident that we have the secret, perhaps even with some improvements, of the hydrogen bomb.*" Gilbert, *'Never Despair,'* p. 1090, (Emphasis added).

[7] The British may have detected the concentrations of isotopes much heavier than plutonium and realized that these isotopes could only have been produced by multiple neutron reactions in a highly compressed second stage. "A careful study of fallout by competent scientists can provide extremely useful information including in [Hans] Bethe's words, the 'key to the whole business,' that an enormous compression had occurred in the secondary, far greater than that possible with chemical explosive"; Daniel Hirsch & William G. Mathews, "The H-Bomb: Who Really Gave Away the Secret?" *Bulletin of the Atomic Scientists*, January/February 1990, p. 28.

tests, called *Mosaic*, was planned for Australia in 1956. The *Mosaic* tests were held in the Monte Bello Islands, the last time these islands would be used for nuclear testing.

Mosaic

The first test, *Mosaic G1* on 16 May 1956, provided scientific data on thermonuclear reactions in light elements, and required small quantities of thermonuclear materials to be incorporated into the fission bomb to see if it could be ignited.[8] The thermonuclear fuel used in the test was reported to be a small quantity of lithium hydride,[9] but was more probably lithium deuteride or lithium deutero-tritide. The UKAEA's Production Group had no experience of making it, and was having difficulty getting a production process to work. The lithium "hydride" was ready just in time.[10]

While the *Mosaic G1* test was technically successful it was disappointing in some respects. It produced, as expected, a yield in the 15-20 kt range and provided confidence about the performance of the implosion system, but showed that their more optimistic hopes about the effects of the thermonuclear reaction had not been realized; the effect of the small quantity of lithium "hydride" had been slight. Another test would be needed.[11]

In the second test, *Mosaic G2,* Arnold reports that natural uranium was used as a tamper, instead of lead as originally planned.[12] Fired on 19 June 1956, *G2* was the largest atomic test in Australia, producing a yield of 98 kt, a figure that the British Government concealed from the Australian government for almost 30 years.[13] "*G1* and *G2* made essential contributions to the knowledge of the fusion reaction, of the high energy neutrons it releases, and of the very complex effect of the fission they cause in natural uranium."[14] These statements imply that the *G2* design may have been similar to the "Second Idea," or "layer cake," approach taken by Sakharov, with a layer of U-238 surrounding a layer of lithium deuteride, which in turns surrounds the fissile core.[15] In any case the *Mosaic* results would be

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[8] There was a problem on how best to approach the Australian government about these tests. Either they were an important step towards testing a megaton weapon (specifically restricted in Australia), or they were the next step in the development of fission bombs, i.e. boosted fission weapons. It was a problem of presentation. British Prime Minister Anthony Eden told Menzies that these tests "would consist of atomic explosions with the inclusion of light materials as a boost" and that "It would of course be made clear in any public announcement that the explosions were atomic and not thermonuclear." Neither test was intended to give a yield more than 2½ times greater than *Hurricane*. Arnold, *Special Relationship*, pp. 109-110. In fact the second test was almost four times as large as *Hurricane*. For an explanation of "boosting" see: Thomas B. Cochran, William M. Arkin and Milton M. Hoenig, *Nuclear Weapons Databook: Volume I: U.S. Forces and Capabilities* (Cambridge, MA: Ballinger Publishing Co., 1984), p. 27.

[9] Arnold, *Special Relationship*, p. 120.

[10] Arnold, *Special Relationship*, p. 120.

[11] Arnold, *Special Relationship*, pp. 124-125.

[12] Arnold, *Special Relationship*, p. 125.

[13] Steve Conner, "The Nuclear Blast that Britain Kept Secret," *New Scientist*, 24 May 1984, p. 4.

[14] Arnold, *Special Relationship*, p. 132.

[15] Andrei Sakharov, *Memoirs*, (New York: Alfred A. Knopf, 1990); Yu. A. Romanov, " The Father of the Soviet Hydrogen Bomb," *Piroda*, August 1990; V.I. Ritus, "Who Else If Not Me?" *Piroda*, August 1990. The *Piroda* articles are conveniently reprinted in, Sidney D. Drell and Sergei P. Kapitza, eds., *Sakharov Remembered: A Tribute by Friends and Colleagues* (New

crucial to the plans for the *Grapple* series which was to begin eleven months later in May 1957 (see Table 2).

Grapple

Nine *Grapple* tests were conducted, four in 1957 and five in 1958. The four in 1957, and three of the five in 1958 were air-dropped from Valiant bombers. It is useful to examine the 1957 tests separately from the 1958 tests.

The 1957 tests The first test of the 1957 series, used a device code-named *Short Granite*, and was conducted on 15 May 1957. This test and the two following were freefall airbursts, detonated at a height of approximately 2300-2400 meters, 1.7 kilometers off the southeast tip of Malden Island. Squadron leader Group Captain Kenneth Hubbard's plane dropped the bomb with precision and "reported that the aircraft experienced shock waves, but not violent ones."[16] Oulton, the task force commander commented that, "The yield of *Short Granite* probably wasn't up to Bill Penney's hopes."[17]

The second *Grapple* test of May 31, used a device code named *Orange Herald*, "different in concept from *Short Granite* - another possible way of achieving the required result".[18] To understand the purpose of this test it is useful to recall how world public opinion viewed atmospheric testing in the period 1954-1958.[19] After the U.S. *Bravo* shot of the *Castle* series on 1 March 1954, people and governments all over the world became increasingly aware of the problems associated with radioactive fallout, and began to raise the issue of banning tests. As the global debate intensified throughout 1955-1956, it appeared to British weapon scientists and to politicians as though a ban might occur before the H-bomb could be tested. As Penney recounts, "Even if we had held our first thermonuclear tests before a moratorium began to operate, the tests might not have been either successful or definitive. What was

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York: American Institute of Physics, 1991), pp. 125-133, 134-148. As part of the Soviet H-bomb program, Sakharov and his colleagues proposed a design in which there were alternating layers of thermonuclear fuel, e.g. deuterium, tritium and a heavy substance like uranium-238. Sakharov called it "sloyka," (layer cake). His colleagues referred to Sakharov's approach as "sugarization" (in English Sakharov means "of sugar".) It was recognized that if tritium were substituted for some of the deuterium the situation would be improved. The problem was that tritium was expensive to make and it radioactively decays with a 12.3 year half-life. Another colleague, Vitaly Ginzberg, proposed substituting lithium-6 for some of the deuterium, as a means of generating tritium in the weapon itself. A further step was taken to incorporate the lithium-6 in the weapon as lithium deuteride. These two ideas of incorporating lithium deuteride and "sugarization" were incorporated in the "Joe 4" test on 12 August 1953.

[16] Hubbard and Simmons, *Operation 'Grapple,'* p. 96.

[17] Oulton, *Christmas Island Cracker*, pp. 333-334. Hubbard, the pilot of the Valiant bomber which dropped the device, stated the 10,000 lb bomb contained the "equivalent of a million tons of high explosive energy." Hubbard and Simmons, *Operation 'Grapple,'* p. 94. As we discuss below we believe he is wrong.

[18] Oulton, *Christmas Island Cracker*, p. 336.

[19] Robert A. Divine, *Blowing on the Wind: The Nuclear Test Ban Debate 1954-1960* (New York; Oxford University Press, 1978); Carolyn Kopp, "The Origins of the American Scientific Debate over Fallout Hazards," *Social Studies of Science*, Vol. 4, No. 4 (November 1979), pp. 403-422. An additional element was the role of the H-bomb played in domestic politics and in the creation of a widespread anti-nuclear movement centered around the Campaign for Nuclear Disarmament. See Richard Taylor, *Against the Bomb: The British Peace Movement, 1958-1965* (Oxford: Clarendon Press, 1988); J.P.G. Freeman, *Britain's Nuclear Arms Control Policy in the Context of Anglo-American Relations, 1957-68* (New York: St. Martin's Press, 1986) esp., pp. 23-102.

needed was a fall-back position."[20] The "fall-back" idea was put to Chief Scientific Advisor Brundrett, who agreed with it as long as it did not interfere with work on the H-bomb. At least one of the *Grapple* tests was of this "fall-back" fission device, and we believe it was *Orange Herald*. Penney described the "fall-back" as "a light weight fission bomb which would be considerably greater in yield than the earliest atomic bombs. This new device would be expensive in fissile material, but in a weapon system with accurate delivery, Britain would still have a formidable deterrent."[21] Oulton said, "as early as February 1957 it had been realised that the *Orange Herald* components with very different packing and transportation requirements, would not go into the bomb-bay of a Valiant" and were shipped to Christmas Island in three loads, each in a separate Hastings aircraft (see Table 3). Oulton's description is consistent with high-yield, pure-fission implosion device, which would have a large diameter, and be as Penney says "expensive in fissile material."[22] Cook "said the device embraced certain variations from the previous weapon."[23]

The third *Grapple* test used a device named *Purple Granite* and was fired on June 19, using a third plane and crew. On the day of the test Hubbard was told that a planned fourth test would not take place and that the Valiants should depart in two days for Britain.

Though Hubbard was led to believe that the fourth test was cancelled because the tests were successful, apparently everything did not go satisfactorily. On the evening after the *Purple Granite* test Cook told Oulton, "We haven't got it quite right. We shall have to do it all again, providing we can do so before the ban comes into force; so that means as soon as possible."[24] A second source states that, "The first Grapple series off Malden was something of a damp squib."[25] According to Brookes, "The first three

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[20] Penney, "Cook," *BMFRS*, p. 51. "This then was the political background to Aldermaston's work from 1953 to 1956. Penney and his scientists were working in an atmosphere compounded equally of extreme urgency and extreme uncertainty. They were under pressure to complete their research and development programmes as quickly as possible, to beat the ban on testing - and even perhaps a ban on fissile material production - that seemed inevitable sooner or later. This sense of urgency affected everyone in the project, and prompted the most strenuous efforts from scientists, engineers and industrial workers alike." Arnold, *Special Relationship*, p. 86.

[21] Penney, "Cook," *BMFRS*, p. 51.

[22] We think it is significant that no press representatives or other observers were allowed to witness the first explosion (*Grapple 1*), perhaps because of fear of its possible failure, or that the explosion might not have been quite as large as expected. The press was invited to witness the second *Grapple* test (*Grapple 2*), perhaps because it was not a novel design and they were more confident that it would work. As it turned out, because the journalists wanted to publish their stories in the Sunday papers they were briefed by a brigadier general as to what the explosion would be like, using the first test as a guide. All but one of the press corps ("Cassandra" (William Connor) of the *Daily Mirror*) wrote their reports before the explosion took place. The "eye-witness" accounts which appeared in the press were no such thing. Chapman Pincher, *Inside Story* (New York: Stein and Day, 1979), p. 178. Cassandra provided a lurid account in Monday's *Daily Mirror* (3 June 1957), "'A Rehearsal for the Death of the World,'" where he said the power of the blast was five million tons of TNT. It also may be significant that the code-name of the second device is different from the first and third. The *Orange Herald* test was the only one in which there were press observers. Very limited details about the other six crucial *Grapple* tests were provided to the press by the Ministry of Supply in London. They are remarkable for the lack of information they provide; See, *The Times*, May 16, 1957, p. 12; June 1, 1957, p. 6; June 20, 1957, p. 10; November 9, 1957; April 29, 1958, p. 8; September 3, 1958, p. 10; September 12, 1958, p. 9.

[23] "Second British Nuclear Test in the Pacific," *The Times*, June 1, 1957, p. 6.

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

[25] Blakeway and Lloyd-Roberts, *Fields of Thunder*, p. 158. Random House (2d ed., 1987) defines squib as "a small firework

Grapples were relatively small detonations ..."[26] Blakeway and Lloyd-Roberts say that "the size of the first bombs were, according to [unnamed] senior members of the task force, only half a megaton."[27] Chapman Pincher was told secretly "they had all been something of a flop."[28]

Presumably, the first and third tests did not work as planned and after informing Aldermaston to make some changes, another device was readied for a new fourth test.[29] Oulton tells us that on July 25th official word was received that further megaton tests would take place in November.[30] In order to save time, the task force of 2000 men at sea off Malden Island was dispensed with. Future tests were to take place just off Christmas Island itself.[31]

In September 1957 No. 49 Squadron was informed that they would be needed once again at Christmas Island. A detachment trained intensively and four planes returned in mid-October for a single test, called *Grapple X*. On 7 November 1957 Valiant bomber XD824 was taxied over to the AWRE assembly building area on Christmas Island and was loaded with the improved device, called "*Round C*."[32] The following day Squadron Leader Barney Millett's crew dropped *Round C* off of Christmas Island.[33] This time there were many witnesses who attested to its effects. The detonation took place only 25 miles from the main base and airfield, with its population of some 3000 men.[34] The size of the explosion may have been larger than anticipated and the blast wave was powerful. According to Oulton, Bill Cook's initial impression was "we can't tell until we do the proper analyses, but at first sight it looks

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consisting of a tube or ball filled with powder, that burns with a hissing noise terminated usually by a slight explosion."

[26] Andrew Brookes, *V-FORCE: The History of Britain's Airborne Deterrent* (London: Jane's, 1982), picture caption following p. 84. Presumably Brookes's candidate for the H-bomb is Grapple X, "... Squadron Leader Barney Millett's crew dropped what was probably the first British megaton device on November 8, 1957." Ibid.

[27] Blakeway and Lloyd-Roberts, *Fields of Thunder*, p. 158. We would argue that the correct way to read this sentence is that all three tests totaled 500 kilotons in yield, not each of them individually.

[28] "I must record one further Whitehall deception about Operation Grapple. The official statements put out by the government claimed that the three test explosions ... had been highly successful. In fact, as I was told secretly after returning to London, they had all been something of a flop. They were big blasts, as I had seen for myself [he only witnessed second test], but the yield had proved very disappointing. This had to be kept secret because there would have to be a repeat of the operation after improvements had been made to the weapon and the government believed that the Socialists would make political capital out of the partial failure." Pincher, *Inside Story*, p. 179.

[29] *Short Granite* and *Purple Granite* may have been similar designs given the similarity of their code names. One of the participants has told the authors that he recalls that the name of the device in the cancelled fourth test was, "Green Granite," though the order of the firing was changed several times. Private communication to authors.

[30] Oulton, *Christmas Island Cracker*, p. 366. The original fourth test may have been cancelled because it was known that it would not work.

[31] Blakeway and Lloyd-Roberts, *Fields of Thunder*, p. 158.

[32] Oulton, *Christmas Island Cracker*, p. 386.

[33] Brookes, *V-FORCE*, pp. 84-85.

[34] Hubbard and Simmons, *Operation 'Grapple,'* p. 106. The senior scientists and officers viewed the tests from a specially constructed bunker at 'C' site, 15 miles from the explosions; Blakeway and Lloyd-Roberts, *Fields of Thunder*, p. 161.

as though we've got what we wanted."[35]

What then should we conclude about the 1957 tests? By the summer of 1957 Britain had announced quite loudly to the world that thermonuclear tests had been conducted. Prime Minister Macmillan wrote in his memoirs, "On May 15 came the successful explosion of the first British H-bomb."[36] From all appearances it looked as though there was a third full member of the H-bomb club, after U.S. entry in October 1952 and Soviet entry in November 1955. Of course in a narrow, technical sense Britain had conducted "thermonuclear" tests, in that fusion materials (deuterium and tritium or their chemical compounds) were involved in the explosion. But if this were all that was implied, the United States exploded its first thermonuclear device in May 1951, and the Soviets in August 1953 (See Table 4). But these earlier U.S. and Soviet tests were not two-stage radiation implosion designs that fully exploited the use of the thermonuclear materials.[37]

It is doubtful that any of the four 1957 *Grapple* tests 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" design. And as we shall see in the next section, when U.S. and U.K. scientists resumed scientific cooperation in the summer of 1958 the British provided the Americans with information on two boosted fission designs, which had presumably been tested but not stockpiled. Assuming they were tested, the most likely development, or proof, tests of the booster concept were *Short Granite*, *Purple Granite* and *Round C*.

As discussed below, 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.

The 1958 tests On April 28 Valiant XD825 flew the same pattern as the earlier *Grapples* dropping device *Grapple Y* from 45,000 feet with a detonation at 7700 feet.[38] Hubbard comments on the "extremely impressive" blast wave and "Although this was the fifth megaton weapon detonation I had witnessed, it was surely the most impressive due to my close proximity."[39] Although Hubbard claims it was the fifth megaton weapon, it was undoubtingly the first explosion of such yield, and the first

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[35] Oulton, *Christmas Island Cracker*, p. 396.

[36] Harold Macmillan, *Riding the Storm 1956-1959* (New York: Harper & Row, 1971), p. 296.

[37] There is a practical limit on the yield of single-stage nuclear weapons - a few hundred kilotons to about a megaton - due to the size and weight of the device that can be delivered and the quantity of fissile material required. In a two-stage device radiation (x-rays) from the fission (or boosted fission) primary is contained and used to transfer energy to compress and ignite a physically separate component (the second stage) containing fusion or fissile material, or both. Additional stages can also be incorporated. Much higher yields can be achieved in this manner, and in fact there is no theoretical limit to the number of stages that might be used, and no theoretical limit to the yield achievable. The largest multi-stage thermonuclear device tested was 58 megatons. The largest multi-stage thermonuclear weapon stockpiled was in the range 20-30 megatons.

[38] For the 1958 tests of the *Grapple* series there was a change in Task Force Commanders, John Grandy took over from W. Oulton and Ginger Weir was replaced by Jack Roulston as Air Task Force Commander. Hubbard and his 49 Squadron were directed to participate and training ensued during January and February in the U.K. and in Libya. By March 28 four Valiants were back at Christmas Island.

[39] Hubbard and Simmons, *Operation 'Grapple,'* p. 114. This is the only test in which the test name and the device name are the same.

successful two-stage thermonuclear test.[40]

On 2 September a device named *Flagpole 1*, the first of four *Grapple Z* tests, was loaded aboard a Valiant and dropped in the same manner as before, but exploding at a higher altitude. Nine days later on September 11 the last air drop occurred when device *Halliard I* was successfully detonated as the second airdrop *Grapple Z* test. Hubbard comments that the mushroom cloud "towered to well over 60,000 feet."[41] By September 25 all the Valiants had returned to Britain.

Also as part of *Grapple Z* two kiloton-sized tests were conducted over the southeast portion of the atoll. Devices *Pennant 2* (on August 22) and *Burgee 2* (on September 23) were suspended from balloons and detonated at a height of 1450 feet.[42] These two tests were concerned with a fission primary for the H-bomb.

We estimate that the combined yield of the seven crucial *Grapple* tests during 1957 and 1958 was 8.5 megatons. Specifically, the four 1957 tests are estimated to have had a cumulative yield of one megaton, and the three large thermonuclear tests during the 1958 series are estimated to have averaged 2.5 megatons each (see Appendix).[43] Of the 8.5 megatons of total yield we estimate that 6.1 Mt is the fission yield portion and 2.4 Mt is the fusion yield portion.

Just after *Grapple Z* Hubbard's No. 49 Squadron was directed to plan for the next test at Christmas Island, code named *Grapple Mike*, about which nothing is known. But by late November 1958, Britain joined the U.S. and Soviet Union in a testing moratorium which would last until 1961. *Grapple Mike* was cancelled.[44] The British reviewed their test policy in December 1958, and it was decided for planning purposes to assume the indefinite suspension of all British nuclear tests. However when the U.S. and Soviet Union resumed testing in 1961, Britain did not resume the *Grapple* series and would never again test in the atmosphere.

Although Britain no longer conducted tests at Christmas Island, the site would be used by the Americans in 1962 for their last atmospheric tests before the signing of the Partial Test Ban Treaty on 5

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[40] The next day following the *Grapple Y* test, Hubbard was told that his Valiants could leave beginning on May 4 and by May 16 they were all back at their home base in the UK. There they continued to train until four planes returned, the last arriving on July 31 to participate in two live drops as part of Operation *Grapple Z*.

[41] Hubbard and Simmons, *Operation 'Grapple,'* p. 123.

[42] The maritime code names of the Grapple Z devices would not appear to have any significance.

[43] The methodology for this estimate comes from information provided by the AEC on the cumulative yields of U.S., Soviet and British tests for the period 1957-58; JCAE, *Fallout From Nuclear Weapons Tests*, Volume 1, 5-8 May 1959, p. 23. Subtracting out the U.S. portion and making certain other assumptions leaves a rough estimate of the British share. We now know that the total megatonnage for the Hardtack I series was 34 megatons with the fission portion 12.562 Mt.

[44] Hubbard and Simmons, *Operation 'Grapple,'* pp. 124-125. On 29 May 1958 Macmillan explained the year's schedule to certain Ministers: "Our last test (a few weeks ago [on 4 April]) was successful. Nevertheless it is absolutely vital for us to complete this series in September. If all goes well, we shall need only two explosions; but if (as is very possible) we have a failure *in the new and very special system which we want to test*, we shall need two more." *Riding the Storm*, p. 489, (Emphasis added). Apparently all went well in the two large tests conducted on September 2 and 11. The two other tests that were not conducted may have been *Grapple Mike*.

August 1963 prohibiting nuclear testing in the atmosphere, in outer space and underwater.[45] In return for the U.S. use of the base at Christmas Island, British scientists were at last granted access to American test data[46] and were allowed to participate in the underground nuclear test program at NTS.

Reestablishing Anglo-American Cooperation

In the aftermath of the Suez crisis in October 1956 the US and the UK began to make concerted efforts to improve all aspects of their relationship.[47] Three important meetings during 1957 laid the groundwork for the full resumption of cooperation in the nuclear weapons field. The first meeting, between Duncan Sandys, Minister of Defence and Charles Wilson, Secretary of Defense took place from January 28 to February 1 in Washington. Several important subjects were discussed, including the adaptation of British bombers to carry US nuclear weapons, storage of US nuclear bombs on British territory and the coordination of bombing targets between the Strategic Air Command and Bomber Command.[48]

The second meeting, between Eisenhower and Macmillan, took place from 21-24 March in Bermuda. From this meeting came the publicly announced decision to deploy Thor missiles to the UK. There were also two other matters covered in a secret annex, one regarding prior consultation on testing intiatives and the other about a common policy towards French nuclear ambitions.[49]

The Sputnik launch on 4 October 1957 accelerated the process to reverse the policies on nuclear cooperation. Macmillan took advantage of the moment and proposed a third meeting. President Eisenhower accepted, believing that improved US-UK nuclear cooperation would enhance the collective strength of the West vis-à-vis the Soviet Union. During the Washington summit, from October 23-25, 1957, Macmillan and Eisenhower agreed to a "Declaration of Common Purpose" which would be a turning point towards the greater sharing of information.[50] But full cooperation could only come if the Atomic Energy Act were amended.[51] On 27 January 1958 AEC Chairman Lewis Strauss sent a letter to the chairman of the Joint Committee on Atomic Energy detailing the proposed amendments. Eleven days

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[45] The U.S. entered into an agreement with the U.K. in late February 1962 to use Christmas Island for 24 atmospheric nuclear tests as part of Operation *Dominic I,* which were carried between April 25 and July 11, 1962. The U.K. participated in Operation *Dominic*. The U.K. support task was code-named Brigadoon and consisted of 300 men; Arnold, *Special Relationship*, p. 216; Blakeway and Lloyd-Roberts, *Fields of Thunder*, p. 177.

[46] Blakeway and Lloyd-Roberts, *Fields of Thunder*, p. 178.

[47] For the general political background see Timothy J. Botti, *The Long Wait: The Forging of the Anglo-American Nuclear Alliance, 1945-1958* (New York: Greenwood Press, 1987); Jan Melissen, "Prelude to Interdependence: The Anglo-American Relationship and the Limits of Great Britain's Nuclear Policy, 1952-1957," *Arms Control*, Vol. 11, No. 3 (December 1990), pp. 205-231.

[48] Jan Melissen, "The Restoration of the Nuclear Alliance: Great Britain and Atomic Negotiations with the United States, 1957-58," *Contemporary Record: The Journal of Contemporary British History*, Vol 6, No. 1 (Summer 1992), pp. 76-77. In the first half of 1957 a large number of bombs were stored in Britain.

[49] Melissen "Restoration," pp. 77-79.

[50] Botti, *The Long Wait*, pp. 199-212; Macmillan, *Riding the Storm*, pp. 313-341, 756-759; Melissen, "Restoration," pp. 83-86.

[51] Botti, *The Long Wait*, pp. 213-228.

of hearings were held in January, February, March, and April before the JCAE's Subcommittee on Agreements for Cooperation.[52] Throughout May and June the legislation was refined and then passed by both houses. It culminated in President Eisenhower signing into law on July 2 amendments to the Atomic Energy Act that allowed warhead information to be exchanged with the British. The two governments signed the agreement the following day and it entered into force on August 4.

After the signing it did not take long for US and British scientists to begin their exchanges. The first meeting was held in Washington, DC, from August 25-27, 1958.[53] Some recently declassified Atomic Energy Commission documents shed new light on details of the relationship of British and American scientists, of how Britain built its H-bomb, and its subsequent arsenal. The American participants transmitted to the British a written report and oral statements concerning weapons then in production, or about to be. Included were details of size, weight, shape, yield, amount of special nuclear material, method of nuclear safing, mechanical and electrical design, and vulnerability. The US weapons described were: Mark 7, Mark 15/39, Mark 19, Mark 25, Mark 27, Mark 28, Mark 31, Mark 33, and Mark 34. The Mark 15, 27, 28 were thermonuclear weapons. [54]

The UK representatives presented parallel information indicating what weapons they intended to develop, including two rather sophisticated small fission devices, one of which had been tested and the other to be tested.

According to the AEC report, "During the first meeting it became obvious that the United Kingdom has achieved an advanced state of weapon research and development in both fission and thermonuclear fields. Moreover, it appeared likely that certain advances made by the United Kingdom would be of benefit to the United States."[55] This accords with passages in Harold Macmillam's memoirs where he says of these talks, that they "proved to be of exceptional value. I was particularly glad to hear that, somewhat to the surprise of our friends, it was found that the specialist information was not all on one side."[56] In his diary entry of 1 September 1958 he wrote, "in some respects we are as far, and even further, advanced in the art than our American friends. They thought interchange of information would

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[52] *Hearings before Subcommittee on Agreements for Cooperation, JCAE, Amending the Atomic Energy Act of 1954 - Exchange of Military Information and Material with Allies*, 85th Cong., 2d sess., 1958. Eisenhower said in his State of the Union message on January 9, that it was "... wasteful... for friendly allies to consume talent and money in solving problems that their friends have already solved."

[53] AEC, Quarterly Progress Report to the JCAE, Part III - Weapons, July-September 1958, p. 14. Melissen says the dates on this document are not correct and should be August 27-28; "Restoration," p. 106.

[54] In the U.S. arsenal the Mark 7 was a 1700 lb fission bomb. It was also used for the Corporal and Honest John missiles. The Mark 15 was an early 7500 lb thermonuclear bomb. The Mark 39 was used on the Snark and Redstone missiles. The Mark 19 was a 280 mm gun-type artillery shell. The Mark 25 was the warhead for the Genie air-to-air missile. The Mark 27 was a 3200 lb Navy thermonuclear bomb, also used in the Regulus cruise missile. The Mark 28 was a 2000 lb thermonuclear bomb. The Mark 31 was used in the Nike-Hercules and Honest John missiles. The Mark 33 was an 8-inch gun type artillery shell. The Mark 34 was used for a Navy strike bomb (Hotpoint), torpedo (ASTOR) and depth charge (Lulu).

[55] Ibid.

[56] Macmillan, *Riding the Storm*, p. 565. See also Macmillan's letter to Sir Edwin Plowden, Ibid., p. 566. In a September 26, 1958 letter to Eisenhower, Commissionaer Libbey said theat the British scientists "were judged to be of outstanding caliber by their U.S. counterparts"; quoted in Melissen, "Restoration," p. 93.

be all *give*. They are keen that we should complete our series, especially the last megaton [*Halliard*, September 11], the character of which is novel and of deep interest to them."[57] The novelty that Macmillan speaks of apparently has to do with the configuration of the two stages, using a spherical rather than cylindrical geometry. In a later meeting, we are told in a September 1960 report, that information and data was received from the UK about "weapon design 'Peanut.'"[58] This "Peanut" shape accords with a description of what modern weapons look like; "You may recall that a modern weapon looks like two basketballs side by side; what we call the primary, and what we call the secondary or thermonuclear components."[59]

Also at this first meeting it came to light that "the British apparently do not have an appreciation that plutonium produced from uranium subjected to higher burnup in their power reactors is usable in weapons. This knowledge would be of great significance to their civilian power programs. In addition, they have apparently not exerted major effort toward making their weapons one-point safe." [60]

Los Alamos Director Norris Bradbury mentions a meeting with the British, though it is difficult to determine exactly when it occurred.

> "Sometime after the Mike shot [31 October 1952], contact with the British had been re-established on purely fission things. The British were allies, after all, a small, poor country. And so we had established some degree of technical assistance in this particular field. The discussions went on partly in England and partly here. It soon became perfectly clear that the British had something else in mind besides the conventional implosion weapon. They hinted around about this and I would have made a small bet that what we were talking about was the same idea that formed the basis of Mike. So I asked if they would be willing to disclose the weight, size and shape of this thing and just what it looked like from the outside. They were, and did so - just what you could see. I then hastily asked for a recess because it was perfectly obvious they were describing something that we had gone through great pains in inventing by Teller and Ulam and others. And they'd invented it too. Whether or not there was technical leakage was never learned."[61]

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[57] Macmillan, *Riding the Storm*, p. 565 (Emphasis in original).

[58] AEC, Monthly Report to the GAC, September 1960, p. III-53.

[59] HASC, DOE FY 1986, p. 209.

[60] AEC, Quarterly Progress Report to the JCAE, Part III - Weapons, July-September 1958, p. 14. The following paragraph is contained in a draft letter from President Eisenhower to Harold Macmillan, dated July 21, 1958: "The second point deals with the military usefulness of plutonium generated in atomic power reactors. It is widely believed that unless the uranium fuel elements in which plutonium is made are exposed only briefly and are frequently replaced with fresh fuel, that the plutonium is not weapons grade. When the new military agreement becomes effective, our people will be in a position to tell yours that you can save considerable sums relative to your present costs of atomic power by leaving the fuel in the reactors for longer periods and nevertheless produce plutonium suitable for weapons. Thus, there will be a direct financial benefit to your civilian power program which will stem from the new military agreement"; Memorandum to General Goodpaster, from Lewis L. Strauss, 29 July 1958, enclosure. It is not known if the letter was sent.

[61] Norris Bradbury, "Los Alamos - The First 25 Years," in Lawrence Badash, Joseph O. Hirschfelder and Herbert P. Broida, eds., *Reminiscences of Los Alamos 1943-1945* (Dordrecht, Holland: D. Reidel Publishing Company, 1980), pp. 169-170. This meeting may be one of a series conducted between technical experts held December 3-5, 1957 in the Pentagon; see Botti, *The Long Wait*, pp. 201, 204, 206. Penney says "The United States in the autumn of 1957 approached the United Kingdom with an

At the August meeting, the British extended a verbal invitation to the AEC to send U.S. observers to Christmas Island.

A second meeting was held in Albuquerque from September 15-17 1958. Among its highlights were:

1. "We [the U.S.] provided the British with blueprints, material specifications, and relevant theoretical and experimental information related to the XW-47 warhead; Mark 28, 44, 45, and 48 warhead; and the (deleted) for our TX-41 and TX-46 weapons now under development.
2. The British provided similar information on their high- yield fission bomb, now in stockpile; 2,200-pound thermonuclear bomb, small (deleted) device; two boosted fissions designs; planned 1,500 pound thermonuclear weapon; and proposed 6-inch device.
3. Both parties discussed in detail neutron sources for initiators, high explosive specifications, yields and designs, and mechanical and electrical components."[62]

For the Americans this was the first time they had a real opportunity to take stock of the British program. As the report says, "The British have performed experiments in both [... deleted ...] and their program in this regard approximates our own experiments of 1954-55. They have tested radiation-implosion, two-stage devices corresponding to our state of knowledge of about 1954-55. They fully understand the advantage of the [... deleted ...] design and their state of knowledge is about the same or somewhat better than ours of 1956."[63]

At this meeting an invitation was extended to UK representatives to visit the Nevada Test Site in October. Three AWRE representatives did visit from October 6-11, and observed test procedures,

(..continued)

invitation to explain the position which had been reached in the technology and design of British nuclear weapons, with a half-promise that if the position was technically good, collaboration in nuclear weapons might be resumed in areas where both sides had a stated interest. A presentation was made and was favourably received." Penney, "Cook," *BMFRS*, p. 51.

[62] AEC, Quarterly Progress Report to the JCAE, Part III - Weapons, July-September 1958, p. 15. Botti, the most careful student of the creation of the partnership, says; "Although the JCAE made certain that the administration did not agree to any exchange of hydrogen weapons data under the Anglo-American bilateral agreement of July 3, 1958, it is unclear whether the May 7, 1959, agreement for transfer of nonnuclear components and special nuclear materials for 'atomic weapons' permitted an exchange of hydrogen weapons data. It must be assumed, however, that soon thereafter the British and Americans made arrangements that did permit such an exchange." *The Long Wait*, p. 248. As these documents show the exchange was extensive and comprehensive from the very first meetings in August and September 1958 and included very specific information about a whole range of hydrogen weapons. Among those participating were Sir William Cook, Edward Teller, Major General Herbert B. Loper, Assistant to the Secretary (Atomic Energy), and Brigadier General Alfred D. Starbird, Director of AEC Division of Military Application; AEC, Albuquerque Operations Office, Office of Information, AL-59-PQ, 11 September 1958.

[63] AEC, Quarterly Progress Report to the JCAE, Part III - Weapons, July-September 1958, p. 15. The U.S. conducted three important test series in the period 1954-56. After making the successful breakthrough to a two-stage, H-bomb in *Mike* (October 1952), the 1954 *Castle* series was crucial in proof testing certain weapons and proving the feasibility of solid-fueled (lithium deuteride) thermonuclear weapons that could be stockpiled. The fourteen tests of Operation *Teapot*, held at NTS in 1955, were for the purpose of establishing the feasibility of 16-inch diameter implosion systems and proving the effectiveness of tritium gas boosting of hollow pit systems, as either fission weapons or as primaries for two-stage weapons. The 17 shots of Operation *Redwing*, conducted in the South Pacific in mid-1956, tested designs of small diameter implosion systems (8 and 12 inch), and small diameter two-stage systems (13-15 inch), and several high-yield weapons about to enter the stockpile. Six tests were in the megaton range (1, 1.9, 3.4, 3.5, 4.7, 5 Mt), four between 190 and 370 kt, and seven between sub kt and 39 kt.

diagnostic instrumentation and witnessed the firing of shots on the 8th and 10th.[64]

On October 23-25, 1958 representatives of the CIA, DOD, and AEC discussed with British Intelligence representatives their interpretations of British and Soviet nuclear weapon capabilities and nuclear tests. In this meeting, the US presented analyses of its intelligence information about British and Soviet test shots. The US data on the UK test shots were compared with UK test data and then used to evaluate the accuracy of US interpretations. The British also provided their intelligence information on specific Soviet shots. "Despite the different background and experience of U.S. and U.K. groups on weapons development, their independently derived evaluation techniques were in many cases similar, but even when different they produced remarkable agreement on the nature of Soviet nuclear weapons tests. These discussions gave confidence to our estimates of the general characteristics of most of the tested Soviet nuclear devices and to our estimates of the rate and direction of the Soviet weapons development program."[65]

In a 6 September 1958 letter President Eisenhower authorized that fabrication prints, design prints, and material specifications be furnished to the United Kingdom on the Mark 28 weapon.[66] Soon after the details were worked out to expedite British production of the Mark 28. Ten Americans visited Aldermaston from November 17-25 to inspect the AWRE facilities and to discuss weapon electronics; uranium and plutonium fabrication; high explosives; tritium; (deleted), beryllium; solid fusion materials; plastics, rubber, and adhesives; engineering; and weapon assembly.[67] Their goal was to have a production unit completed by April 1960. From December 8 to the 17, 1958 fifteen U.K. delegates visited the major AEC production facilities concerned with the fabrication of the Mark 28 and were given detailed information on tooling and techniques, and shown pertinent documents and drawings of weapon parts. In January and February 1959 three groups of representatives from the United Kingdom made 2-week visits to AEC installations.

On April 13-14, 1959 a joint US-UK conference was held in London to review the exchanges of atomic information since August 1958 and develop a program for future exchanges.[68] The conference established 15 areas of atomic weapons design and technology for study by Joint Working Groups (JOWOGS). Also at the same meeting the U.K. indicated its desire to produce another device. Though the exact reference is deleted, a later Report says that full information on the Mark 47 has been provided "upon which the United Kingdom can base a decision as to whether or not they should produce this weapon also."[69]

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[64] AEC, Memorandum for Chairman Seaborg, from BGEN A.W. Betts, concerning Weapons Test Information, September 15, 1961, pp. 1-2.

[65] AEC, Program Status Report to the JCAE, December 31, 1958, p. 14.

[66] AEC, Quarterly Progress Report to the JCAE, January-March 1959, Part III - Weapons, p. 6. See also AEC, Letter from General Manager to Herbert B. Loper, October 30, 1958.

[67] AEC, Program Status Report to the JCAE, December 31, 1958, Part III - Weapons, p. 15.

[68] AEC, Quarterly Progress Report to the JCAE, April-June 1959, Part III - Weapons, p. 4.

[69] AEC, Progress Report on Selected Programs to the JCAE, May 1960, Part III/Weapons, p. 15. The U.S. used the W47 warhead on the Polaris A1 and A2 SLBM. The 720 lb Livermore warhead had two yields; 600 kt and 800 kt.

A second meeting (the meetings came to be called Stocktake) was held in Washington in October 1959, a third in London in May 1960, a fourth in Washington in October 1960, a fifth in July 1961, a sixth in Washington on July 23-24, 1962, a seventh in the UK on May 27-29, 1963.[70] At these meetings JOWOGS were added, cancelled, or modified and subjects for Exchange of Information by Visits and Reports (EIVRS) were established as well.

As the relationship became more routine the President determined that more and more information could be given to the British. For example, the July-September 1959 report stated, "Information necessary to explore jointly with the United Kingdom various concepts which might lead to the development of a 500 -to 600 -pound, deleted warhead," ... and "warheads in the weight range of 100 to 200 pounds with yields of deleted" and design information on the 1600 lb XW-35.[71]

By May 1960 the US had provided the UK with the nonnuclear parts to six Mark 28/49 weapons to assist in the Mark 28 production of the British. By May 1961 they had produced a modified version of the US Mark 28 bomb and were planning to produce several variations of the Mark 57.[72]

On a ongoing basis information was exchanged on a huge number of topics. The following is a representative, though not exhaustive list that shows the range of topics and the kinds of information discussed and exchanged: one-point safety, computer codes, metallurgy and fabrication technology for beryllium, uranium and plutonium, corrosion of uranium in the presence of water and water vapor, outer space testing, the technology of lithium compounds, high explosives, deuterium monitors, extinguishing plutonium fires, high speed cameras, mechanical safing, liquid and solid explosive shock initiation, environmental sensing switches, neutron sources, clandestine testing, tritium reservoirs, neutron sources, telemetry, hydrodynamic and shock relations for problems with spherical and cylindrical symmetry, cross sections, radiochemistry, atomic demolition munitions, warhead hardening, and asymmetric detonations.

By May 1961 the UK was planning to use the Skybolt missile system and was considering use of the XW-59 as the warhead. The program eventually would be cancelled. By October 1962 the British had requested information on the XW-58 and by the end of year it was being supplied.[73] At this point the Livermore designed 250 lb warhead with a yield of 200 kt was nearing production for its use on the U.S. Navy's Polaris A3 SLBM. It is most likely that the British produced a version of their own for their Polaris missiles.

The Director of Military Application noted in a 15 September 1961 memo that, "In the three years since the 1958 Amendment to the U.S. Atomic Energy Act became effective, the President (or the AEC and DOD by its delegation) has made 16 statutory determinations authorizing the transmission to the U.K.

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[70] Los Alamos National Laboratory Director, Sigfried Hecker attended the Stocktake '91 in London in June 1991. It was the 21st review of the 1958 US/UK agreement: *Los Alamos News Bulletin*, 12 July 1991, p. 3.

[71] AEC, Quarterly Progress Report to the JCAE, July-September 1959, Part III, p. 5. The W35 had just been cancelled in favor of the W49, for use on the Atlas D, Thor and Jupiter.

[72] AEC, Progress Report on Selected Programs to the JCAE, May 1961, Part III/Weapons, p. 8.

[73] AEC, Monthly Report to the GAC, October 1962, p. III-64; AEC, Progress Report on Selected Programs to the JCAE, December 1962, Part III/Weapons, p. 24.

of Restricted Data to improve weapon design, development or fabrication capability of the U.K."[74]

[74] AEC, Memorandum for Chairman Seaborg, from BGEN A.W. Betts, concerning Weapons Test Information, September 15, 1961, p. 2. One scholar makes the curious comment that "Contrary to popular belief and the logic of the 1958 US-UK agreement and its subsequent amendments, all British nuclear warheads have been of indigenous design, rather than copies of American types.": Simpson, *Independent State*, p. xxix.

Table 1
BRITISH OBTAIN U.S. THERMONUCLEAR FALLOUT DATA

To obtain the fallout data from the American thermonuclear tests the RAF plan was to have two Canberra aircraft with wing-tip samplers and a small sampler attached to the underside of the fuselage. The RAF aircraft were flown from England to Kwajalein by way of Australia and the Admiralty Islands. The departure point of the last leg was Momote. Enroute from Momote to Kwajalein on 23 February 1954, one Canberra lost contact, disappeared, and was not found. The other Canberra landed at Kwajalein. A replacement aircraft was also lost enroute from Momote to Kwajalein. Though the plane and crew were found on an atoll on March 11, the aircraft could not be used. Thus only one Canberra was operational for sampling missions for events *Bravo* (February 28), *Romeo* (March 26), and *Koon* (April 6). An engine failure just prior to take-off prevented participation in *Union* (April 25). The second replacement Canberra arrived at Kwajalein on April 27 and the two planes participated in events *Yankee* (May 4) and *Nectar* (May 13). For each event the British were given notice of the date and time of detonation, meteorological data, and vectoring information to correctly track and intercept the cloud. RAF insignia were deleted. The code name "Eager Beaver" was used for operational missions as a voice call sign. Because their ability to collect samples was impaired due to the loss of some aircraft the U.S. provided filter papers that it had collected. The British utilized Hastings transport planes to fly the collected air samples from Kwajalein back to England the day after each event.

Sources: Headquarters, Joint Task Force Seven, Memorandum for Record, prepared by Col. David O. Byars, Jr. USA for Commander's Notebook, Subject: Summary of British Participation in Operation CASTLE, 8 October 1954; Letter to Sterling Cole, Chairman JCAE, from Lewis Strauss, Chairman, AEC, 11, June 1954.

Table 2
SELECTION OF A NEW TEST SITE FOR *GRAPPLE*

As early as August 1955 the British had begun to plan seriously for a series of tests in the Pacific, code-named *Grapple*. Britain searched for islands in a large ocean area, far from land masses and people, as Australia did not want H-bombs tested on her territory. The *Grapple* planning committee accepted the choice of Christmas Island in November 1955,[75] its isolation considered ideal for atmospheric testing.[76] In March and April 1956 the base on Christmas Island was established. Christmas Island was initially chosen as the main base with Malden Island, some 400 nautical miles to the south, to be used for instrumentation during the weapon drop.[77] In late April 1956 journalist Chapman Pincher, in the *Daily Express*, broke the news that the tests would take place near Christmas Island. On 7 June 1956 Prime Minister Anthony Eden informed Parliament of the forthcoming tests,[78] and a month later the general public was told in an announcement on 7 July 1956, two years after the decision was taken.[79]

[75] Blakeway and Lloyd-Roberts, *Fields of Thunder*, p. 146.

[76] Christmas Island, one of the Line Islands group, is situated just south of the equator in the middle of the Pacific Ocean. Hawaii is a thousand miles to the north, while Fiji lies 1500 miles to the south-west. It is the Pacific's largest coral atoll, 35 miles by 24 miles at its widest point. The highest point is only 25 feet above sea level. On 12 July 1979, Christmas Island ceased to be part of the British Crown Colony of the Gilbert and Ellice Islands and became part of the Republic of Kiribati. The former Christmas Island is now called Kiritimati. Blakeway and Lloyd-Roberts, *Fields of Thunder*, pp. 146-148.

[77] Malden island is a flat triangular coral island about five miles in length from east to west and about 4½ miles at its greatest breadth. It was discovered by Captain the Rt Hon Lord Byron of HMS *Blonde* on 29 July 1825. Malden island was formally occupied and claimed for Britain by a British subject from Australia, Benjamin B. Nicholson, in 1864. From that time until 1927 the atoll was dug for guano and at one stage was producing 12-14,000 tons annually. The guano business ceased after World War I and all the inhabitants left. When the British arrived once more in the 1950s they found three wild pigs and a settlement of boobie birds; Blakeway and Lloyd-Roberts, *Fields of Thunder*, p. 148; Kenneth Hubbard and Michael Simmons, *Operation 'Grapple': Testing Britain's First H-Bomb* (London: Ian Allan Ltd, 1985), p. 39.

[78] "Her Majesty's Government has decided to carry out a limited number of nuclear explosions in the megaton range. The tests will be high air bursts and will not involve heavy fall-out. All safety precautions will be taken in the light of our knowledge and the experience gained from the tests of other countries." In his memoirs Eden refers to the announcement but cannot be correct by implying that hydrogen bombs first began production, untested, in January 1955; "On June 7, 1956, I announced in the House of Commons that only in the following year the United Kingdom would carry out a number of tests of the hydrogen bomb, which had now been in production for eighteen months." Anthony Eden, *Full Circle*, (Boston: Houghton Mifflin, 1960), p. 422.

[79] Blakeway and Lloyd-Roberts, *Fields of Thunder*, p. 148.

Table 3
TRANSPORTING THE GRAPPLE COMPONENTS

The components of each of the nine *Grapple* devices were airlifted by at least two (and possibly more) courier Valiants, except in the case of *Orange Herald* where Hastings were used. Normally the planes flew the same route to the Pacific as the other Valiant bombers that dropped them. The 10,350 mile journey would begin with the device components transported from Aldermaston to RAF Wittering, where 49 Squadron was based. From there a Valiant would first stop to top-off its fuel tanks at a RAF base in Aldergrove, Northern Ireland, just east of Belfast. Then it was a 2200 mile flight to Goose Bay air base in Labrador. The next leg was an almost equal flight to Namao, a Canadian air force base in Alberta. From southern Canada the Valiant would fly another 1125 miles to Travis AFB, outside of San Francisco. The next stop was Hickham AFB in Honolulu and then the last leg to Christmas Island. Immediately upon arrival of the courier planes the special cargo would be handed over to the Scientific Weapons Team and placed in the weapon assembly area.

It is obvious that the U.S. and Canadian governments permitted these British airplanes to overfly their airspace and that many arrangements had to be devised at each of the different air bases, regarding security and refueling, among other things. The details of these agreements and arrangements are not known.

Source: Hubbard and Simmons, *Operation 'Grapple,'* pp. 60-70.

Table 4
CONFUSION IN THE DEFINITION OF AN H-BOMB

Was Prime Minister Macmillan wrong in calling the first *Grapple* test on 15 May 1957 an H-bomb? There is no doubt that the British government has sought to confuse the issue from 1957 until now. In an official table listing the tests, the Ministry of Defense defines "Megaton - yield range" as a "few hundred kiloton to several Megaton," while "kiloton - yield range" is defined as "1-1000 kiloton". Thus a large "boosted" fission device could be defined as "megaton", while a small two-stage thermonuclear device could be defined as "kiloton." To the uninitiated one look at the "Megaton" description of the first *Grapple* test on 15 May 1957 leads to the assumption that that was when the first successful British two-stage H-bomb was tested. To date many accounts of the *Grapple* series, even by observers and participants, have been either deliberately or unwittingly deceptive and/or misinformed.

The fact of merely using hydrogen materials in tests (e.g. tritium, deuterium) may have been all that was needed in some people's minds for it to be an H-bomb. There seems to be a similar dynamic at work with respect to the Soviet thermonuclear development effort. The Soviet device for the "Joe 4" test on 12 August 1953 was the single-stage layer-cake design developed by Sakharov. Sakharov speaks of this design in terms of a "backup".[80] Sakharov, Zeldovich, and Khariton made their conceptual breakthrough in early 1954, in what Sakharov refers to as the "Third Idea," basically the Teller-Ulam configuration. On 22 November 1955 the "Third Idea" was successfully tested and the Soviet Union became the second member of the H-bomb club. Nonetheless, Premier Malenkov on 8 August 1953, announcing the "Joe 4" test (four days before it took place), claimed that the United States had "no monopoly in the production of the hydrogen bomb." In a Soviet government announcement of August 20 five references are made to a "hydrogen bomb." Even Sakharov speaks of it in these terms. Great honors were bestowed as a result of the accomplishment. Sakharov was made a full member of the Academy of Sciences by a unanimous vote in October, a Hero of Socialist Labor in December and given a Stalin Prize. It would only be the following year that the "Third Idea" would become the basis for a true two-stage thermonuclear weapon.

Perhaps something like this was occurring in the tightly restricted circles of the British government. The politicians either did not know or did not care to be precise about bomb designs, and neither the American or the Soviets, who may have known, would publicly correct the record.

It is also important in weighing evidence to question how much was known by the various participants. The most comprehensive description of Operation *Grapple* has been by No. 49 Squadron leader Group Captain Kenneth Hubbard, whose Valiant aircraft dropped the bombs. As he says, "everything relating to this operation was in the highest level of security, all information would be on a need to know basis."[81] Neither the pilots, nor the squadron leader had a "need to know" exactly what type of bomb he was dropping. As the day of the first *Grapple* test approached Hubbard says, "Security on the island was extremely strict and even though my own crew was to drop the first live weapon, it was considered that our knowledge of the details of this should be restricted to the appropriate switching drills on the aircraft weapons panel. Our know-how was concentrated on the aircraft, its capabilities and various emergency procedures to be adopted in the event of weapon malfunction or fault in release

[80] Sakharov, *Memoirs*, pp. 184, 188.

[81] Hubbard and Simmons, *Operation 'Grapple,'* p. 34.

mechanism."[82] He goes on to say that with 'D' Day two days away his aircraft, Valiant XD818, "was scheduled to be taxied to the weapon area and handed over to the Scientific Weapons Team to test and load the live nuclear H-bomb, code named '*Short Granite*.'" After handing over the plane, "from this point we would not be allowed near the aircraft until the morning of 'D' Day with '*Short Granite*' loaded and ready for the first scale test."[83] In other words, the crew did not witness and in effect did not know what was loaded in their plane. Furthermore, all airdrops used the same *Blue Danube* casing, whose ballistics were well known; and all seven airdrops followed the same pattern with the Valiant bomber flying at Mach 0.76 airspeed and releasing the bomb at 45,000 feet. The Scientific Weapons Team fuzed the 1957 devices to detonate at roughly 7500 feet, while two of the 1958 devices went off at higher altitudes, possibly implying a larger explosion. At the time of detonation the bomber would be nine nautical miles away and by the time the blast wave hit it would be 12 nautical miles away. There was no physical evidence by which the pilots could determine whether the device was fission or fusion, much less the number of stages.

Although Hubbard repeatedly implies that it is a *hydrogen* bomb that he dropped at the first *Grapple* test -- "Tomorrow the world would know that Britain had a Hydrogen bomb in her armoury" -- like Prime Minister Macmillan, he surely did not appreciate the difference between a single-stage and a two-stage thermonuclear weapon.

[82] Hubbard and Simmons, *Operation 'Grapple,'* p. 82.

[83] Hubbard and Simmons, *Operation 'Grapple,'* pp. 90, 92.

Table 5
PATRIMONY OF THE BRITISH H-BOMB

We do not know which British scientists were instrumental in solving the conceptual problems that resulted in a British hydrogen bomb. In 1985 one person came forward to say that he was responsible. In a 13 May 1985 letter to Prime Minister Thatcher, John C. Ward said:

> "In the spring of 1955 advertisements were prominently displayed for theoretical physicists to join the staff at Aldermaston ... I was offered a position but decided to refuse ... When I telephoned William Cook to tell him of this decision, he was so upset that I said I would come if the matter was sufficiently urgent. He said it was indeed most urgent...
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> "To my amazement, when I reached Aldermaston I was assigned the improbable job of uncovering the secret of the Ulam-Teller invention, an idea of genius far beyond the talents of the personnel at Aldermaston, a fact well-known to both Cook and Penney. Under great stress, and with no assistance whatever, I came up with the correct scheme within six months, minor modifications excepted (and also obvious precautions). When presented at a subsequent meeting, a crucial one, judging by the full-dress uniform of the visiting Admiral, my proposal (with working drawings of a primary), the only one offered, was preemptorily rejected by Penney, who declared the matter not to be urgent anyway! I was supported barely pro-forma, if at all, by Cook. Afterwards Penney demonstrated his complete lack of understanding of the problem in a private talk with Cook and myself. I was not invited to subsequent meetings held to discuss the project.
>
> I therefore quite correctly and naturally resigned forthwith, and returned to the U.S. taking the first job I cold get."

John Clive Ward was born in London on 1 August 1924 and got his Ph.D from Merton College, Oxford in 1949. At an early age he gained international renown for the "Ward identity," a basic theorem of quantum electrodynamics. While at the Clarendon Laboratory at Oxford, he submitted four contributions that were published in the 1950 volume of the *Physical Review*, "The Scattering of Light by Light," (Vol. 77, p. 293); "An Identity in Quantum Electrodynamics," (Vol. 78, p. 182): "A Convergent Non-Linear Field Theory," (Vol 79, p. 406): "Quantum Effects in the Interaction of Electrons with High Frequency Fields," (Vol. 80, p. 119). With Elliott W. Montroll, Ward coauthored an important article entitled, "Quantum Statistics of Interacting Particles," *Physics of Fluids* Vol. 1, 1958, pp. 55-72.

Andrei Sakharov, in recounting some of the key achievements in physics in the late forties says, "There were titans who overcame all of these difficulties --Tomonaga, Schwinger, Feynman, Dyson, Wick, Ward, and many others." (p. 84). Ward spent three periods at the Institute for Advanced Study, Princeton, New Jersey; 1951-52, 1954-55, and 1960-61. He also taught at the Carnegie Institute of Technolgy (1959-60) and Johns Hopkins (1961-66) in the U.S., and at Macquarie University in Sydney, Australia (1967-1984). He is a Fellow of the Royal Society and won its Hughes Medal in 1983. He also won the Danny Heineman prize.

After Ward left Aldermaston Cook arranged for two other theorists, Keith Roberts and Bryan Taylor, to continue work on two-stage radiation implosion devices.