Chapter One: British nuclear research and development April 1940 – October 1941

The genesis of Britain's nuclear programme was possible due to the rapid scientific advances in nuclear physics in the 1930's. James Chadwick had discovered the existence of the neutron as the last part in the existing scientific model of the atom, at the Cavendish Laboratory in Cambridge in 1932. He was a protégé of Ernest Rutherford[1] and one of the ablest minds in experimental physics. Chadwick had the fortune of studying at Cambridge. 'In 1932 no physics research establishment in the world possessed such excellent instruments as the Cavendish Laboratory at Cambridge'.[2] Chadwick's discovery of the neutron meant the chain reaction could be properly considered to make an atomic device. Neutrons were essential for this process as they had no electrical charge. 'This characteristic of being electrically neutral makes it possible for the neutron to approach close to the charged nuclei of other atoms'.[3]

Nazi Germany had made the breakthrough discovery in December 1938. Two chemists Fritz Strassman and Otto Hahn had proved that it was possible to split the atom and produce vast amounts of energy.[4] Gowing argues 'It was one of the most fateful coincidences of history that the discovery of atomic fission came in the same year as the outbreak of the Second World

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[1] Ernest Rutherford came to England after being awarded a scholarship and was admitted to the Cavendish Laboratory at Cambridge in 1895. He later became Professor of Physics at McGill University in Canada in 1898. Whilst there, he formulated the theory of atomic disintegration with Frederick Soddy. This theory accounted for the tremendous heat energy radiated by uranium. Rutherford was awarded the Nobel Prize for Chemistry in 1908. During World War One, he did research on submarine detection for the admiralty. In 1920, he predicted the existence of the neutron, later found by Chadwick.

[2] Jungk, R *Brighter Than 1000 Suns*, London, Gollancz and Hart Davis, 1958, p. 57

[3] Compton, A.H *Atomic Quest*, London, Oxford University Press, 1956, p. 15

[4] The process of fission occurs when a neutron strikes the nucleus of a uranium atom and splits the atom into two, usually producing barium and krypton. These two halves would repel each other due to their large electrical charges and produce heat and energy. 'Fission' is an unusual choice of name; it originates from the biological term that describes cell division.

War.'[5] As a German had discovered fission in Germany, it was natural to assume their atomic research would be ahead of other nations. The German war office commandeered the use of the Kaiser Wilhelm Institute for their experiments into nuclear research in September 1939. The institute was newly completed, finished in 1937 and was well equipped for such research. It also received excellent funding from the Nazi Party. Germany had a Uranium Project. It also had a Uranium Society and the Kaiser Wilhelm Institute for Physics 'was made the scientific centre of the Uranium Society'.[6] Secrecy was paramount. Secrecy went against scientific ethics because it was considered important to publish research which could be debated and experimentally proved by someone else's findings from the same experiment. Furthermore, secrecy was thought to hinder progress and was frowned on by most of the scientists but was essential due to the bomb's destructive potential and political implications. However it must be stated that there was more scepticism than anything over the possibility of using nuclear fission for a bomb. Many physicists in 1939 believed technical challenges were 'too numerous and too complex to be solved in the near future, if indeed they could be solved at all'.[7]

There were experiments conducted independently by talented groups of physicists into what happened when uranium underwent fission. These experiments showed 'that for each uranium nucleus split, several neutrons were obtained.'[8] These extra, or 'free' neutrons meant in theory a chain reaction could be instigated, given suitable conditions.[9] Some neutrons would be

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[5] Gowing, M and Arnold, L. *The Atomic Bomb*, London, Butterworth, 1979, p. 3

[6] Jungk, R. *Brighter Than 1000 Suns*, London, Gollancz and Hart Davis, 1958, p. 90

[7] Sherwin, M.J *A World Destroyed*, New York, Vintage books, 1973, p. 13

[8] Crammer, J.L and Peierls, R. *Atomic Energy*, Middlesex, Penguin Books, 1950, p. 16

[9] 'Free neutrons', also known as secondary neutrons, are produced from fission and the number estimated to be made by a single fission of a nucleus was 2.2. These extra neutrons would travel through the uranium and hit other nuclei, releasing further neutrons in the 'chain' process.

captured. The mass after fission was found to be less than before. 'This meant that 17 neutrons remained to be accounted for. At least some of them remained free.'[10]

The Allies were worried that Nazi Germany would utilize the potential of radioactive energy to make a devastating weapon. G.P Thomson, professor of physics working at Imperial College, London, was concerned in April 1939 about the supplies of Belgian uranium. He wished these to be bought by Britain to stop Germany acquiring them. Henry Tizard[11] was given the task of investigating the possibility of using uranium as an explosive by the Committee for Imperial Defence. He took a keen interest in trying to secure the supplies due to worries the Germans were buying uranium from Belgium. However on subsequent investigation, the Union Miniere told Tizard there had been no unusual demand for the stocks from any other party so the British didn't see any point in the expense of buying up the stocks. 'Tizard was unwilling to advise the purchase of all available uranium stocks… and the Belgians were unwilling to grant Britain an option on every ton that was produced.'[12] It was thought advisable to try to have the stocks moved to a safer location in an effort to stop Germany acquiring them.

G.P. Thomson applied through the Air Ministry for a ton of uranium oxide to conduct research into the possibility of a chain reaction in uranium.[13] He obtained the uranium oxide but concluded 'a chain reaction in natural uranium was unlikely and a war project therefore impractical'.[14] However, a chain reaction was thought to be possible using the moderator of

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[10] Reidman, S.R *Men and Women Behind the Atom*, London and New York, Abelard Schuman, 1957, p. 124

[11] Henry Tizard was chairman of the Committee for the Scientific Survey of Air Defense, also connected to the Ministry of Air Production. He was leading the charge for the development of radar at the same time as the early discussions on the atomic bomb.

[12] Irving, D *The Virus House*, London, William Kimber, 1967, p. 35

[13] A chain reaction means the process of fission is replicated many times due to the free neutrons produced during fission hitting other uranium nuclei.

[14] Rhodes, R *The Making of the Atomic Bomb*, New York, Simon and Schuster, 1986, p. 329

heavy water[15] if the uranium isotopes[16] were separated. A chain reaction needed uranium 235 which only constitutes 0.7% of ordinary uranium. The rest is mostly uranium 238 with traces of uranium 234, which is unsuitable for nuclear fission.

The Germans did not have the necessary resources for separating the isotopes of uranium. However, Germany did have access to the world's only heavy water factory which they had taken when invading and conquering Norway. When the Germans finally subdued the Norwegians in May 1940, one primary objective was the Norsk Hydro Plant which produced heavy water as a waste product from making electricity. The Germans ordered the plant to increase heavy water production. 'When this became known in London, it was recognised as a sign that the Germans thought they might manage to make an atomic bomb out of heavy water.'[17] The plant was expanded in order to produce 1.5 tonnes of heavy water per year. Germany had a ton of heavy water by 1942.

Germany's uranium research had serious flaws. Not only was there a lack of organisation, but also a certain amount of arrogance. The Germans believed if they were struggling to progress with uranium research then the Allies must be also. The Allies interpreted the total absence of German 'leaks' of information on their uranium programme as a sign of efficient German secrecy. The Germans made a mistake with their dogmatic policies. 'By persecuting all scholars

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[15] Heavy water is water with hydrogen atoms that have a neutron as well as a proton. This hydrogen isotope is known as Deuterium. The chemical formula for heavy water is D_2O. Deuterium's mass number is 2, double that of ordinary hydrogen. Moderators such as heavy water could slow down neutrons and keep chain reactions under control. Other possible moderators considered included carbon in the form of graphite to create a chain reacting pile.

[16] An isotope is one of two or more atoms that have the same atomic number, which is the number of protons in the nucleus, but a different mass number. This is the number of protons and the number of neutrons in the nucleus combined.

[17] Foot, M.R.D *SOE: The Special Operations Executive 1940-46*, London, British Broadcasting Corporation, 1984, p. 211

afflicted with the Jewish 'taint', Germany lost some of the greatest scientists in the world'.[18] These émigrés ended up in allied countries such as Britain, France and the United States. In Britain, émigrés were not permitted to work on radar due to secrecy of information but this exclusion 'left them all the more free to contemplate the mysteries of nuclear fission'.[19]

In Britain, the scientists G.P Thomson, James Chadwick, John Douglas Cockcroft who had been a student of Ernest Rutherford at Cambridge and Francis Simon, who was working at the Clarendon Laboratory in Oxford, discussed a paper published in spring 1940 by German scientist refugees Otto Frisch[20] and Rudolf Peierls[21]. This paper stated that a uranium bomb would be feasible. The much studied Frisch-Peierls Memorandum was important for a number of reasons. Firstly it claimed that a uranium bomb was possible. 'We have discussed this possibility and come to the conclusion that a moderate amount of ^{235}U would indeed constitute an extremely efficient explosive.'[22] The memorandum stated such a bomb would be a weapon of mass destruction and 'the only defence would be the deterrent effect of possessing such bombs oneself'.[23] Chillingly, the scientists foretold that 20% of an atomic explosion would be radiation and it would be lethal enough to kill humans long after the original explosion had taken place. 'In addition to the destructive effect of the explosion itself, the whole material of

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[18] Goudsmit, S.A *Alsos*, American Institute of Physics, New York, 1947, p. 235

[19] Clark, R.W *The Birth of the Bomb,* London, Phoenix House, 1961, p. 50

[20] Otto Frisch was born in Vienna and educated at Vienna University. In 1933, Frisch came to England to work with Patrick Blackett at Imperial College, London. He then had a spell researching at Niels Bohr's Institute in Copenhagen before the Second World War. After his time at Los Alamos, Frisch returned to England to work at the Atomic Energy Research Establishment at Harwell.

[21] Sir Rudolf Peierls was born and educated in Berlin, Germany. He studied under Werner Heisenberg at Leipzig and did further research at Rome, Cambridge and Manchester universities before being appointed professor at Birmingham University in 1937. After the war he took a post at Oxford University in 1963. He was knighted in 1968 and taught from 1974-1977 at the University of Washington.

[22] Gowing, M *Britain and Atomic Energy*, London, Macmillan, 1964, p. 390

[23] Irving, D *The Virus House*, London, William Kimber, 1967, p. 64

the bomb would be transformed into a highly radioactive state.'[24] Furthermore, the estimated power of a 5kg atom bomb was the same as several thousand tons of conventional dynamite. 'The blast from such an explosion would destroy life in a wide area. The size of this area is difficult to estimate, but it will probably cover the centre of a big city.'[25] These predictions were staggering and had obvious military implications in a time of war. 'The Frisch-Peierls Memorandum…is a remarkable example of scientific insight. The two scientists had performed one of the most difficult tasks in science – they had asked the right questions'.[26] It was a coherent and surprisingly accurate document considering the bomb was only a concept at this stage.

The memorandum wasn't so accurate in its guess at the critical mass of uranium needed for a bomb. This prediction was rather small, at only one pound. There had not been an accurate enough estimate of the uranium cross section, needed to confirm the critical mass.[27] That said, it could safely be concluded that the critical mass was not in tons, as had been previously thought but until then 'no one had thought of finding out if this was correct.'[28] Frisch and Peierls stated anything below critical mass was safe but anything above was an explosive. 'The bomb would therefore be manufactured in two (or more) parts, each being less than the critical size, and in transport all danger of a premature explosion would be avoided if these parts were kept at a distance of a few inches from each other.'[29] Also, the scientists conceded their estimates might be inaccurate because they had been working on 'certain theoretical ideas

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[24] Gowing, M *Britain and Atomic Energy 1939-1945*, London, Macmillan, 1964, p. 392

[25] Gowing, M and Arnold, L *The Atomic Bomb*, London, Butterworth, 1979, p. 34

[26] Gowing, M and Arnold, L *The Atomic Bomb*, London, Butterworth, 1979, p.13-14

[27] A 'cross section' in this case is not a measurement of size. It is actually a probability of how many uranium atoms could be expected to undergo fission under certain conditions. The figure is expressed in standard form. 10^{-23} was the original estimate although this figure was subsequently found to be too large and refined.

[28] Clark, R.W *The Greatest Power on Earth: The story of Nuclear Fission*, London, Sidgwick and Jackson, 1980, p. 88

[29] Clark, R.W *Tizard*, London, Methuen and Co, 1965, p. 215

which have not been positively confirmed.'[30] The memorandum acknowledged there were difficult problems associated with separating the uranium 235 isotope. However, the authors argued 'These difficulties are by no means insuperable. We have not sufficient experience with large-scale chemical plant to give a reliable estimate of the cost, but it is certainly not prohibitive.'[31] Frisch and Peierls also communicated their ideas to Mark Oliphant[32] who was director of the physics department at Birmingham University. Oliphant advised them to inform the Tizard Committee. This was sound advice as Tizard ran the committee dealing with applications of science in war but was also connected with the Air Ministry. Bombs of the size predicted by Frisch and Peierls could be dropped by air. Ties between science and government would also be formed.

At the same time as the Frisch-Peierls Memorandum, there was a visit to England from Lt. Jacques Allier, a French intelligence officer working for the French Secret Service. Allier explained to G.P Thomson that Germany had become very interested in uranium research and was concentrating efforts on making heavy water for isotope separation. This was disturbing to Thomson as it looked as though the Germans were forging ahead. Thomson also stated that uranium was not the only fissile material that might make a weapon. It might also be feasible to use plutonium for a functional device.[33] However plutonium had its own problems as it was much more hazardous to handle than uranium.

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[30] Clark, R.W *Tizard*, London, Methuen and Co, 1965, p. 217

[31] Gowing, M and Arnold, L *The Atomic Bomb*, London, Butterworth, 1979, p. 34

[32] Sir Mark Oliphant was born in Adelaide, 1901. He studied at Trinity College Cambridge and attained his Ph.D in 1929. Working with Rutherford at the Cavendish, he discovered the tritium isotope of hydrogen in 1934 and became a professor at Birmingham University in 1937. After the war, he spoke against an American monopoly of nuclear technology and was knighted in 1959.

[33] Plutonium is a man made element, transmuted when uranium 238 absorbs neutrons during fission. When uranium 238 absorbs a neutron, it emits an electron by beta decay and loses negative charge. This moves the atom one place up in the periodic table, hence, element 93, neptunium, is created. Neptunium is chemically unstable and the beta emission is repeated. It decays to form element 94: plutonium 239.

G.P Thomson and Henry Tizard were not convinced by the émigrés' memorandum but combined with Allier's visit, it was decided the claims should not be ignored. Henry Tizard had the idea of making a group to investigate the possibility of nuclear weapons and suggested that G.P Thomson should lead this group. The team was named the MAUD Committee. Its brief was to investigate whether there was any hope of obtaining an atomic weapon and if such a bomb were capable of being produced during war time. The MAUD Committee was originally going to be called the Thomson Committee after G.P Thomson. However, this may have given clues as to the reason for its existence so the cover name of MAUD was adopted. The name sprang from a garbled telegram sent by Lise Meitner in Germany to an English friend, telling of Niels Bohr's agitation over the Germans invading Norway and Denmark. The ending words were 'please inform Cockcroft and Maud Ray Kent'[34]. John Cockcroft received the message but Maud Ray Kent seemed to make no sense. He suggested these words 'might contain a hidden reference to some sort of ray.'[35] There was also the suggestion of an anagram for 'radium taken' which could have been a warning from the newly occupied territories 'to the effect that Germany was purchasing surreptitiously all available supplies of radio-active materials.'[36] Thomson used the first word in this suspected anagram as a cover name. 'The committee members did not learn until 1943 that Maud Ray was the governess who had taught Bohr's sons English; she lived in Kent.'[37]

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[34] CKFT 10/1, *Report on Telegram Received by Prof. Cockcroft on 19/5/40*, Churchill Archives Centre, p. 1
[35] CKFT 10/1, *Report on Telegram Received by Prof. Cockcroft on 19/5/40*, Churchill Archives Centre, p. 1
[36] CKFT 10/1, *Report on Telegram Received by Prof. Cockcroft on 19/5/40*, Churchill Archives Centre, p. 1
[37] Rhodes, R *The making of the Atomic Bomb*, New York, Simon and Schuster, 1986

The committee stressed the importance of Britain and the allies obtaining the bomb before Germany. 'German interest in Norwegian heavy water, in Portuguese Uranium, and the placing of orders for a large number of fans suitable for a gaseous diffusion plant[38] was observed'.[39] Britain attained a unique position by forming the MAUD Committee. It was a trailblazer. The Committee was 'the first in any country to consider how it might be possible to construct a specific nuclear weapon'.[40] There was the lethargic Briggs Uranium Committee[41] in the United States, but in the early stages, American scientists believed the enormous technical obstacles to a nuclear weapon would prove insurmountable. The funds for the Briggs committee were limited and it focused on researching the general properties of uranium. That the U.S became the driving force in the nuclear arms race was in no small part due to the encouragement received from the scientists working on technical challenges and theories in Britain.

The problems in Britain began with scientists trying to inform politicians and subsequently having to ask for funds. Clashes were inevitable but the politicians' scepticism stemmed from having no clear understanding of the complexities involved in nuclear physics. In a letter to Sir Kingsley Wood, the Secretary of State for Air, Churchill dismissed the possibility of an imminent nuclear attack from Germany in August 1939. He cited the technological difficulties of extracting enough uranium to be useful. 'This will be a matter of many years'.[42] The threat of a German atomic bomb was unlikely as 'only a comparatively small amount of uranium in

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[38] Gaseous diffusion was one method of separating the uranium isotopes. If gases are diffused through a membrane, they diffuse at different rates according to their molecular weight. Lighter gases will diffuse faster than heavier ones. Uranium was not found naturally as a metal, it was usually in the form of a compound, either uranium oxide or the corrosive gas uranium hexafluoride, known by the scientists as 'hex' for short.

[39] Pierre, A *Nuclear Politics: The British experience with Independent Strategic Force 1939-1970*, London, Camelot Press, 1972, p.16

[40] Clark, R.W *The Birth of the Bomb*, London, Phoenix House, 1961, p. 65

[41] This committee was run by Lyman J. Briggs, who was director of the Bureau of Standards.

[42] Churchill, W.S *The Second World War: Volume 1*, London, Cassell, 1948, p. 301

the territories of what used to be Czechoslovakia is under the control of Berlin'.[43] Other sceptics spoke in the same vein. G.P Thomson's fear of a German atomic attack reached General Ismay, Secretary for Imperial Defence. Ismay asked the opinion of John Anderson, who in 1939 was Lord Privy Seal. According to Wheeler-Bennet: 'John listened in silence and then, somewhat with the air of one explaining the alphabet to a child, remarked that an atom bomb was "a scientific but remote possibility"'.[44] Henry Tizard remained sceptical, even after the Frisch-Peierls memorandum was made known to him. Tizard became more interested due to the estimate of a pound for the critical mass, which made a nuclear weapon a little more practical. 'A uranium-bomb might still be the most remote of possibilities but it could not be definitely ruled out.'[45]

Conversely, the scientists' frustration came from their lack of understanding about politics and inability to access the corridors of power. As the 'phoney war' ended and Hitler was marching through Europe, the scientists had to convince Whitehall that their project deserved top billing. Peierls wrote to Lord Cherwell[46], arguing the probability of success was 'sufficiently high'[47] to warrant further investigation. It could be annihilation if Hitler acquired the bomb first. John Cockcroft said when the scientists realised the significance of the Frisch-Peierls paper, 'Our first reaction was to consider the disastrous results such a bomb would have if

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[43] Churchill, W.S *The Second World War: Volume 1*, London, Cassell, 1948, p. 301

[44] Wheeler-Bennett, J *John Anderson*, London, Macmillan, 1962, p. 289

[45] Clark, R.W *Tizard*, London, Methuen and Co, 1965, p. 218

[46] Lord Cherwell, also known as Frederick Alexander Lindemann, was born in Germany. He was educated at the University of Berlin and also at the Sorbonne in Paris where he worked on problems of atomic heat. In 1914 he became Director of the Royal Flying Corps Experimental Physics Station at Farnborough. He later returned to Oxford and became Professor of Experimental Philosophy and the director of the Oxford Clarendon Laboratory. Cherwell was a close friend of Churchill's, becoming his personal assistant in 1940. Cherwell served as Postmaster-General from 1942-45. In the 1951 Churchill government, he advised on nuclear research and general science issues. He resigned in 1953.

[47] AB 1/106, Lord Cherwell's Papers, Miscellaneous Notes and Reports on Uranium Projects, *Peierls to Lindemann, 2/6/40,* National Archives, p. 2

used against us by the Germans.'[48] The few physicists who had correctly foreseen the bomb would have far reaching political implications, wondered if Hitler really had it in 1939. This would go some way to explaining his reckless military gambles. It was thought to be 'the unknown quantity, the X, in the 1939 power-politics equation'.[49]

The first meeting of the MAUD Committee, which was part of the Ministry of Aircraft Production, was held on 10th April 1940 in Burlington House, London. The original members of the MAUD committee were G.P Thomson as Chairman, Cockcroft, Chadwick, Philip Moon and Mark Oliphant. The group no doubt was preoccupied with the German invasion of Norway. 'It probably met as much to hear a visitor, the ubiquitous Jacques Allier of the Banque de Paris and the French Ministry of Armament, as to discuss the Frisch-Peierls work.'[50] This group needed a consensus over whether a nuclear project was feasible. However the risks of producing weapons of this nature were big as there was no way to test such weapons on a small scale.

There was a vast array of problems to be investigated. The most pressing was the fact that uranium 235, the fissionable isotope, was so rare compared to uranium 238. 'These two isotopes are chemically identical; therefore, ordinary chemical separation techniques do not work'.[51] The only difference was the rare isotope had slightly less mass. The two isotopes would have to be separated at huge expense. Thomson stated 'There were plenty of ways known in 1940 of separating isotopes, but all difficult, especially when the isotopes differ so

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[48] Cockroft, J.D (Ed) *Atomic Challenge*, London, Winchester Publications, 1947, p. 9
[49] Jungk, R *Brighter Than 1000 Suns*, London, Gollancz and Hart Davis, 1958, p. 75
[50] Rhodes, R *The Making of the Atomic Bomb*, New York, Simon and Schuster, 1986, p. 330
[51] Shcroeer, D *Science Technology and the Nuclear Arms Race*, New York, John Wiley, 1984, p. 25

little in mass, only 1.2 per cent.'[52] An alternative could be plutonium as it possessed chemically different properties to uranium and could be separated relatively simply. Peierls and Francis Simon were put in charge of investigating methods of isotope separation. Professor Chadwick undertook investigations into the fundamental physics. Imperial Chemical Industries were enlisted to help the team of scientists working on the problem at Birmingham University.

The MAUD meetings had occasional visitors to them, such as distinguished foreign scientists, informants like Lt. Allier from the Deuxieme Bureau, the French Secret Service, and various people in industry who could help with ideas for production. This system worked very well as it linked the scientists with people of essential expertise. Secrecy was paramount concerning the Frisch-Peierls calculations as 'even rumours of some connection between uranium isotope separation and a bomb might set the Germans thinking along the right lines'.[53] Secrecy was implemented in an utterly ridiculous way. Because Frisch and Peierls were classed as 'enemy aliens', to start with they were not allowed to sit on the committee they helped instigate. Frisch complained 'it was obviously inefficient. Not only had our report started the whole thing, but we had also thought about many of the additional problems that would arise.'[54] The problem was solved by splitting the MAUD Committee into a policy committee for the English directors of the research and a technical subcommittee, which the 'alien' scientists could attend. This set a trend for the cynical use of foreign born scientists.

As the project was entirely new and on a large scale, vast amounts of money would have to be spent before any practical results became obvious. Even allowing for this, early estimates of

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[52] Thomson, G.P *Nuclear Energy in Britain During the Last War*, Oxford, Clarendon Press, 1962, p. 7
[53] Irving, D *The Virus House*, London, 1967, p. 64
[54] Frisch, O *What Little I Remember*, Cambridge, Cambridge University Press, 1979, p. 130

cost were highly speculative and optimistic. A summary of the project estimated the cost of making several bombs to be 4 – 5 million pounds.[55] The military viewed 'with suspicion anything new that appears to require radical departures from established methods or, worse still, suggests the progressive obsolescence of their own brand of warfare.'[56] It could not be guaranteed that the resources needed for the research would be easily available during wartime, especially because MAUD was only loosely connected to the Whitehall apparatus. When the scientists estimated the cost of a uranium production plant, it was 'probably the first time that physicists had ever had to accustom themselves to the sum of a million pounds as a unit of cost'.[57]

The main reason MAUD acted so fast to take action was that it was a scientific group which fully understood what the Frisch-Peierls Memorandum could mean. It was obvious to the group that if they had worked out a solution to the theoretical difficulties of the bomb, any able physicist in Germany could do likewise. It is hard to overstate the immense difficulty of the task MAUD faced, not only overcoming technical challenges but also alerting the government to the urgency of the work.

The war created another problem. Many eminent scientists who could help the Allied effort were in Paris which was under imminent threat of German capture. The eccentric Earl of Suffolk[58], British scientific attaché to Paris, was handed a list of who should be evacuated to

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[55] AB 1/106, Lord Cherwell's Papers, Miscellaneous Notes and Reports on Uranium Projects, *MAUD, Summary*, National Archives, p. 1

[56] Freedman, L *The Evolution of Nuclear Strategy*, London, Macmillan, 1981, p. 24

[57] Bertin, L *Atom Harvest*, London, Secker and Warburg, 1955, p.60

[58] The 20th Earl of Suffolk was a bomb disposal expert. He worked as Liaison Officer for the British Department of Scientific and Industrial Research in the early part of the Second World War. After hs successful mission to rescue machine tools and scientists from France, he returned to England to work as a

Britain if Paris became under serious threat. Herbert Morrison[59], the British Minister of Supply, had given the Earl this task as a special assignment. Morrison recounted 'I invited him to act in France on behalf of the Ministry of Supply and try to get hold of a lot of machine tools in French engineering works which would be invaluable to us.'[60] Morrison also asked Suffolk to rescue the heavy water stocks 'partly to prevent them falling into the hands of the Germans but also because it was badly needed by British scientists.'[61] Morrison pays tribute to Suffolk's bravery of venturing 'into a country which was more or less completely overrun by the Germans, and with very few chances of getting out with his own life.'[62]

The Earl had a list of 150 scientists and technical personnel to be evacuated from France before it fell to the Nazis. He was hampered as some scientists felt it was their duty to stay in France, such as Frédéric Joliot-Curie[63]. 'Joliot-Curie, who reached Bordeaux after the *Broompark* had been moved from the quay, decided to remain in France, where he was to become a formidable leader of the Resistance'.[64] Also Joliot-Curie felt tied to his laboratory 'which included a recently completed cyclotron, the first ever made in Central and Western

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Research Officer for the Ministry of Supply. The Earl specialised in defusing unexploded bombs and was invaluable during the Blitz. He died while trying to defuse a bomb on Erith Marshes, on May 12th 1941.

[59] Herbert Morrison was born in Lambeth, London in 1888. After being a shop assistant, he helped to found the London Labour Party, becoming its secretary in 1915. Morrison entered the London County Council in 1922, becoming its leader in 1934. In Churchill's War Cabinet, Morrison served as Home Secretary and Minister of Home Security.

[60] Morrison, H *Herbert Morrison: An Autobiography by Lord Morrison of Lambeth*, London, Odhams, 1960, p. 180

[61] Morrison, H *Herbert Morrison: An Autobiography by Lord Morrison of Lambeth*, London, Odhams, 1960, p. 180

[62] Morrison, H *Herbert Morrison: An Autobiography by Lord Morrison of Lambeth*, London, Odhams, 1960, p. 180

[63] Frédéric Joliot-Curie was born in Paris, 1900. He studied at the Sorbonne and joined the Radium Institute in 1925. He married Irene Joliot-Curie in 1926, sharing the Nobel Prize with her in 1935 for making the first artificial radio isotope. Joliot Curie was a strong supporter of the Resistance during the war and a member of the Communist Party. He died in 1958 from cancer caused by lifelong exposure to radiation.

[64] Clark, R.W *The Greatest Power on Earth*, London, Sidgwick and Jackson, 1980, p. 99

Europe'.[65] He found it impossible to sail for England due to 'his responsibility for the welfare of a great number of young scientists.'[66] Many others could not be contacted due to the chaos of the German advance. Around 40 scientists made the voyage, along with a strange consignment. 'It took the form of thirty-six gallons of heavy water which they nursed like the best Napoleon brandy.'[67] There was also £2.5 million of industrial diamonds and tools rescued. The scientists and heavy water were escorted aboard the *Broompark* for the trip. Plans were made to save the heavy water should the ship be attacked by the Germans. 'The Earl had the cans lashed to a raft in the hope of saving them should the ship be torpedoed – the odds of which he privately judged to be about even.'[68] The *Broompark* completed the journey unscathed, despite a neighbouring vessel being sunk by a mine, and docked safely at Falmouth Roads off the coast of south Cornwall. The achievement of saving the heavy water was an important asset as it represented most of the world stock at the time and was as crucial a loss to Germany as it was a gain for the Allies.

The success is all the more noteworthy since it was the second time the heavy water had been snaffled from under the noses of the Germans in 1940, having previously been smuggled out of Norway to France by Allier. He had been sent to Norway by the French Secret Service, to stop the heavy water being poached by I.G Farben in March 1940. Allier was sent with full powers 'false papers and… all the paraphernalia of the hero of a spy story with the exception of a false beard.'[69] If he was unsuccessful in the negotiations, Joliot-Curie had instructed Allier to contaminate the heavy water stocks with either cadmium or boron. 'The slightest trace of

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[65] Jungk, R *Brighter Than 1000 Suns*, Gollancz and Hart-Davis, 1958, p. 104

[66] TMSN 4 *Letter written by Hans Halban, 16/7/40,* Churchill Archives Centre, p. 1

[67] Bertin, L *Atom Harvest*, London, Secker and Warburg, 1955, p. 55

[68] Dahl, P.F *Heavy Water and the Wartime Race for Nuclear Energy*, Bristol and Philadelphia, Institute of Physics Publishing, 1999, p. 128

[69] AB 1/91, Heavy Water from Norsk Hydro Elektrisk, *Top Secret note on Allier's activities, 6th March 1946,* National Archives, p. 1

either element would render the heavy water useless as a chain-reaction moderator free of neutron capture'.[70] In the event, this proved unnecessary. The director of Norsk Hydro, Axel Aubert 'agreed not only to lend France the entire stock of heavy water…but also assured Allier that France would have priority claims on production in the near future'.[71] Allier told Aubert why heavy water was so vital. He found that Aubert had become suspicious of I.G Farben's request for such huge stocks of heavy water, with no plausible explanation of why it was needed. Aubert then handed the supplies to Allier 'without a murmur'[72]

Frank Foley from M.I.6 was on hand to help load the heavy water onto a plane to Scotland from Norway. 'From Oslo Allier's team flew it to Edinburgh in two loads – German fighters forced down for inspection a decoy plane Allier had pretended to board at the time of the first loading – and then transported it by rail and channel ferry to Paris.'[73] This mission enabled the heavy water to be stored in France for experiments until the Germans invaded and it was moved for the second time. Two of the refugee scientists from France, Hans von Halban[74] and Lew Kowarski, were allotted to the Cavendish Laboratory in Cambridge to help the British research by the MAUD Committee. When the French physicists arrived in Britain, they were informed that even though they were allies 'since they had no identity cards they were legally unable to move anywhere.'[75] In fact the French physicists found themselves under the

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[70] Dahl, P.F *Heavy Water and the Wartime Race for Nuclear Energy*, Bristol and Philadelphia, Institute of Physics Publishing, 1999, p. 105
[71] Dahl, P.F *Heavy Water and the Wartime Race for Nuclear Energy*, Bristol and Philadelphia, Institute of Physics Publishing, 1999, p. 107
[72] AB 1/91, Heavy Water from Norsk Hydro Elektrisk, *Top Secret note on Allier's activities, 6th March 1946*, National Archives, p. 1
[73] Rhodes, R *The Making of the Atomic Bomb*, New York, Simon and Schuster, 1986, p. 327
[74] Halban was Austrian by birth. He was educated in Austria and Germany, achieving a Ph.D in Physics at Zurich University in 1935. He later became a member of Frédéric Joliot-Curie's team working at the College de France in 1937. Halban was often frustrated his nuclear research was held up with administrative delays during the war. After the war, he returned to pure physics research at the Clarendon Laboratory in Oxford.
[75] Clark, R.W *The Greatest Power on Earth*, London, Sidgwick and Jackson, 1980, p. 99

restrictions imposed on ‘enemy aliens’. They could not use a map to find the Cavendish Laboratory and had a curfew. Furthermore, their arrival was not enthusiastically received by other scientists. Halban and Kowarski had been working on nuclear power as a source of energy, not on fission for a bomb. The British had succeeded in an elaborate rescue plan of the French scientists but had no plan of what to do with them once they got to England. Nevertheless, Halban has recounted ‘the Ministry of Supply took all steps to make the continuation of our work possible.’[76] In Halban’s opinion, the amount of heavy water rescued was ‘sufficient to decide whether Uranium can be used in combination with heavy water for the production of divergent chain reactions or not.’[77] Halban hoped then to proceed very quickly with his part of the work, as preliminary experiments had been completed in France and he expected ‘to obtain definitive results no later than January next.’[78]

The fall of France had another consequence. Recently declassified material has stressed the ‘collapse of France and the emergence of undisputed Nazi control over practically all of continental Europe jarred the United States into awareness of the necessity of strengthening its national defenses.’[79] Accordingly, the Briggs Uranium Committee was stepped up in importance to become a subcommittee of the National Defence Research Committee and given more funds. This subcommittee was then accountable to Dr. Vannevar Bush, who was president of the Carnegie Institution. He had formerly been the dean of the school of engineering at Massachusetts Institute of Technology. Even so, the Briggs Committee didn’t move forward quickly, partly due to Briggs himself. ‘Although Briggs was a physicist, his own

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[76] TMSN 4, *Letter from Hans Halban, 16/7/40*, Churchill Archives Centre, p. 2
[77] TMSN 4, *Letter from Hans Halban, 16/7/40*, Churchill Archives Centre, p. 1
[78] TMSN 4, *Letter from Hans Halban, 16/7/40*, Churchill Archives Centre, p. 3
[79] Gale Reference Library, Harry S. Truman Library, *History of United States-British and Canadian Atomic Relations, March 2nd 1949*, p. 2. Thank you to Dr. Gábor Bátonyi for providing me with this document.

experience and interests lay outside the field of nuclear physics, and his numerous other responsibilities proved to be serious distractions.'[80] Additionally, the Briggs Committee was different from MAUD as it was less willing to take the advice of émigré scientists. 'An advisory committee inspired by Szilard[81] [in May 1940] and composed of men appointed by Briggs…was informed at its first meeting that it would be disbanded because not all its members were U.S citizens of long standing.'[82]

In Britain, the MAUD Committee started assigning tasks to teams working at different universities and laboratories. Regarding the French scientists' work on heavy water and uranium, Halban suggested the experiments should be relocated to Canada as there would be less danger of bombing raids. However, Chadwick felt Britain would then be at risk of losing control over the work. For this reason, Chadwick 'was inclined to think that the work should start at once, either in Liverpool or in Cambridge.'[83] There were 'very reasonable grounds for believing that the slow neutron reaction would go'[84] meaning a chain reacting pile using uranium and heavy water could be produced. As this reaction used slow neutrons, it would not be an explosive but could have possible military value as 'it was suggested that the radiations produced would be such as to render uninhabitable a very large area.'[85] Mark Oliphant wrote to

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[80] Sherwin, M.J *A World Destroyed*, New York, Vintage Books, 1975, p. 28

[81] Leo Szilard was born in Budapest, Hungary in 1898. He studied physics in Berlin. He fled to England in 1933 to escape the Nazis, emigrating to the USA in 1938. Szilard worked on nuclear physics at Columbia University. He approached Albert Einstein to convince Einstein to warn President Roosevelt about the possibility of making an atom bomb. Szilard worked with Enrico Fermi on the first nuclear reactor and was a key figure in the Manhattan Project. After the war, Szilard researched molecular biology.

[82] Sherwin, M J *A World Destroyed*, New York, Vintage Books, 1975, p. 30

[83] CHAD 1 28/6, *Notes of a meeting at the University of Liverpool, Sunday 30th June 1940*, Churchill Archives Centre, p. 2

[84] CHAD 1 28/6, *Notes of a meeting at the University of Liverpool, Sunday 30th June 1940*, Churchill Archives Centre, p. 2

[85] CHAD 1 28/6, *Record of a Meeting held with Dr. von Halban and M. Kowarski, June 24th 1940*, Churchill Archives Centre, p. 3

John Cockcroft saying he was not enthusiastic about the French slow neutron work but added he was disturbed 'by their news of the activities of the German isotope separators.'[86]

Universities played a prominent role in the early research. 'So advanced in character was this work that it was virtually confined to the universities, unlike many areas of electrical science, for example, where expertise lay as much in industrial research laboratories.'[87] Dr. Peierls had a team working on determining the size of the uranium cross section at Birmingham University. He enlisted the help of talented mathematicians due to the need for maximum accuracy. One of these recruits was Klaus Fuchs. Fuchs had studied at Bristol and Edinburgh Universities and had come to Britain due to his hatred of the Nazi regime. Fuchs was also known to have Communist sympathies. Klaus Fuchs 'took a leading part in the calculations of the critical size of the bomb'.[88] The future Soviet spy had found a handy niche for himself on the British team. A second group was working in Birmingham under the direction of Walter Haworth. They concentrated on 'chemical work on the production of gaseous uranium compounds and metallic uranium'.[89] There was a small group at Bristol working on the fundamental physics of creating a bomb. This group was guided by Alan Nunn May, another future spy, and Cecil Powell.[90]

Chadwick and his team at Liverpool University also concerned themselves with determining the uranium cross section. Chadwick worked in close collaboration with Peierls in

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[86] CKFT 10/1, *Oliphant to Cockcroft, 6th July 1940*, Churchill Archives Centre, p. 1

[87] Sanderson, M *The Universities and British Industry 1850-1970*, London, Routledge and Kegan Paul, 1972, p. 343

[88] Jungk, *Brighter Than 1000 Suns*, Gollancz and Hart-Davis, 1958, p. 106

[89] Dahl, P.F *Heavy water and the Wartime Race for Nuclear Energy*, Bristol and Philadelphia, Institute of Physics publishing, 1999, p. 123

[90] Cecil Powell was born in Kent and educated at Cambridge, attaining his Ph.D in 1927. He worked throughout his career at the University of Bristol and was part of a movement to increase the social responsibility of scientists after the dropping of the atomic bomb.

Birmingham. Frisch suggested to Mark Oliphant that he should conduct his part of the MAUD work at Liverpool. Oliphant wrote to Cockcroft suggesting the person Chadwick would find most helpful was Frisch 'but as Liverpool has now been declared a protected area it will mean that special permission must be obtained for him to work there.'[91] Frisch felt he would be sidelined at Birmingham due to the university being geared to radar work 'whereas the Liverpool Institute had not started any war work and moreover had a cyclotron which would serve as a powerful source of neutrons whose energy we could control.'[92] Cyclotrons were not common as they were a precision instrument and very expensive. They were the early particle accelerators. When heavy German bombing began at the start of the Blitz, the work undertaken at Liverpool was moved to the Cavendish Laboratory at Cambridge. This was to safeguard against heavy bombing raids expected near Liverpool docks and the surrounding area. At Cambridge, Dr. Norman Feather took over the research, having previously worked with Chadwick during the search for the neutron.

The most problematical task of isotope separation was taken on by the Clarendon Laboratory at Oxford. Francis Simon was in charge of this work. Simon was an outstanding physicist. He had been given shelter in Britain from Nazi Germany in 1933. He was an expert in thermodynamics and had a cryogenics team at Oxford. 'He was unequalled as a low temperature physicist, he had drive, organizational prowess, amiability, and a sense of humour; he was an inspiring supervisor of postgraduates.'[93] Simon was the perfect choice for investigating diffusion as he had studied the properties of liquids at high pressures. Simon was

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[91] CKFT 10/1 *Oliphant to Cockcroft, 6th July 1940*, Churchill Archives Centre, p. 1

[92] Frisch, O *What Little I Remember*, Cambridge, Cambridge University Press, 1979, p. 132

[93] Morrell, J *Science at Oxford 1914-1939: Transforming an Arts University,* Oxford, Clarendon Press, 1997, p. 412

aware of the immense task MAUD had given him. 'You couldn't spit on the floor without separating isotopes, Simon joked; the problem was to collect them.'[94]

Simon was aided by Dr. Nicholas Kurti from Hungary, Dr Arms from America and Dr. Kuhn from Germany. Simon experimented by hammering the holes of a kitchen sieve flat, so the spaces between them were like pinholes. This gave him the idea of gaseous diffusion through a barrier to enrich uranium 235. An industrial scale of this idea would be needed and this would involve thousands of repetitions, taking up electricity to run the plant. There would be huge technical difficulties with the method. 'The barrier – filter might have been a better name – would need billions of holes with a diameter less than one tenth the mean free path of a molecule, about one ten-thousandth of a millimetre.'[95] Isotope separation 'promised to be the most complicated task of chemical engineering that man had ever considered'.[96] Not only were the methods for separation difficult, the equipment needed would also have to be sophisticated and therefore more expensive. The only compound found suitable for gaseous diffusion in 1940 was uranium hexafluoride. 'In addition there were the immense engineering problems involved in pumping a uniquely corrosive gas through the immense number of membranes.'[97] Simon first started his primitive experiments in June 1940 and these carried on through the summer and autumn. The centrifuge method of isotope separation had been considered but ruled out due to mechanical difficulties. No apparatus could spin the tubes fast enough. At the same time as Simon's team was carrying out its groundbreaking research, the group 'had to report their movements to the local police, in accordance with the defence regulations for

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[94] Rhodes, R *The Making of the Atomic Bomb*, New York, Simon and Schuster, 1986, p. 339
[95] Hewlett, R.G and Anderson, O E *The New World: A History of the United States Atomic Energy Commission Volume 1 1939-1946*, Pennsylvania State University Publishing, 1962, p. 31
[96] Clark, R.W *The Birth of the Bomb*, London, Phoenix House, 1961, p. 91
[97] Clark, R.W *The Greatest Power on Earth*, London, Sidgwick and Jackson, 1980, p. 111

aliens.'[98] This was an added and infuriating burden which shows how well the teams working for MAUD adapted to the constraints imposed on their research during the war.

Imperial Chemical Industries played an important part in isotope separation as they helped develop the stages of the diffusion plant that was planned by Simon's team at the Clarendon. 'It was in this area that the close connections between university and industrial contributions were most clearly seen.'[99] This project was well worth the effort. It would be lucrative as a diffusion plant would need thousands of individual stages to make the isotope up to a pure enough state for fission. The porous membranes had to be at an exact size to effectively separate the uranium 235 isotope and the tubes needed had to be of a specific alloy which could withstand the corrosive effect of hexafluoride. 'In the search for means of constructing the very fine mesh of the filters ICI Metals at Witton were called in… The actual plant itself was built by Metro-Vickers.'[100] Imperial Chemical Industries' involvement showed Britain was the first to understand the scale of industrial participation needed to develop the apparatus for producing the bomb.

Before he left England, Allier had another problem for the British to be working on. He had been given, by Joliot-Curie, a list of German physicists who would be able to engage in nuclear research. He showed this list to Henry Tizard and suggested checking whether these physicists were still at their own universities or had been posted somewhere unusual. 'Would this not be

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[98] Fort, A *Prof: The Life of Frederick Lindemann*, London, Jonathan Cape, 2003, p. 307

[99] Sanderson, M *The Universities and British Industry 1850-1970*, London, Routledge and Kegan Paul, 1972, p. 344

[100] Sanderson, M *The Universities and British Industry 1850-1970*, London, Routledge and Kegan Paul, 1972, p. 344

a good indication of whether the enemy had formed its own Maud Committee?'[101] German periodicals were also studied to see which German physicists were still publishing papers on nuclear physics. These checks continued as there was little information about German scientists coming from the Secret Service. Francis Simon wrote to Chadwick saying 'Peierls and Fuchs went last week to London chiefly in order to go through the German periodicals which have arrived lately and to find out where the people who are liable to work on this subject are at present.'[102] Their results were inconclusive but they did find that both nuclear fission and isotope separation were being mentioned freely as late as the summer of 1941 which Peierls thought was a bluff. Samuel Goudsmit[103] has emphasised 'Whenever they [the Germans] printed something we wouldn't have published, we concluded it was done deliberately to mislead us.'[104]

An important political event changed priorities. Winston Churchill had won power and replaced the ailing Chamberlain government. Henry Tizard was pushed into the background by Lord Cherwell who became a scientific adviser to the Prime Minister. Cherwell, known previously as Frederick Lindemann, had worked at Oxford, transforming research at the Clarendon Laboratory. He had recruited Francis Simon, Nicholas Kurti and for a short time Leo Szilard to work at Oxford when the future for these anti-Nazi scientists looked bleak for them in Germany. Morrell has stated that Cherwell 'insisted right from the start that the power to acquire good men to research on promising problems was more important than the

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[101] Clark, R.W *The Birth of the Bomb*, London, Phoenix House, 1961, p. 79

[102] CHAD 1 19/8 *Simon to Chadwick, 19/9/41*, Churchill Archives Centre, p. 1

[103] Samuel Goudsmit was the scientific head of the Alsos Mission. This was an American Scientific Intelligence operation which followed the Allied armies as they invaded Europe after D-Day. The aim was to find any German physicists that could give answers about the scale of the German atomic bomb project. The Americans wanted to find out how far the Germans had progressed in their nuclear research and whether there was any real danger that the Germans could construct an atomic bomb.

[104] Goudsmit, S.A *Alsos*, New York, Schuman, 1947, p. 9

possession of big apparatus in magnificent buildings.'[105] Cherwell's appointment as scientific advisor could have spelt disaster for the atomic programme as he was as much, if not more of a sceptic as Henry Tizard. Fortunately, even though he remained sure the programme was a waste of time and resources, he didn't order the work to be wound up. This was probably because most of the nuclear research was being done by émigrés who were not able to concentrate on immediate war work, even though most teams were led by English physicists. Also, Cherwell was a good friend of Francis Simon. The fall of France may have led to Cherwell being more receptive to innovations that could win the war.

In December 1940, Francis Simon made a report for the Government detailing the expected size and cost of a uranium production facility. Simon's report was thorough. He had considered materials, staffing and building costs. 'The report dealt with materials and processes which had been used only rarely, and then on a laboratory scale, but would now have to be dealt with on an industrial scale.'[106] As it was the height of the Blitz, Simon personally drove to London to hand the report in so the information was kept secure. The production plant would have to be vast, estimated to cover 'a site of about 20 acres'[107] and would be an obvious target for German bombing raids. This made Simon argue for production to be in the United States or somewhere in the Empire. The estimated cost of a production plant was an optimistic £5 million[108]. More accurate estimates would only be possible 'towards the end of 1941, when the 20 stage [pilot plant] model will have been run and production methods will have been

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[105] Morrell, J *Science at Oxford: Transforming an Arts University*, Oxford, Clarendon Press, 1997, p. 386
[106] Clark, R W *The Greatest Power on Earth*, London, Sidgwick and Jackson, 1980, p. 112
[107] CHAD 1 28/6, Reports and Notes on MAUD Committee, *Remarks on the Separation Plant by Dr. F Simon*, Churchill Archives Centre, p. 4
[108] CHAD 1 28/6, Reports and Notes on MAUD Committee, *Remarks on the Separation Plant by Dr. F Simon*, Churchill Archives Centre, p. 5

investigated more thoroughly.'[109] There could be no certain answer to the question of how much power was needed to run the plant. A rough estimate was made that '40,000 K.W for the whole plant will cover the power requirements.'[110] Simon's report was based on guesswork due to the numerous technical uncertainties still to be clarified. However, it was a remarkable document as it had considered the important issues in detail and the cost of the pilot plant turned out to be only three times as expensive as Simon had estimated.

At the MAUD Technical subcommittee meeting on the 8th January 1941, the discussion centred on the increasing importance of plutonium. Plutonium was now thought of as another possible super explosive. As it had two more units of electrical charge than uranium 'it was more likely to be subject to fission because of the extra repulsion of the nuclei charges.'[111] This being realised, it meant Halban and Kowarski's work became more promising, as slow neutron fission could create plutonium. Using the abundant uranium 238 isotope, it would be possible to create plutonium by neutron capture. 'Their scheme is to transform 92 [uranium] into 94 [plutonium] by use of a slow neutron policy and to separate the 94 by a chemical method'[112] as plutonium would be chemically different to the uranium and the advantage of using the abundant uranium 238 isotope for this process 'does not require elaboration.'[113]

In February 1941, James Conant, distinguished chemist and president of Harvard, and a delegation of scientists from the United States visited Britain and investigated the progress made on atomic research. They were greatly impressed and were given a complete update of

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[109] Gowing, M *Britain and Atomic Energy 1939-1945*, London, Macmillan, 1964, p. 424

[110] CHAD 1 28/6, Reports and Notes on MAUD Committee, *Remarks on the Separation Plant by Dr. F Simon,* Churchill Archives Centre, p. 4

[111] CHAD 1 12/2, *MAUD Technical subcommittee meeting, 8/1/41*, Churchill Archives Centre, p. 6

[112] CKFT 10/1, *Cockcroft to Fowler*, Churchill Archives Centre, p. 1

[113] TMSN 3, *Report on work carried out in Cambridge, September-December 1940,* Churchill Archives Centre, p. 1

Britain's work in the field up to that time. The American scientists were not optimistic that atomic research would have a military impact on the war. 'American scientists considered uranium research a waste of Britain's already strained resources: if anything valuable emerged from the work in this area in America the British would be informed.'[114]

The MAUD Technical Committee had its third meeting on 9th April 1941 at Burlington House to discuss progress. This meeting shows an impressive start to solving technical problems had been made in a short time. Referring to the work at Birmingham University Peierls stated 'there was now practically no doubt that the fission cross-section of 235 is large enough to make practicable the construction of a bomb of reasonable size'.[115] A critical size of a few kilograms would be manageable and 'a larger number of smaller bombs would be more valuable from an operational standpoint'[116] than a small number of very large bombs. An early conservative estimate of the critical size was '4 to 5 kg'.[117] Early tests of theory had given 'a completely positive answer' and the scheme looked highly promising.[118] A note was read out by G.P Thomson saying the Americans were working on producing samples of uranium 235 but would conduct experiments on it themselves before sending it across the Atlantic, due to the risk of loss. 'Professor Chadwick considered this a wise precaution, and suggested that the need for haste be impressed upon the Americans.'[119] This shows Britain was already trying to push the American programme along. Commenting on the work at Oxford, Francis Simon

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[114] Sherwin, M.J *A World Destroyed*, New York, Vintage Books, 1975, p. 35

[115] CHAD 1 12/2 *Minutes of third meeting of MAUD Technical subcommittee, 9/4/41*, Churchill Archives Centre, p. 2

[116] AB 1/106, Lord Cherwell's Papers, *Minutes of Conversation with Professor Thomson and Lord Melchett at Nobel House, 2/5/41*, National Archives, p. 1

[117] AB 1/543, Tube Alloys Progress Reports, Birmingham University, *Prof. Peierls, March 1941*, National Archives, p. 1

[118] AB 1/543, Tube Alloys Progress Reports, Birmingham University, *Prof. Peierls, March 1941*, National Archives, p. 1

[119] CHAD 1 12/2 *Minutes of third meeting of MAUD Technical subcommittee, 9/4/41*, Churchill Archives Centre, p. 4

told the committee that much progress had been made with developing barriers for diffusion in the form of metal gauzes. 'The possibility of making membranes from plastics was also being considered.'[120] Finally, Dr. Alan Nunn May leading the team at Bristol said no significant progress had yet been made with the atomic bomb detector but preliminary work had been conducted. G.P Thomson said 'it seemed desirable for a prototype detector to be produced.'[121] This could then show if Germany had already exploded atomic weapons. Peierls noted problems of separating the uranium, producing power for the full scale plant, making the uranium into a block and initiating the chain reaction were still to be resolved.

At the fifth meeting of the MAUD policy committee on 19th May 1941, the British scientists discussed how to bring the Americans to heel over publication of material that could be useful to the enemy. 'Professor Chadwick drew attention to the fact that information on 93 [neptunium] and 94 [plutonium] had appeared in an issue of the *Physical Review* and stressed the importance of asking the Americans to refrain from publishing such matters.'[122] The Americans were not as cautious about publication as they were yet to be involved full scale in the war and had yet to receive the MAUD Committee Report on nuclear fission so didn't know how important the issue would turn out to be.

President Franklin Roosevelt's executive order of 28 June 1941 set up the Office of Scientific Research and Development in the United States in connection with interchange of information between the U.S and Britain. This formalised connections between the two governments over

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[120] CHAD 1 12/2 *Minutes of third meeting of MAUD Technical subcommittee, 9/4/41*, Churchill Archives Centre, p. 7

[121] CHAD 1 12/2 *Minutes of third meeting of MAUD Technical subcommittee, 9/4/41*, Churchill Archives Centre, p. 8

[122] CHAD 1 12 2 *Minutes of fifth meeting of MAUD Policy committee, 19/5/41*, Churchill Archives Centre, p. 1

atomic weapons. 'The OSRD was to serve as a center for mobilizing the scientific resources of the nation and applying the results of research to national defense.'[123] The President now had more control over scientific projects. 'Now the work was under the protective arm of the President, should Bush decide that an all out effort was in the national interest, he could go directly to the White House for support.'[124] On 8th July 1941 an aide memoire was left with President Roosevelt by the British ambassador Lord Lothian 'in which was proposed a broad interchange of secret technical military information between the American and British Governments.'[125]

In July 1941, the MAUD Report gave its findings into the possibility of a nuclear bomb. The report concluded a bomb made from uranium 235 was feasible and estimated the material to make a bomb would be available by the end of 1943. Most worrisome was the fact that the Germans might be able to copy the research done in Britain as 'the lines on which we are now working are such as would be likely to suggest themselves to any capable physicist.'[126] The cost of a nuclear bomb production plant would run to 5 million pounds but the project was necessary as a bomb would be an active deterrent to attack from other states. The nuclear bomb was therefore defensive as well as offensive and if developed would play an integral role in diplomacy. The report stated the most important points in considering nuclear energy as an explosive would be 'the concentrated destruction which it would produce, the large moral effect, and the saving in air effort the use of this substance would allow, as compared with

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[123] Hewlett, R.G and Anderson, O.E *The New World*, Pennsylvania State University Press, 1962, p. 41
[124] Ibid.
[125] Gale Reference Library, Harry S. Truman Library, *History of United States-British and Canadian Atomic Relations, March 2nd 1949*, p. 3
[126] Gowing, M *Britain and Atomic Energy 1939-1945*, London, Macmillan, 1964 p. 395

bombing with ordinary explosives.'[127] MAUD was confident a nuclear bomb could have a decisive impact on the war.

The MAUD Committee's role was vital. It turned a theoretical hunch that the atomic bomb was possible into a reality because Britain encouraged the U.S to start on a hasty programme of research due to the committee's findings. As Pierre states 'One must admire the ability of the British to ask the right questions and draw the appropriate conclusions.'[128] The Committee's investigation 'had swung opinion to the horrifying conclusion that a bomb could indeed be built if suitable means for separating Plutonium or enriched Uranium could be developed.'[129] The MAUD Committee provided the impetus for the British programme and research in Britain compared to the U.S was proceeding much faster into development of nuclear weapons. Gowing states the MAUD Committee was 'one of the most successful committees this country has ever seen'[130] due to its sense of urgency and initiative. The MAUD Report was convincing to the politicians also. Even though it was written entirely by scientists 'in a masterly synthesis of scientific observation and theoretical reasoning they had written a report that was readable to the layman'.[131] The MAUD Report was passed on to the Hankey Committee for consideration.

The thought that Germany could develop such a weapon finally made the politicians jump down from the fence on the side of the scientists. Lord Cherwell summarised the report for Churchill and he did this very effectively as he was a competent physicist. Cherwell wrote a

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[127] Gowing, M *Britain and Atomic Energy 1939-1945*, London, Macmillan, 1964 p. 397

[128] Pierre, A *Nuclear Politics*, London, Oxford University Press, 1972, p. 23

[129] Zimmerman D *Top Secret Exchange: The Tizard Mission and the Scientific War*, Stroud, Alan Sutton, 1996, p.188

[130] Gowing, M and Arnold, L *The Atomic Bomb*, London, Butterworth, 1979, p. 14

[131] Pierre, A *Nuclear Politics*, London, Oxford University Press, 1972, p.22

minute to the Prime Minister and 'the minute, written on 27 August, succeeded in describing nuclear possibilities, the dangers as well as the opportunities, in words which any educated man could understand.'[132] This minute admitted the whole process was 'extremely elaborate and costly'[133] but was a feasible idea. Churchill wrote to General Ismay on 30th August 1941 stating 'Although personally I am quite content with the existing explosives, I feel we must not stand in the path of improvement.'[134] Churchill asked for the views of the Chiefs of Staff who replied on 3rd September that the highest priority should be given to building an atomic weapon. 'But, like Cherwell, they were not anxious to see Britain dependent on another power. It was therefore decided that she should press on alone, without U.S help'.[135]

Churchill suggested a committee to coordinate the research into nuclear weapons. The committee was based in the Department of Scientific and Industrial Research. 'It quickly drew into its very secret fold most of the eminent theoretical physicists in the United Kingdom, and some from abroad.'[136] It was christened the Directorate of Tube Alloys. This choice of name, again due to the need to be cryptic, was to give the committee an important sounding title for resources. The name 'Tank Alloys' had been proposed but John Anderson suggested 'Tube Alloys' as all the contraptions needed by war seemed to need tubes and the gaseous diffusion of uranium hexafluoride required many tubes in its thousands of individual stages.

John Anderson was made the head of the committee. 'It was a singularly happy appointment. John's first love had been science, a field in which he had shown considerable promise as a

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[132] Clark, R.W *The Greatest Power On Earth*, London, Sidgwick and Jackson, 1980, p. 125
[133] AB 1/170, *Cherwell's Minute to the Prime Minister on the use of Atomic Energy for a Bomb, 27/8/41*, National Archives, p. 1
[134] Churchill, W.S *The Second World War: Volume 3, The Grand Alliance*, London, Cassell, 1950. p 730
[135] Clark, R.W *The Greatest Power on Earth*, London, Sidgwick and Jackson, 1980, p. 126
[136] Melville, H *The Department of Scientific and Industrial Research*, London, George Allen and Unwin, 1962, p. 41

student.'[137] He had written a paper on explosives while studying at Edinburgh University. 'By an extraordinary coincidence Anderson… had gone after graduating from Edinburgh University in 1903 to Leipzig for postgraduate work in chemistry where he had decided to do research on uranium.'[138] He had a grounding in the methods of scientific research and was also adept at talking to the Americans about atomic fission. Another good move was to involve Wallace Akers of I.C.I. Akers was an astute industrialist but also a superb communicator and could smooth out any big disagreements between the scientists and industrialists. He steered the programme of transforming research into production very nimbly and was a valuable addition to the project. Tube Alloys was given a budget of £100,000 to cover the first six months.

Henry Tizard was still highly doubtful of the chances of atomic weapons, even after the MAUD Report. He cited the numerous practical problems to be overcome and said 'even if the optimism of the physicists is justified, the time and money needed to produce a practical success will be far greater than that indicated in the report'.[139] He added the probability of producing an atomic bomb 'has increased but is still very small'.[140] Tizard was not only a sceptic; he fervently wished the bomb to fail as he could imagine the impact an atomic weapon might have on the world. Tizard and Anderson recommended the setting up of a full scale production plant in the U.S, partly due to its risk of being bombed in Britain and also due to the further stretching of Britain's resources in war. Dr. Pye, who was the Director of Scientific Research for the Ministry of Aircraft Production, was also sceptical a bomb could be made during the war. He wrote to Chadwick saying the MAUD Committee was 'over optimistic in

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[137] Wheeler-Bennett, J *John Anderson: Viscount Waverly*, London, Macmillan, 1962, p. 290

[138] Pierre, A.J *Nuclear Politics*, London, Oxford University Press, 1972, p. 30

[139] Clark, R.W *Tizard*, London, Methuen and Co, 1965, p. 298

[140] Clark, R.W *Tizard*, London, Methuen and Co, 1965, p. 299

its view about the time scale.'[141] He added: 'You may feel that a Heath Robinson kind of bomb is all that is required in this special case but, in fact, even this would mean a difficult piece of engineering'[142] which would adversely affect the timescale suggested.

Because the U.S was not involved in the war until December 1941, it didn't advance its research until there was an urgent reason to do so. America had been concentrating on making atomic energy as a source of power rather than an explosive. 'Some nuclear scientists such as Fermi[143] had their primary interest in building a nuclear reactor.'[144] The U.S was more swayed by the argument for nuclear bombs for national defence but also felt atomic research to be a waste of time and money. Gowing has emphasised Britain's role. 'Only when they read the brilliant British Maud Report, which was given to them in the late summer of 1941, did they take the project seriously and persuade their government to set up what became the huge Manhattan Project.'.[145] In the long term, it was clear that nuclear bombs would be developed eventually. The idea of one nation having a monopoly on such important technology didn't go well with the Americans who wanted mutual ownership as a deterrent to any other country attacking in the future. When Thomson handed James Conant the MAUD Report it served as a catalyst for American action. 'It brought at the same time a sobering reminder that, as of late, much of the expertise of Nazi Germany's Kaiser Wilhelm Institutes in Berlin-Dahlem…had been set aside for uranium research.'[146] The MAUD Report effectively resurrected the

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[141] CHAD 1 12/2 *Pye to Chadwick, 19/9/41*, Churchill Archives Centre, p. 1
[142] CHAD 1 12/2 *Pye to Chadwick, 19/9/41,* Churchill Archives Centre, p. 1
[143] Enrico Fermi was born in Rome, 1901. He studied at Pisa University and became professor of theoretical physics at Rome University in 1927. In 1934, Fermi and his colleagues split uranium nuclei with neutrons and produced artificial radioactive substances. He was awarded the Nobel Prize for physics in 1938 and became a professor at Columbia University in 1939. He oversaw the running of the first chain-reacting pile in 1942.
[144] Schroeer, D *Science, Technology and the Nuclear Arms Race*, New York, John Wiley, 1984, p. 35
[145] Gowing, M *The Atomic Bomb*, London, Butterworths, 1979, p. 15
[146] Dahl, P.F *Heavy Water and the Wartime Race for Nuclear Energy,* Bristol and Philadelphia, Institute of Physics Publishing, 1999, p. 172

American programme which had been drifting during the summer of 1941. 'The Briggs committeemen…listened intently to Thomson's discussion of gaseous diffusion. It confirmed their plans to send Pegram and Urey to investigate at first hand.'[147]

Obviously if the U.S collaborated, it would also bring vast resources to the project. Britain played a huge role in creating and sustaining American enthusiasm for the atomic bomb project. As Bertin has pointed out 'it is difficult to believe that it was not in great measure due to the prestige of scientists working in Britain and their confidence in the feasibility of the bomb project that the American government were persuaded to embark on the programme when and on the scale that they did'.[148] The MAUD Report must have been especially convincing because the Americans did not want to embark on any costly programme unless it would have a direct bearing on the war. 'The assumption that the weapon would be built quickly for use during the war was implicit in the decision to develop it.'[149] After the British had passed on their findings, the Americans disbanded the erratic Briggs Uranium Committee and formed the more dynamic secret committee known simply as Section-1. The MAUD report 'gave Bush and Conant what they had been looking for: a promise that there was a reasonable chance for something militarily useful during the war in progress.'[150]

Britain made a serious political miscalculation in October 1941. President Roosevelt sent overtures to Britain to form a joint British-American nuclear programme. 'A reply was not received until December, at which time Churchill simply gave a general assurance of 'readiness'

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[147] Hewlett, R.G and Anderson, O.E *The New World*, Pennsylvania State University Publishing, 1962, p. 44
[148] Bertin, L *Atom Harvest*, Turnstile Press, London, 1948, p.50
[149] Sherwin, M.J *A World Destroyed*, New York, Vintage Books, 1973, p. 13
[150] Hewlett, R.G and Anderson, O.E *The New World*, Pennsylvania State University Publishing, 1962, p. 43

to collaborate.'[151] This had a long term impact on American attitudes towards Britain and had serious consequences for Britain's post war programme. At the time it was felt by many British statesmen, such as Lord Cherwell that it would be foolish to become dependent on the United States as this would affect the post war political situation by tying Britain to American foreign policy. Also, as Britain was geared for war, it was argued that Britain could keep technical information a secret more effectively than the U.S could and she might let something slip to the enemy. Roosevelt's offer 'was treated very coolly, and indeed the British missed the bus.'[152] Even though Churchill had been encouraging over the chance of a joint project 'the fact that he had taken two months to write showed Britain's reluctance to give up its edge.'[153] This stance showed national independence was still valued most highly, despite the strains of war on British resources.

It would be easy to be critical of Britain's decision not to make a firm agreement on a joint programme. This would be unfair given the context of war and the pressure of fighting against Germany as Britain was the only European power still free of occupation. There is the fact that a joint agreement would have made sound economic sense and the U.S would be a much safer place to start uranium production. Also, because Britain was at the time further ahead in research, this could have been exploited for political gain and influence with Roosevelt.

On the negative side of a joint agreement, Britain could tie itself to American policy and at the time the American offer was rejected, Britain was still ahead in research. 'It is true that, mainly because the English had been forced to think in order to survive at all, in most military

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[151] Pierre, A *Nuclear Politics*, London, Oxford, University Press, 1972, p. 27
[152] Gowing, M and Arnold, L *The Atomic Bomb,* London, Butterworth, 1979, p. 15
[153] Hershberg, J.G *James. B Conant,* Stanford, Stanford University Press, 1993, p. 179

scientific fields they were ahead.'[154] The British may have thought themselves so far ahead as to be able to join with America at a later date. Understandably, war was making Churchill want independence and any military pact with the U.S could have unforeseen post war implications. As Pierre has argued, the primary motivation for the British 'was probably the desire to remain independent by retaining complete control over their own project.'[155] For instance, if Britain had made strong ties with the U.S, future conflicts between the U.S and the Soviet Union could have serious effects on British foreign affairs.

Pye wrote to Chadwick on 16th October 1941, informing him that it had been 'agreed on all hands that the 20-stage separation plant should go ahead.'[156] The British Tube Alloy team also agreed to give the Americans all the information Britain had on atomic research so far 'including plans for the 20-stage separation plant.'[157] U.S scientists Urey and Pegram visited Chadwick at Liverpool and saw how British scientists had considered fast neutron fission for a bomb. The Americans had only previously considered neutrons that were slowed by a moderator before this time. Urey was especially impressed with how far British teams had solved technical difficulties and British work on the separation of uranium was also looking promising. The Americans' positive reports of progress made in Britain filtered through to Washington and confirmed the optimism of the MAUD Report in stating an atomic bomb may have a decisive role in the present war. 'Urey and Pegram's account of what they learned in England was, arguably, even more important than the MAUD Report in persuading their

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[154] Snow, C.P *Science and Government*, London, Oxford University Press, 1961, p. 44
[155] Pierre, A *Nuclear Politics*, London, Oxford University Press, 1972, p. 29
[156] CHAD 1 19/8 *Pye to Chadwick, 16/10/41,* Churchill Archives Centre, p. 1
[157] CHAD 1 19/8 *Pye to Chadwick, 16/10/41,* Churchill Archives Centre, p. 1

countrymen that a nuclear weapon was a practical possibility.'[158] This was proof, if any were needed, that an American atomic project was essential, feasible and urgent. Anglo-American exchanges had helped formalise the process of research in the two countries and played a hugely important role in getting the United States to throw its resources behind the bomb.

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[158] Dahl, P.F *Heavy Water and the Wartime Race for Nuclear Energy*, Bristol and Philadelphia, Institute of Physics Publishing, 1999, p. 176