Chapter Three: The Allies and the bomb, August 1943 to August 1945

1. Germany

Churchill realised a German nuclear weapon could threaten London. If Germany had a nuclear reactor it would be possible to launch a radioactive strike on the British capital. Accordingly, the British planned an audacious raid on the German heavy water supply in Norway. An attack squad was parachuted into the Norsk Hydro plant on 16th February 1943. This attack was 'completely successful.'[1] The attack party planted explosives in the factory, causing extensive damage 'and over 4 months' stock of "heavy water" were destroyed.'[2] Later that year, the British were dismayed to learn via the Norwegian underground that the Norsk Hydro plant had not in fact been put out of action. By August 1943 it had resumed production. The fact that the Germans had rebuilt the High Concentration Plant so rapidly was taken by the Allies as 'a clear indication that the uranium project had a high priority in the German war effort.'[3] John Anderson decided prompt action was essential and the plant should be attacked once again. James Chadwick agreed and the argument was bolstered by the chance that the Germans would realise 'that the output could be greatly increased.'[4] As the Germans had stepped up security at the plant, this made an undercover raid impossible so 'only a daylight bombing attack would be really successful'[5] in halting production.

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[1] CAB 126/171, Heavy Water (Deuterium Oxide): General File, *S.O.E and "Heavy Water"*, National Archives, p. 5

[2] CAB 126/171, Heavy Water (Deuterium Oxide): General File*, S.O.E and "Heavy Water"*, National Archives, p. 5

[3] Goudsmit, S *Alsos*, New York, Schumann, 1947, p. 9

[4] AIR 8/1767, S.O.E Attack on Heavy Water Plant at Vemork, Norway, *Production of Heavy Water, 20/8/43*, National Archives, p. 1

[5] AIR 8/1767, S.O.E Attack on Heavy Water Plant at Vemork, Norway, *Production of Heavy Water, 20/8/43*, National Archives, p. 1

On 16th November 1943, the American Eighth Air Force bombed the High Concentration Plant and knocked it out of action. 'Abraham Esau of the Reich Research Council decided then to rebuild in Germany. To expidite construction the council planned to dismantle the Vemork plant and remove it to the Reich.'[6] This meant the valuable stocks of heavy water in the plant had also to be moved. On February 9th 1944, the Norwegian resistance gave word through clandestine radio that the Germans would be moving the heavy water, or 'certain rare chemicals'[7] within two weeks. This gave the British little warning to arrange an attack and not enough time to get a party of saboteurs into position.

The only trained operative left in the region the British could enlist was Knut Haukelid. He would have to arrange the destruction of the heavy water himself with whatever underground assistance he could find. Haukelid decided a one man attack on Vermork was too risky considering the high security measures in place but when the heavy water was transferred, an attack on the transport would be possible, either on the transport train or on the ferry chosen to carry the heavy water across Lake Tinnsjo. The transport train would be well guarded and an attack on the railway not certain to succeed. An attack on the transport system had the added problem that it would endanger the lives of civilians as the train and the ferry both carried passengers. Eventually, it was decided that an attack on the ferry was the only viable option. Sinking the ferry had a distinct advantage as the lake was so deep there would be little chance of rescuing the heavy water from the bottom. Haukelid had help from the new chief engineer at Vermork, Alf Larsen, who arranged for the heavy water to be transported on a Sunday morning, when the ferry would be least busy.

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[6] Rhodes, R *The Making of the Atomic Bomb,* New York, Simon and Schuster, 1986, p. 513
[7] PREM 3/139/4, Tube Alloys, *S.O.E Activities in Scandinavia, Norway, May 1945*, National Archives, p. 3

Before carrying out the plan, Haukelid frantically cabled London to find out if it was necessary to attack the heavy water. He feared there would be major Nazi reprisals in the area for the attack if it were to succeed, due to the loss of German lives. Sir John Anderson instructed 'that everything possible should be done to destroy the stocks in transit'[8] regardless of reprisals, which hopefully would not be too severe. London had decided the heavy water could still be put to use by Germany and nothing must be left to chance.

Haukelid discovered the heavy water would be loaded aboard the *Hydro* and would sail on 20th February. 'The heavy water of enrichments varying from 97.6 down to 1.1 per cent would be transferred to some thirty-nine drums labelled potash-lye.' [9] On the night before the ferry was to set sail, Haukelid and his amateur accomplices inspected the ferry. The Germans had been expecting some kind of Allied action and had stationed many more guards in the valley but 'by some strange oversight not a single German guard was posted on the Hydro herself'.[10] Haukelid made explosives that would be sealed in the hull of the boat and detonated with alarm clocks. This was timed to be when the ferry was halfway across the lake. His accomplice convinced the Norwegian ferry guard that the group were hiding from the Gestapo. This gave Haukelid time to plant the explosives in the hull and rig up the alarm clocks, an especially dangerous task because the detonators were only a third of an inch from the fuses. When the explosives were sealed in the hull, Haukelid and his assistants escaped, giving the excuse of needing to retrieve possessions. The ferry sailed on time.

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[8] CAB 126/171, Heavy Water (Deuterium Oxide): General File, *S.O.E and "Heavy Water"*, National Archives, p. 6
[9] Rhodes, R *The Making of the Atomic Bomb*, New York, Simon and Schuster, 1986, p. 514
[10] PREM 3/139/4, Tube Alloys, *S.O.E Activities in Scandinavia, Norway, May 1945 memo by the Minister of Economic Warfare,* National Archives, p. 2

Forty five minutes into the journey, the explosives blew up. Crew and passengers ran for the life boats, 26 people drowned and all 49 drums of heavy water rolled overboard. The *Hydro* 'sank in 4 minutes, 300 metres from shore and where the water was over 400 metres deep.'[11] Of the drums of heavy water 'four partially filled ones bobbed to the surface and were saved, rendering the effective loss of heavy water perhaps 500 kilos.'[12] There had been elaborate plans for the sabotage, should the first attempt at Lake Tinnsjo be unsuccessful. There was a second SOE unit waiting to attack the cargo vessel that was going to transport the heavy water to Hamburg should a plan B have been required.

Whether the destruction of the heavy water in Norway was the most important factor in stopping Germany from making a bomb has been hotly debated. Walker has argued Germany was already so far behind that 'the heavy water that had been sunk could not have been used effectively by the German nuclear power project to make nuclear explosives.'[13] Rudolf Peierls revealed that messages from opponents of the Nazis in Germany reached the British 'most saying that only a small reactor project was actually underway.'[14] The Germans were probably working on the uranium question as a long term project. Peierls had conducted his own research using current published teaching lists at German universities which pointed to a small German uranium project. 'These lists, which would have been difficult to fake, showed that most of the German physicists were in their normal places, lecturing on their normal

[11] CAB 126/171, Heavy Water (Deuterium Oxide): General File, *S.O.E and "Heavy Water"*, National Archives, p. 11
[12] Dahl, P.F *Heavy Water and the Wartime Race for Nuclear Energy*, Bristol and Philadelphia, Institute of Physics Publishing, 1999, p. 232
[13] Walker, M *German National Socialism and the Quest for Nuclear Power*, Cambridge, Cambridge University Press, 1989, p. 138
[14] Peierls, R *Atomic Histories*, New York, American Institute of Physics, 1997, p. 112

subjects.'[15] However, this wasn't taken as conclusive evidence that a German research programme was not being pursued.

In any case, the action of destroying the heavy water was a massive blow to Germany and gave the British reassurance that they had done all they could to prevent a German nuclear attack. The British attacks on German heavy water production had a decisive impact on the German atomic programme. The official historian of S.O.E, M.R.D Foot also argues that the impact of the sabotage was critical. 'The break in their supply of heavy water was so abrupt and so complete that the German scientists who had been working on the project gave it up; and were directed by Hitler to work on revenge-weapons such as the v-1 and the v-2 instead.'[16] In war, the British could not afford to underestimate the enemy. Germany's reliance on heavy water for their uranium work made their programme especially vulnerable and British Intelligence did exceptionally well to exploit this weakness so dramatically.

2. France

France created problems for two important reasons. Firstly, the scientists Hans Halban, a French national of Austrian descent and Lew Kowarski, a French national of Russian descent who had previously worked on nuclear fission back in Paris, were known to have taken out patents for the design of a nuclear pile. Britain had done a deal with France recognising French interests in these patents. If the French fought for their rights on these patents, Britain and the U.S would have had to provide them with information on their own designs, therefore

[15] Peierls, R *Atomic Histories*, New York, American Institute of Physics, 1997, p. 229
[16] Foot, M.R.D *SOE: The Special Operations Executive 1940-1946*, London, British Broadcasting Corporation, 1984, p. 211

endangering security. This would also have challenged the Anglo-American monopoly on nuclear weapons and commercial interests after the war. France might then have pushed for inclusion on the Tube Alloys project after being made aware of the progress in America. It was thought President De Gaulle[17], leader of the newly liberated France,[18] had taken an interest. President Roosevelt was 'categorically against any engagement with France that could make her a fourth atomic partner'[19] and wanted Britain to delay discussions with the French. John Anderson agreed with General Groves there should be no mention of the Tube Alloys project to France, other than a promise of further discussion after the end of hostilities. The Americans were disturbed as they had not been made aware by the British of any prior obligations to France before signing the Quebec Agreement.

The second problem concerning the French was security. Jules Gueron, another French scientist working in Montreal, wished to visit liberated France to solve personal matters. Groves was much perturbed as Gueron had suggested 'he intended to talk with Joliot Curie, who, it was known, had joined the Communist Party.'[20] Gueron had learned much about the American programme that could be useful to liberated France. The American Secretary for War, Henry Stimson, brooded over the obstacle. There was a chance that France could 'play power politics – to bring or threaten to bring Russia into the picture.'[21]

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[17] Charles De Gaulle was born in Lille. He was an officer in the First World War. He sought refuge in England after the German occupation of France in 1940. He became the focus of the French resistance during the Second World War and returned to Paris with the first liberation forces in 1944. De Gaulle founded a new political party Rally of the French People after the war in 1946. He became the first President of the Fifth Republic in 1958.

[18] France was liberated by the Allies after the D-Day Normandy landings. Paris was liberated on 25th August 1944, with the French armies reorganised for an attack on the retreating Germans by 15th September 1944.

[19] Goldschmidt, B *The Atomic Complex*, Illinois, The American Nuclear Society, 1982, p. 63

[20] Hewlett, R.G and Anderson, O.E *The New World*, Pennsylvania State University Publishing, 1962, p. 331

[21] Hewlett, R.G and Anderson, O.E *The New World*, Pennsylvania State University Publishing, 1962, p. 333

More importantly, the leading French scientist working on the Anglo-Canadian heavy water work, Hans Halban, was thought to be a major security risk by General Groves. As declassified documents show, Halban was generally thought to be an oddity 'a somewhat unusual person who creates an exotic and unreal atmosphere around himself and his work.'[22] Halban was thought to have passed on information about the Canadian heavy water reactor while visiting France to discuss patents with Joliot Curie, specifically talking about the construction of graphite piles for plutonium. Thus the Americans regarded the French scientists in Montreal with some suspicion 'so much so that Sir John Cockcroft was sent out to Montreal and replaced Halban as Director of the Laboratories.'[23]

There were a number of solutions to the security dangers considered by the Americans. Archive material shows the harsh treatment Groves had in mind for the French. The solution depended on the attitude of France to being left out of discussions on nuclear power. Until French views were known, it was thought best to keep the French scientists Gueron, Goldschmidt and Kowarski in Montreal. Halban however 'would be given a holiday of indefinite duration in the United States but would not leave the United States or Canada'.[24] He would also be forbidden to communicate with anyone at the Montreal Laboratory on anything other than personal matters, except through the Director of the project.

If there was a positive reaction from France over the policy of waiting for nuclear energy discussions, the idea was to send Halban away from Montreal to a University such as Toronto

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[22] KV 2/2422, Hans Halban Security Report, *Reports of Aliens from Home Office Records*, National Archives, p. 1
[23] KV 2/2422, Hans Halban Security Report, *Reports of Aliens from Home Office Records*, National Archives, p. 1
[24] CHAD IV 4/4, French Members of Montreal Staff, *Groves recommendations on security risks posed by French scientists on the Montreal Project, 20/1/45*, Churchill Archives Centre, p. 1

to work on pure research 'in the general field of the project'[25]. If he refused, he was to be offered a holiday in the United States until the end of his contract with the British. If both of these options were refused 'he should be interned as the only safe method of preserving security.'[26] The other three French scientists, Gueron, Goldschmidt and Kowarski would have their contracts extended 'for the duration of the war and six months thereafter'[27] while ensuring information entrusted to them was kept as secure as possible.

If the reaction from France and Joliot-Curie was hostile a very radical step was proposed by General Groves. 'My recommendation from the security standpoint would be that Kowarski, Gueron, Goldschmidt and Halban be placed in confinement in Canada and not be permitted to communicate with anyone. This would be the only way to preserve security.'[28] This extreme case was perhaps too radical to be practical, especially as no hard evidence to doubt the integrity of any of the French scientists had been uncovered. The only line of consideration for Groves had been the security issue and he differed from the opinion of Sir John Anderson who trusted Halban's integrity. John Anderson argued a visit by Halban to Joliot-Curie might have benefits. Halban 'could take advantage of the opportunity to persuade Joliot that France should not yet raise her claims on the future.'[29] The French question was further evidence of the cynical use of foreign scientists. The French had been welcomed because they were useful to the project but if any threat of proliferation surfaced, they were to be shut in a camp on their own. The fact that no other British expert apart from John Anderson leapt to defend the

[25] CHAD IV 4/4, French Members of Montreal Staff, *Groves recommendations on security risks posed by French scientists on the Montreal Project, 20/1/45*, Churchill Archives Centre, p. 2
[26] CHAD IV 4/4, French Members of Montreal Staff, *Groves recommendations on security risks posed by French scientists on the Montreal Project, 20/1/45*, Churchill Archives Centre, p. 3
[27] CHAD IV 4/4, French Members of Montreal Staff, *Groves recommendations on security risks posed by French scientists on the Montreal Project*, Churchill Archives Centre, 20/1/45, p. 2
[28] CHAD IV 4/4, French Members of Montreal Staff, *Groves recommendations on security risks posed by French scientists on the Montreal Project, 20/1/45*, Churchill Archives Centre, p. 3
[29] Hewlett, R.G and Anderson, O.E *The New World*, Pennsylvania State University Publishing, 1962, p. 333

French scientists rather suggests Britain would have cast off the French contribution to stay best friends with the Americans.

As events transpired, none of Groves' unorthodox suggestions was put into effect. Halban didn't leave the Montreal team but worked quietly as head of a Division responsible to Sir John Cockcroft. Halban should not be excused for passing confidential information to the French but in fairness to him, he did this at a time when the Free French 'were being more and more ostracised by the United States Authorities.'[30] If further proof were needed that the Americans had no time for the French, this came in November 1944. President Roosevelt sent a cable to Winston Churchill advising that France should be left out of the next Big Three conference. Roosevelt said France's inclusion would turn the conference into 'a debating society'[31] that would 'confuse our essential issues.'[32] Roosevelt added the Big Three would be capable of discussing which parts of Germany should be allotted to France after the fall of the Nazis while claiming he was 'sympathetic to the French point of view'[33] and hopeful that France would be strong after the war.

3. British and American Collaboration at Los Alamos

The British made a hasty exodus to America after the Quebec Agreement was signed. A raft of British scientists and equipment made the journey to the States in the autumn of 1943. The most famous of these scientists was probably Niels Bohr. He and his family had been rescued

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[30] KV 2/2422, Hans Halban Security Report, *Reports on Aliens from Home Office Records*, National Archives, p. 2
[31] FO 954/9A, *Telegram no. 649, President Roosevelt to Prime Minister, 19/11/44*, National Archives, p. 1
[32] FO 954/9A, *Telegram no. 649, President Roosevelt to Prime Minister, 19/11/44*, National Archives, p. 1
[33] FO 954/9A, *Telegram no. 649, President Roosevelt to Prime Minister, 19/11/44*, National Archives, p. 1

from Denmark by Allied Intelligence which was alerted by underground resistance of his impending deportation to the Reich. John Anderson was involved in deciding to rescue Bohr. Wheeler Bennet wrote 'John acted immediately; Niels Bohr, he directed, must be got out of Denmark at once. And both by hook and by crook this was accomplished by Allied Intelligence.'[34] Not all the Americans welcomed him with open arms as he was not an American or British citizen. He was even suspected of being a Russian sympathiser.

When Bohr went to America he was amazed at the progress the Americans had made towards the bomb. He took on the alias of 'Nicholas Baker' to make his name sound more English. Bohr was concerned about the effects of atomic weapons on the post war world. When he returned to England in April 1944, he wished to speak about his concerns with Churchill. Lord Cherwell set up a meeting between Bohr and Churchill. Bohr had memorised a set speech to Churchill to express his concerns. The meeting didn't go well. Bohr became very nervous upon speaking and 'Churchill gained the impression that he was a muddled thinker, whose one anxiety was that we should give away our secrets to the Russians.'[35]

The expansion of the programme had been aided with the setting up of the Los Alamos plant in New Mexico, chosen for its remote location. 'Inaccessibility was most important in selecting a site. There had to be some rail and road facilities, of course, but since the weapons work was not expected to require a large installation, convenience could be sacrificed for the benefits of isolation.'[36] The site fitted in well with the military men who approved of the desert and open

[34] Wheeler-Bennett, J John Anderson: Viscount Waverly, London, Macmillan, 1962, p. 296
[35] Jones, R.V *Most Secret War,* London, Hamish Hamilton, 1978, p. 477
[36] Hewlett, R.G and Anderson, O.E *The New World*, Pennsylvania State Publishing, 1962, p. 229

spaces that would be useful for testing purposes. It rapidly expanded as more and more experts were drafted in to speed up the project.

Rudolf Peierls made a tour of the American and Canadian research facilities on behalf of the British to catch up with work done whilst collaboration had broken down. On 13th September 1943, Peierls met Robert Oppenheimer, Director of Los Alamos.[37] Oppenheimer at first gave the impression that theoretical work was under control and the Americans were not in need of much assistance. Peierls personally doubted this and felt the Americans' theoretical methods to be crude and 'numerical results obtained on that basis should be regarded with great caution.'[38] Oppenheimer told Peierls that British help would be valued in hydrodynamics as the American methods in this field appeared 'very inadequate.'[39] Oppenheimer also felt Los Alamos was lacking in manpower and would be grateful of British expertise in theoretical issues. From this it appeared that Oppenheimer's opinions on U. S progress differed from those of the American military. He seemed to suggest that far from everything being under control, the Americans were keen for any help on offer. Peierls also took note of how the Americans had collected their results; this had been very different to the way the British team had worked before. The Americans had obtained as many results as possible 'with rather questionable methods'[40] whereas the British team had obtained too few results with more reliable methods.

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[37] Oppenheimer was born in New York. He studied at Harvard, Cambridge and Gottingen, where he attained a Ph.D in 1927. He returned to the U.S and established schools of theoretical physics at Berkeley and the California Institute of Technology. After the Manhattan Project, he worked at Princeton University. Oppenheimer was morally opposed to the hydrogen bomb and had to retire from U.S politics after being declared a security risk in 1953.

[38] AB 3/86, Notes on tour of United States and Canada, Peierls et al, *Meeting between Peierls and Oppenheimer on theoretical problems 13/9/43*, National Archives, p. 1

[39] AB 3/86, Notes on tour of United States and Canada, Peierls et al, *Meeting between Peierls and Oppenheimer on theoretical problems 13/9/43*, National Archives, p. 2

[40] AB 3/86, Notes on tour of United States and Canada, Peierls et al, *Meeting between Peierls and Oppenheimer on theoretical problems, 13/9/43*, National Archives, p. 2

The same day, there was a meeting at the War Department in Washington where General Groves was the next to ask for British assistance. He hoped James Chadwick and Mark Oliphant would go and work at Los Alamos as the group was 'badly in need of senior experimental physicists.'[41] It was suggested Peierls and his team could best be used at the Diffusion Plant at Kellex, where 'theoretical work was very inadequate.'[42] Oppenheimer suggested if Peierls could not be utilised in the American Diffusion Project, his team could become a valuable addition to Los Alamos where theoretical work was 'seriously behind schedule.'[43] Oppenheimer told Peierls he 'would like an arrangement by which we [the British] were largely independent and free to choose our own problems'[44] to work on.

Just as the British arrived, the American gaseous diffusion programme was in dire straits. The British had valuable experience in this field. Naturally, General Groves was keen for the British experts to provide 'an independent assessment of the practicability of the various parts of the project'[45] to speed up the solving of technical difficulties. British representatives met the American Diffusion team at Kellex Offices on 16th September 1943. According to Peierls' report, both groups agreed 'how deplorable it was that the collaboration was interrupted as many of our [British] suggestions could have been incorporated with advantage if they had been available in time.'[46] Peierls regularly mentioned in his reports that the Americans had not had access to results available from his groups' work at Birmingham. At the following Kellex

[41] AB 3/86 Notes on tour of United States and Canada, Peierls et al, *Meeting at War Department in Washington 13/9/43,* National Archives, p. 1

[42] AB 3/86 Notes on tour of United States and Canada, Peierls et al, *Meeting at War Department in Washington 13/9/43*, National Archives, p. 6

[43] AB 3/86 Notes on tour of United States and Canada, Peierls et al, *Meeting at War Department in Washington, 13/9/43,* National Archives, p. 5

[44] AB 3/86, Notes on tour of United States and Canada, Peierls et al, *Meeting between Peierls and Oppenheimer on theoretical problems*, *13/9/43*, National Archives, p. 2

[45] Gowing, M *Britain and Atomic Energy 1939-1945*, London, Macmillan, 1964, p. 252

[46] AB 3/86, Notes on tour of United States and Canada, Peierls et al, *Meeting at Kellex Offices in New York, 16th September 1943,* National Archives, p. 1

meeting of 21st September, it was found British help was needed in several vital areas. The British technicians could be useful for membrane testing and the physics of isotope separation 'where little work has been carried out in America.'[47] Help in developing barriers for diffusion was much welcomed as this included the corrosion problems due to uranium hexafluoride. There were also many general engineering problems in urgent need of attention. The British suggested changing the barrier material for the diffusion plant as the first choice was not working as expected. Also, a special type of nickel powder was needed by the Americans for the barriers and it was only made by the Mond Nickel Company in Wales. The British Government paid for 3,000 tons of this powder. The required amount was 'sent meticulously on schedule'.[48]

The system of compartmentalisation infuriated the British scientists who tried to argue the policy wouldn't apply to them as their numbers were so small and their talents so varied. However, General Groves was adamant the system was crucial. Leo Szilard, who was working with the Americans, incurred the General's wrath, saying compartmentalisation hindered making the bomb quickly enough as there was no way to converse with the other teams about solutions to technical problems. In echoes of the ideas to remove the French scientists, Groves wanted to label Szilard an enemy alien and have him detained for the duration of the war due to his opposition to the military. Groves 'apparently equated disagreement with disloyalty and scaled the ratio of the two conditions directly: anyone who caused him as much pain as Leo Szilard must be a spy. It followed that he ought to be watched.'[49] Groves had Szilard followed by the secret police but this didn't reveal anything unusual about Szilard's habits and certainly

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[47] AB 3/86, Notes on tour of United States and Canada, Peierls et al, *Meeting at Kellex Offices in New York, 21st September 1943*, National Archives, p. 2
[48] Gowing, M *Britain and Atomic Energy 1939-1945*, London, Macmillan, 1964, p. 256
[49] Rhodes, R *The Making of the Atomic Bomb*, New York, Simon and Schuster, 1986, p. 506

not enough to have him removed from the project. The Americans were notoriously suspicious of foreign born scientists. 'It did not help the British cause, therefore, that of the university scientists who had hitherto visited America specifically in connection with the project, not one was British born.'[50]

James Chadwick was given responsibility for incorporating the British scientists into the American project and he fulfilled this role exceptionally well. He struck up an unlikely friendship with General Groves. 'This friendship between Groves and Chadwick was born of mutual respect and understanding of the task the other was trying to do and it grew because each man recognised the other as being wholly straightforward and honest.'[51] Chadwick made sure his team adhered to Groves' strict security measures and he didn't put pressure on Groves to solve issues in line with the interests of the British. Chadwick 'realised that the help the British gave, although material, was far outweighed by the knowledge they were gaining through their participation in the American project.'[52] Chadwick pushed to increase the numbers of British scientists on the American project because the knowledge they would gain would be invaluable after the war. Britain played the cards it was dealt in the Quebec Agreement very cleverly by bringing as many scientists as possible. The U.S felt there was no need for the British in the theoretical physics but in the time factor British help would be essential to speed up the project. The production of some parts of the project could be accelerated by months with British assistance. 'Even without taking account of the Maud Report, the British atomic contribution was significant, although estimates of the number of

[50] Gowing, M *Britain and Atomic Energy 1939-1945*, London, Macmillan, 1964, p. 176
[51] Gowing, M *Britain and Atomic Energy 1939-1945*, London, Macmillan, 1964, p. 237
[52] Gowing, M *Britain and Atomic Energy 1939-1945*, London, Macmillan, 1964, p. 238

months that this contribution saved in the completion of the Manhattan Project vary greatly.'[53] Groves was keen for anything that would save time. He was not only fearful of Germany. If the bomb were not made in time to be used in the war, Groves was painfully aware he would have to explain to Congress why $2 billion had been spent on the programme without achieving a tangible result.

On 17th February 1944, James Chadwick suggested that the Americans join with the British – Canadian heavy water project in Montreal. The plant was strengthened by recruiting scientists from Britain, many of whom had been working on radar, and scientists from the U.S. There was a lengthy delay in confirming the go ahead for the plant which nearly dissolved Halban's team. The French scientists were gradually phased out of the programme, although they were not interned as Groves had implied they could be. Chadwick became head of the Canadian programme in September 1944. Chadwick was hindered because the Canadian project suffered from supply problems. Uranium ore was being swallowed up by the work at Los Alamos.

Advances in the enrichment of uranium during 1943 and 1944 meant much more was produced in a shorter time and plutonium became easier to separate in significant quantities. However, many design issues remained. The British scientists working at Los Alamos were valuable in giving second opinions over technical obstacles and provided reassurance the project was proceeding as planned. In the electromagnetic separation[54] team, Mark Oliphant became the *de facto* deputy of the programme at Berkeley whenever Ernest Lawrence was away

[53] Edmonds, R *The Big Three: Churchill, Roosevelt and Stalin*, London, Hamish Hamilton, 1991, p. 401
[54] Electromagnetic separation works by using the magnetic field of particles. Particles will deflect in a magnetic field and the amount of deflection depends on the mass of the particle, so uranium 235 can be separated from uranium 238 in this way. This method was a highly expensive one for producing uranium 235 but it made most of the fissile material for the first uranium bomb.

from the project. Oliphant became very well liked by the Americans and was impressed by how far electromagnetic separation had been refined in the States.

Access to areas of the American programme was not as restricted as the Quebec Agreement suggested. The British were involved in most of the top secret parts of the programme and Peierls and Fuchs in particular were heavily involved in the calculations for the bomb. This points more to American worries over commercial competition as the reason for restricted exchange of information than issues of security.

The chain reaction needed to happen at exactly the right moment. The whole process would take less than three millionths of a second. The two pieces of fissile material would only explode efficiently if brought together at the right time. The major obstacle was that when the device exploded the core would expand rapidly. This meant material would be lost at the outer edge of the core before the chain reaction finished. Therefore an explosion design had to be carefully calculated to keep material in the core. British input for design came into play. Peierls and Frisch had outlined the solution in their 1940 memorandum. They had suggested using a tamper.[55] Without a tamper, a device would only fission around 1% of its uranium and be highly inefficient. The method for firing the uranium device had also been put forward in the Frisch-Peierls memorandum. Their gun-type idea of firing a piece of uranium towards another at high speed was adopted.

[55] A 'tamper' was placed around the core material of the bomb. On detonation, the tamper would reflect neutrons back into the core to stop them escaping, hence making the explosion more efficient. More of the core would undergo fission before the chain reaction fizzled out.

Another design suggestion was 'implosion'. This meant the device would have a central core, a tamper surrounding the core and an arrangement of high explosive around the tamper. The device would explode and the high explosive would put pressure on the tamper and the core. This would create a shockwave and the fissile material would be pushed inwards or 'imploded' to create the critical size and start the explosion. The method of implosion would be used for plutonium devices as the plutonium samples were not as pure as had been thought, they had concentrations of plutonium 240. The isotope plutonium 240 had a high rate of spontaneous fission. This meant that 'If the gun-assembly method were used, spontaneous fission was likely to cause pre-detonation; the explosion would begin before the active material was fully compressed and then fizzle out.'[56]

At the same time as the British were helping the Americans to remedy the last design problems, the Combined Development Trust was conducting worldwide surveys into resources of uranium and thorium. The British had conducted geological surveys for uranium. Uranium was found to be present in the earth's crust in minute concentrations with the problem that 'discrete occurrences in appreciable concentrations are rare.'[57] The Trust also had commercial value for Britain and the U.S due to deposits of radium found in uranium as 'the high price of radium has made the finding of rich deposits of uranium minerals the ambition of every prospector.'[58]

The Trust Agreement was signed on the 13th June 1944. Britain undertook to negotiate with the Dominions, India and Burma over any deposits of uranium or thorium and bring them

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[56] Holloway, D *Stalin and the Bomb*, London, Yale University Press, 1994, p. 106
[57] CHAD IV 8/1, *Report on Sources of Uranium, 17/12/43*, Churchill Archives Centre, p. 1
[58] CHAD IV 8/1, *Report on Sources of Uranium, 17/12/43*, Churchill Archives Centre, p. 1

under British control. The Trust was comprised of six people appointed by the Combined Policy Committee. It undertook extensive negotiations with Belgium over uranium supplies in the Congo and also negotiated with Brazil over its deposits of thorium. 'The Trust assumed control of the uranium and thorium supplies liberated by the advancing allied armies. Most important, it surveyed for the Combined Policy Committee the present and potential sources of raw material throughout the world.'[59] How it would be possible to control the then untapped sources in for example the U.S.S.R was not properly discussed. The Trust was born at a time when it was thought uranium and thorium deposits were rare. Groves wished to use Los Alamos for 'nuclear domination beyond the conflict and a new era of power production'[60] by gaining control of uranium resources. The gaining of raw materials not only supplied what was needed for weapons but also for power plants. The Trust secured 'a veritable monopoly'[61] over uranium resources for Britain and America, while 'avoiding competition between them in foreign markets.'[62]

Churchill and Roosevelt tied up collaboration with the Hyde Park Aide Memoire in September 1944. This stipulated that collaboration 'should continue after the defeat of Japan unless and until terminated by joint agreement.'[63] The Soviet Union was not to be informed about the progress made. The bomb could be used on the Japanese 'who should be warned that this bombardment will be repeated until they surrender.'[64]

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[59] Hewlett, R.G and Anderson, O.E *The New World*, Pennsylvania State Publishing, 1962, p. 288
[60] Bickel, L *The Deadly Element*, London, Macmillan, 1980, p. 230
[61] Goldschmidt, B *The Atomic Complex*, Illinois, The American Nuclear Society, 1982, p. 53
[62] Ibid.
[63] Williams, R.C and Cantelon, P.L *The American Atom: A Documentary History of Nuclear Policies from the Discovery of Fission to the Present 1939-1984*, Philadelphia, University of Pennsylvania Press, 1984, p. 45
[64] Williams, R.C and Cantelon, P.L *The American Atom: A Documentary History of Nuclear Policies from the Discovery of Fission to the Present 1939-1984*, Philadelphia, University of Pennsylvania Press, 1984, p. 45

Chadwick's report in autumn 1944 highlighted the rapid progress made in the year since the British had journeyed to America. Collaboration under the terms of the Quebec Agreement was 'on the whole'[65] working well and the scientists who had made the trip had contributed a significant amount. Even though weapons were close at hand, there was still some doubt as to the best method of collecting bomb material and the most efficient way to put this material to use. A bomb would hopefully be available 'for trial purposes by March 1945.'[66] It would be possible to produce a bomb 'for operational purposes by August 1945'[67] or maybe even sooner, and satisfactory amounts of plutonium would be made from August 1945 onwards.

Only around 50 British scientists made the journey to the states, compared to the several hundred American scientists, but their impact was much bigger in the final design of the bomb than mere numbers would suggest. Frisch was especially crucial. He conducted a series of experiments with uranium 'to establish by practical test how much of this metal was needed to create an efficient atomic explosion.'[68] This was incredibly dangerous, as the apparatus would be close to an explosion when it was nearly at critical size. A sphere was constructed out of uranium blocks cast from the uranium separated at the Oak Ridge plant in Tennessee.[69] Frisch gradually added layers of blocks 'from subcritical size to the point where instrumentation

[65] PREM 3/139/11B, Notes on Tube Alloys, *Report by James Chadwick, Autumn 1944,* National Archives, p. 1

[66] PREM 3/139/11B, Notes on Tube Alloys, *Report by James Chadwick, Autumn 1944*, National Archives, p. 1

[67] PREM 3/139/11B, Notes on Tube Alloys, *Report by James Chadwick, Autumn 1944,* National Archives, p. 1

[68] Bickel, L *The Deadly Element: The Story of Uranium*, London, Macmillan, 1980, p. 246

[69] Oak Ridge was the huge uranium separation plant that provided the enriched uranium for the first atomic bomb. The plant was situated in Tennessee because it had access to electricity from the Tennessee Valley Authority and water from the adjacent Clinch River. The K-25 section of the plant dealt with gaseous diffusion and the Y-12 section focused on the electromagnetic separation method. By spring 1945, Oak Ridge had provided Los Alamos with 132 pounds of enriched uranium that could then be cast for the core of the atomic bomb.

would indicate fission chain reaction was imminent.'[70] He reached the twelfth layer and the instruments could no longer count the neutrons multiplying. His white coat and body were reflecting neutrons back into the apparatus and there was nearly an explosion. Frisch recollected that the dose of radiation he received 'was quite harmless; but if I had hesitated for another two seconds before removing the material… the dose would have been fatal.'[71] Frisch's near death encounter gave the engineers the data about the critical size they'd been waiting for. It was also obvious the uranium bomb would now fission as expected. Frisch gave his calculations to Groves on Friday 13th April 1945.

Philip Moon in the British team helped Kenneth Bainbridge[72] and the Americans to plan how to catch the explosion of the bomb on film. Indirect gamma-ray photography would be the most effective method of picture taking and was 'best used for the early stages of the expansion.'[73] The gamma-ray system used a pinhole camera in a lead box which would catch the image and project it onto a fluorescent screen. This screen would be filmed by an ordinary motion picture camera 'so that pictures could be obtained in more rapid succession than would seem possible by using a heavy shutter to interrupt the gamma-rays.'[74] Photographs could be taken milliseconds into the explosion. James Chadwick also wished to measure the gamma rays

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[70] Bickel, L *The Deadly Element: The Story of Uranium*, London, Macmillan, 1980, p. 247
[71] Frisch, O *What Little I Remember*, Cambridge, Cambridge University Press, 1979, p. 162
[72] Kenneth Bainbridge was a physicist at Harvard. He was the Director of the Trinity test at Los Alamos. Like Oppenheimer, he advocated peaceful uses of nuclear energy after the war and also wanted a ban on nuclear testing.
[73] AB1/568, Dr J Chadwick Correspondence, *Gamma-ray Pinhole Photography, Philip Moon, 2/7/45*, National Archives, p. 1
[74] AB 1/568, Dr J Chadwick Correspondence, *Indirect Gamma-ray Photography of Gadget, 6/4/45*, National Archives, p. 1

precisely 'to deduce the number of fissions taking place'[75] inside the device. Collecting soil samples using a lead lined vehicle was also planned as a way of measuring the radiation.

The argument that the British were restricted at Los Alamos on security grounds seems very flimsy considering the amount of access they had to various areas of the project. The theoretical group that was run by Edward Teller to look at the development of fusion was the most advanced. In this group was to be found Egon Bretscher of the British team who worked with Teller on the preliminary calculations for the next generation of super explosives. These 'super' or hydrogen bombs would not be tested for several years. Due to his insistence on studying fusion, Teller had left a hole in the group perfecting implosion. Rudolf Peierls was chosen to fill the gap and 'Oppenheimer lauded Peierls contributions to the hydrodynamics of implosion.'[76] Peierls did valuable work on calculating blast waves. He led T-1 Division and also advocated perfecting explosive lenses which had been suggested by another of the British team, James Tuck. Explosive lenses were notoriously hard to cast and the materials were brittle so they were also prone to breaking. Explosive lenses were not guaranteed to work or to boost implosion but Peierls was 'among those who insisted that lenses were both feasible to design and essential to obtaining the desired wave shape.'[77] In the same group, Klaus Fuchs worked on solving jets[78] to aim for a symmetrical explosion. T Division was concerned the efficiency of the bomb would be as little as 1%. Fuchs also worked on the initiator programme.[79] He

[75] AB 1/568, Dr. J Chadwick Correspondence, *Indirect Gamma-ray Photography of Gadget, 6/4/45*, National Archives, p. 2

[76] Szasz, F *British Scientists and the Manhattan Project: The Los Alamos Years*, London, Macmillan, 1992, p. 20

[77] Hoddeson, L *Critical Assembly: A Technical History of Los Alamos during the Oppenheimer Years*, Cambridge, Cambridge University Press, 1993, p. 300

[78] Jets were molten metal which would shoot from the core of the device when it exploded and make the implosion asymmetrical. This would reduce the efficiency of the device.

[79] Initiators were composed of beryllium and polonium 210 which emit alpha particles. This reaction would create the necessary neutrons to start the chain reaction.

helped devise an initiator theory which 'by mid-April had enabled the lab staff to design and test the device successfully.'[80] The implosion design was frozen in February 1945 and all work on this moved from theory to production. It is worth emphasising at this point that the British did much significant work on bomb theory. If the theory turned out to be wrong, the bomb would not have worked. As the test proved successful, the British work on theory and implosion must not be underestimated in its importance.

Admittedly, even though the Americans and British co-operated well enough, there was still a certain amount of suspicion boiling beneath the surface, as is shown by declassified correspondence. When Frank Kearton from I.C.I wanted his own team to come to the U.S to help with the diffusion problem, this was met with much American resistance. As Akers told Peierls, collaboration would be 'very difficult if the Americans will not accept our views on the best way in which we can organise our help for them.'[81] General Groves had been twitchy about British involvement all along and had stipulated that 'no member of the British organisation shall have any executive position in the American set up.'[82] This could have been because Groves was jealous of British involvement or even due to him fearing a British executive might prove more efficient than an American one.

The Americans increased their demand for British made nickel powder in April 1945, which gave further ground for suspicion. This nickel powder was the only type that would be suitable for the American diffusion plant. Francis Simon wrote to Akers suggesting the Americans

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[80] Hoddeson, L *Critical Assembly: A Technical History of Los Alamos During the Oppenheimer Years*, Cambridge, Cambridge University Press, 1993, p. 331
[81] AB 3/110, Tube Alloys Correspondence, Simon and Akers in the U.K and U.S, *Akers to Peierls, 26/3/44*, National Archives, p. 3
[82] AB 3/110, Tube Alloys Correspondence, Simon and Akers in the U.K and U.S, *Akers to Peierls, 26/3/44*, National Archives, p. 5

could have an ulterior motive. The new demand indicated the Americans were 'unable to produce with their new methods a suitable nickel powder'[83] to use in their own plant. The Americans could be planning a new diffusion plant with a bigger output. Simon pointed out the British had gifted the nickel powder to the Americans so maybe the extra demand was a ruse 'in order to be independent of our goodwill in the years to come.'[84] It could also be a clever way to saturate British production capacity 'and prevent us thus from building a plant in the near future.'[85]

A full test of the implosion weapon was planned by the U.S in 1945 in New Mexico. Some of the scientists had been preoccupied with the thought that an atomic bomb might ignite the atmosphere. Up until the test they were 'nervously calculating proofs that they did not have the power to destroy everything.'[86] The Trinity test site had been closed air space for several months so training American pilots would not destroy the site, or worse the actual bomb. On 16th July 1945 the world's first atomic bomb exploded, it was a plutonium bomb and had a yield of 14 kilotons of dynamite. The Trinity test was important as it showed the scientists exactly how big the explosion would be in a combat scenario. Trinity was hell unleashed. Frisch said it was like turning the sun on with a switch. His account is very eerie, describing how the bright light and mushroom cloud rose and expanded but 'all in complete silence; the bang came minutes later, quite loud though I had plugged my ears, and followed by a long rumble like heavy traffic very far away.'[87] The British had a large role at Trinity. P.B Moon

[83] AB 3/110, Tube Alloys Correspondence, Simon and Akers in the U.K and U.S, *Simon to Akers, 21/5/45*, National Archives, p. 1
[84] AB 3/110, Tube Alloys Correspondence, Simon and Akers in the U.K and U.S, *Simon to Akers, 21/5/45*, National Archives, p. 1
[85] AB 3/110, Tube Alloys Correspondence, Simon and Akers in the U.K and U.S, *Simon to Akers, 21/5/45*, National Archives, p. 2
[86] Weart, S.R *Nuclear Fear: A History of Images*, Massachusetts, Harvard University Press, 1988, p. 101
[87] Frisch, O *What Little I Remember*, Cambridge, Cambridge University Press, 1979, p. 164

from Cambridge calculated levels of radioactive fall-out using new instruments. These 'were then given to the Health Safety people who utilized them to monitor safety levels.'[88] Trinity was visible for many miles. If it was noticed by the public, it was to be explained to them by the American military as the explosion of an ammunition dump.

President Truman authorised the bomb to be used in the first instance to end the war quickly or so he claimed. Truman wished to save American soldiers lives which would have undoubtedly been lost in a prolonged land invasion of Japan. It was estimated there would be a million casualties from an invasion of Japanese soil.

Another perhaps more important reason, was to stop the Soviet Union invading Japanese soil so the Soviets could not gain territory and try to replicate the communist model in Korea and Northern China. This fact may have sealed Nagasaki's fate. The second strike happened three days after the first which had not given the Japanese military time to judge the situation. The Americans knew the Soviet Union had declared war on Japan on the 9th August so may have bombed Nagasaki the same day to get a quick surrender to stop the Russians encroaching too far into Japan. As soon as Truman knew the test weapon had fired successfully, he could hold the fear of the bomb over Russian heads and get the Soviets out of Asia. This depended of course on the U.S keeping the nuclear monopoly. The Potsdam Conference was bossed by Truman because he'd been informed of the bomb's success, so America would not need Russian help to end the war. Truman took a much tougher line with Stalin than would have been expected considering he was new to his role. The U.S military then wanted the bomb

[88] Szasz, F *British Scientists and the Manhattan Project: The Los Alamos Years*, London, Macmillan, 1992, p. 24

used 'preferably before the Russians attacked, and certainly, if feasible, before the Red Army got very far in its assault.'[89]

Target selection was not delicately handled by the Americans. One example defies logic. The first city on the target list was Kyoto. This city was known to be culturally important to the Japanese and had wonderful architecture. Secretary for War Henry Stimson struck Kyoto from the list, saying the Japanese would never forgive America if they bombed it. No moral objections seem to have been raised at the top over the decision to flatten Hiroshima instead. The preferred targets were decided as Hiroshima, Niigata, Kokura and Nagasaki. City bombing was highly questionable from an ethical standpoint but the Target Committee had decided that a non-combat demonstration would not be dramatic enough to induce surrender from the Japanese. Also, Japanese cities were made from light wooden structures and 'easily susceptible to blast damage, they were ideal as targets for the bomb'.[90]

Britain appeared to have a minor role in the decision to drop the bomb. It is fairly clear that Washington made most of the big decisions in selecting targets and dates. The British appear to have meekly acquiesced in this process. This was probably an attempt to stay on good terms with the Americans. The Quebec Agreement dictated the process to the British who merely consented to the attack on Japan.

Citing moral questions, Churchill stated to the House of Commons in August 1945 that the bomb 'should arouse the most solemn reflections in the mind and conscience of every human

[89] Alperovitz, G *The Decision to Use the Atomic Bomb and the Architecture of an American Myth*, London, Harper Collins, 1995, p. 174
[90] Malloy, Sean (2007) 'The rules of Civilised Warfare: scientists, soldiers, civilians and American nuclear targeting 1940-1945, Journal of Strategic Studies, 30:3, p. 487

being capable of comprehension.'[91] That said, Churchill also saw it as an opportunity for 'a speedy end to the Second World War'[92]. The atomic bomb would mean no land invasion of Japan was needed and would release the Japanese 'from their obligation of being killed to the last fighting man.'[93] He said there had never been a discussion over whether to use the bomb or not. The final decision had been Truman's but Churchill 'never doubted what it would be, nor have I ever doubted since that he was right'. [94] This must be taken with a pinch of salt as Churchill was writing retrospectively. Each politician wanted to present themselves in a kinder light than history has often portrayed them. It could be that Churchill did have doubts but he kept those well hidden.

At ministerial level in both Britain and America there appears to have been little debate over whether to use the bomb. More emphasis was placed on *how* it was used. Truman called the bomb 'the greatest achievement of organised science in history.'[95] Truman regarded the bomb as a military weapon, and as such it should be dropped 'on a military target.'[96] Even Henry Stimson, who had struck Kyoto from the target list, saw the attraction of the bomb as he sought 'to maximise the technical effects of the new weapon, regardless of its human consequences.'[97] Stimson acknowledged the cost of the bomb would look astronomic if it was not used in combat and the fact that targets would need to be visible from 30,000 feet in an air strike pointed to the bombing of cities. Targeting an isolated military installation could result in wasting the bomb if the drop was not accurate enough.

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[91] H.M Treasury, *Statements Relating to the Atomic Bomb*, Her Majesty's Stationery Office, London, 1945, p. 5

[92] Churchill, W.S *The Second World War, Volume VI: Triumph and Tragedy*, London, Cassell, 1954, p. 552

[93] Churchill, W.S *The Second World War, Volume V1: Triumph and Tragedy*, London, Cassell, 1954, p. 553

[94] Churchill, W.S *The Second World War, Volume* V1: Triumph and Tragedy, London, Cassell, 1954, p. 553

[95] Truman, H.S *Year of Decisions*, New York, The New American Library, 1955, p. 465-466

[96] Truman, H.S *Year of Decisions*, New York, The New American Library , 1955, p. 463

[97] Malloy, Sean. L (2007) 'The rules of civilized warfare: Scientists, soldiers, civilians and American nuclear targeting, 1940-1945, *Journal of Strategic Studies*, 30;3, 475-512, p. 501

In contrast to the politicians' enthusiasm, the scientists were very much disturbed at the thought of dropping the bomb as they were more aware of the possible consequences. Leo Szilard was the main organiser of a protest. He'd been appalled by the attitude of James Byrnes, Truman's advisor who wished to use the bomb as a diplomatic threat. Szilard 'returned to Chicago determined to urge some form of collective protest.'[98] This protest took the form of a petition which received 69 signatures from the Chicago based scientists. However, Edward Teller decided it should not be circulated at Los Alamos and Groves' own staff held up the petition at Oak Ridge. There is no evidence to suggest that President Truman ever saw the petition and this episode was another example of how the scientists were very much left out of the decision making process. This was highly unfair as it had been their efforts that had made the technology practical. However, it was probably a foregone conclusion that the scientists devised the technology but the military would decide how to put it to use. The prevailing attitude in Washington was that 'scientists must not concern themselves with devising and proposing policies; they ought to limit themselves to answering such technical questions as they may be asked.'[99] Some scientists had 'pride mixed with guilt as the results of the bombings became known in detail.'[100]

The fact that the bomb was made shows how, even though the British and Americans didn't necessarily agree about collaboration, the scheme worked well enough to get the desired result. The Americans benefited from British expertise and it saved probably as much as six to nine months in the crucial final stages of development. Mutual suspicions on both sides explain in

[98] Alperovitz, G *The Decision to Use the Atomic Bomb and the Architecture of an American Myth*, London, Harper Collins, 1995, p. 187
[99] Szilard, L *The Voice of the Dolphins*, London, Victor Gollancz, 1961, p. 22
[100] Hughes, J *The Manhattan Project: Big Science and the Atomic Bomb*, Cambridge, 2003, p. 95

part why the two teams became independent again after the war although the spy cases also broke in the years immediately after 1945.

Of course the irony was that the Germans were so far behind in the quest for nuclear energy and the Allies didn't realise this until the bomb was almost complete. The British raids on heavy water supplies in Norway were heroic and commendable. Tragically, they were also unnecessary as 'by the end of 1942, the deadly race had only one runner.'[101] Nevertheless, several of the raiders of Norsk Hydro were recommended for decorations by S.O.E. Knut Haukelid was recommended for a D.S.O in recognition of his efforts 'as head of the sabotage group at Rjukan'[102]. Vemork's engineer Alf Larsen was recommended for an O.B.E to reward him for his sabotage work and the valuable information he gave the British about German interest in heavy water production. Haukelid's assistant, Gunner Syverstad, was to be put forward for an M.B.E for his courage during the attack on the *Hydro* ferry. Without Syverstad's help, 'the final operation would have been impossible.'[103]

The Farm Hall transcripts of the interned German scientists are especially revealing about their reactions to the news of Hiroshima. Otto Hahn was genuinely upset the atomic bomb had been used as a weapon and counted himself culpable as the discoverer of fission. Gerlach[104] was merely disappointed and half ashamed that Germany was beaten by the United States in making an atomic weapon as he was the head of the German uranium research group.

[101] DeGroot, G *The Bomb: A History of Hell on Earth*, London, Jonathan Cape, 2004, p. 32

[102] CAB 126/171, Heavy Water, Norway, *Michael Perrin to Gorell Barnes*, *28th March 1944*, National Archives, p. 1

[103] CAB 126/171, Heavy Water, Norway, *Michael Perrin to Gorell Barnes, 28th March 1944*, National Archives, p. 1

[104] Walter Gerlach worked as a lecturer at Frankfurt University before becoming head of the physics section of the Reich Research Council in January 1944. He was interned by the British until January 1946 and thought to be un-cooperative.

Heisenberg initially reacted with denial and said 'I don't believe a word of the whole thing.'[105] It is interesting that von Weizsacker reacted with revulsion. He said: 'I think it is dreadful of the Americans to have done it. I think it is madness on their part.'[106]

The Germans' discussion of isotope separation and plutonium production reveals they were aware of both routes to the bomb but confused about how the Allies got there. Heisenberg argued the Germans had neglected isotope separation as filtering out the uranium 235 was 'such an extremely difficult business.'[107] Korsching[108] marvelled at the huge scale of American and British co-operation to build the bomb so quickly. That sort of effort 'would have been impossible in Germany. Each one said that the other [person's idea] was unimportant.'[109] Heisenberg implied there was a poor relationship between science and government in Germany and hinted the scientists were not trusted enough by the government. All this evidence showed is that the basic knowledge of atomic weapons was in the hands of the Germans, they just hadn't had enough support to make full use of it.

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[105] Bernstein, J *Hitler's Uranium Club: The Secret Recordings at Farm Hall*, New York, American Institute of Physics, 1996, p. 122
[106] Bernstein, J *Hitler's Uranium Club: The Secret Recordings at Farm Hall*, New York, American Institute of Physics, 1996, p. 123
[107] Bernstein, J *Hitler's Uranium Club: The Secret Recordings at Farm Hall*, New York, American Institute of Physics, 1996, p. 125
[108] Horst Korsching was a colleague of Heisenberg's and joined the staff at the Kaiser Wilhelm Institute in 1937. He worked during the war on isotope separation.
[109] Bernstein, J *Hitler's Uranium Club: The Secret Recordings at Farm Hall*, New York, American Institute of Physics, 1996, p. 127