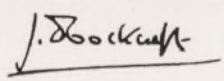

JOHN DOUGLAS COCKCROFT

1897-1967

Elected F.R.S. 1936

SECTION I: MAINLY PERSONAL

Early years

THE COCKCROFT family settled in Todmorden, on the borders of Lancashire and Yorkshire, not later than the fifteenth century as peasant farmers on the higher ground. In the days of subsistence agriculture, such farmers produced and spun their own wool, and wove their own coarse cloth. By the sixteenth century, some of the inhabitants of the area had become primarily weavers with hand looms, using fibres largely imported from other parts of England and from Ireland. Their light, cheap and gaily coloured materials found a ready market on the Continent, and even in the Americas. Cotton from the Levant was first used by these hand-loom weavers at the beginning of the seventeenth century, sometimes mixed with flax in the weaving. Pure cotton cloth was not produced till after the middle of the eighteenth century, and became of primary importance only after the development of spinning and weaving machinery. There appears to have been a continuous involvement of the Cockcrofts in the weaving industry of the Calder Valley. When hand looms were replaced by power looms, it became necessary to organize larger units employing considerable capital and many operators. Such a mill was founded in Todmorden in 1846 by the Cockcrofts. In 1899 they removed to Birks Mill, Walsden, where a water wheel and steam engine were used as the sources of power. In 1922 electric power was introduced in place of the steam engine, supplemented later by a water turbine working under pressure from their moorside reservoir.

The family business flourished till it experienced serious financial troubles at the end of the last century. J. A. Cockcroft inherited the difficult and protracted task of re-establishing its fortunes, ably assisted by his wife, A. M. Cockcroft (formerly Miss Fielden), herself the daughter of a cotton manufacturer. She had to bring up her family of five sons almost alone, under conditions of financial stringency, while her husband struggled with the mill. The father instilled in his children a sound knowledge of business principles and of the technology of weaving. The mother was an intelligent woman, with musical ability, and her fine character did much to mould that of her sons.

The eldest child, John Douglas Cockcroft, was born on 27 May 1897. In boyhood he developed a keen interest in the machinery of the mill. He enjoyed walking on the Pennine moors, so satisfying the contemplative side of his character. In later years, he often tired out companions by the vigour with which he walked in the Alps, the open country round the research establishments he was to lead in England and Canada, or on the marshes near his country cottage at Cley. Despite the speed of his advance, and his apparent desire to reach an objective without delay, he was keenly observant, seeing and remembering more of the countryside than did the laggards. Throughout his life, he found refreshment in the open air and in listening to good music.

John Cockcroft's early education was obtained at Walsden Church of England School (1901-1908) and Todmorden Elementary School (1908-1909). He has written (1)* of the period 1909-1914, when he was at Todmorden Secondary School:

'My interests . . . were fairly general. I had good teachers in physics and mathematics (Mr Luke Sutcliffe and Mr Ernest Farrer), and became specially interested in atomic physics through J. A. Crowther's books with their descriptions of Thomson's and Rutherford's work. I developed an ambition to do research work in experimental physics, but was advised to study mathematics at Manchester first.'

At the conclusion of his secondary education he was awarded a County Major Scholarship, West Riding of Yorkshire, and enrolled at Manchester University in 1914.

Cockcroft has recorded that during the year spent at the University he was much influenced by the remarkable mathematician Horace Lamb, whose lectures he attended, but that he was too immature at 17 years of age to gain from him as much as he would have done at a slightly greater age, or to show any outstanding ability in mathematics. He elected to attend also the first-year lectures in physics, which Rutherford himself had to take over when the original lecturer failed completely to maintain order in the class. Rutherford made a deep impression on young Cockcroft, an impression of greatness and of dedication to physics which was to ripen later into the affectionate regard which Rutherford inspired in all who worked closely with him.

War Service, 1915-1918

Cockcroft volunteered for service with the Y.M.C.A. in the summer of 1915, and spent some months at Kinmell Camp, near Abergele, North Wales, before being called up for military service. After preliminary training he was drafted to the Royal Field Artillery, as a signaller. He was twice mentioned in despatches for his meritorious service in some of the most bitter engagements of the war, and was recommended for a decoration as sole survivor at a forward signalling post from which he maintained

* Numbers in parentheses refer to the numbered Bibliography at the end of this Memoir.

continuous contact with his battery. In the spring of 1918 he was sent to an Officers' Training Unit and was commissioned Second Lieutenant shortly before the end of the war. He was released from the Army in the autumn of 1918 in order to continue his university training.

This period of his life was seldom mentioned by Cockcroft, even to his closest friends. His physical toughness, combined with his ability to concentrate on the task in hand, brought him relatively unscathed through a bloody conflict. However, the experience left him with a deep hatred of war, though he never shirked his duty in defence of Britain, and after the Second World War he identified himself closely with disarmament and the search for more sane methods for the settlement of international disputes.

Manchester College of Technology

After release from the Army, Cockcroft entered as a student at the College of Technology, University of Manchester, to study electrical engineering under Professor Miles Walker, and in 1920 he became a College Apprentice with Metropolitan Vickers Electrical Company. Following a short period of training, he worked in the Research Department of that Company at Trafford Park and, as part of his apprenticeship, did some research with Miles Walker, obtaining the M.Sc. Tech. degree in 1922.

Undergraduate at Cambridge

Miles Walker was aware of the increasing necessity for the use of sophisticated mathematical techniques in physics and engineering. He recognized the ability of his student, and encouraged him to further his mathematical training in Cambridge. Cockcroft went up to St John's College in 1922, having been awarded a Sizarship and the Miles Walker Studentship of the Manchester College of Technology. He entered with enthusiasm into college life, playing hockey as a relaxation. Walker provided him with a letter to Rutherford, who received him with characteristic kindness, encouraging him to spend as much time as he could spare from his mathematics in the advanced practical class in physics, presided over by Appleton and Thirkill. His development in mathematics was directed and much influenced by Mr E. E. Cunningham, his Tutor in St John's College. He also attended the course of lectures given by Sir Joseph Larmor.

Cockcroft distinguished himself in the Mathematical Tripos, Part II, in 1924, as a B* Wrangler, and obtained the B.A. degree. He was awarded a Foundation Scholarship of St John's College, and a State Scholarship, and was accepted by Rutherford as a Research Student in the Cavendish Laboratory. Later sections describe his subsequent career.

Marriage and family

On 26 August 1925, at Todmorden, John Cockcroft was married to Eunice Elizabeth Crabtree, daughter of Herbert Crabtree, J.P., C.C., and Margaret Crabtree (formerly Holden) of Stansfield Hall. The Crabtrees also were cotton manufacturers, and John and Elizabeth had known one another from childhood. They lost their first child, 'Timothy', at two years of age. Subsequently, they had four daughters, Joan Dorothea (a trained nurse specializing in the care of sick children), Jocelyn (who took a degree in biochemistry and is married to Dr Michael Blackburn of the University of Sheffield), Elizabeth Fielden (who trained as a social worker and is now a school teacher), and Catherine Helena (Mrs Milford, now working with her husband as a teacher in Uganda). The youngest child, Christopher Hugh John, took the Engineering Tripos in Cambridge, and has joined the family business in Todmorden.

Cockcroft's family life was exceptionally happy. His wife was his companion and partner in every way, and a devoted mother. In 1926 the Cockcrofts built a house in Sedley Taylor Road, Cambridge, and there colleagues, students and friends found that warm, informal hospitality which was to characterize their other homes in war-time England and Canada, and afterwards at Harwell and Churchill College. They were especially kind and helpful to visitors from abroad. In 1952 they bought a home at Cley, on the Norfolk coast, which became a place of relaxation for the whole family and their friends. Cockcroft enjoyed walking across the salt marshes in the crisp air, and liked to see his children sailing their boats on the creeks and inlets. He found peace in the quiet beauty of the Norfolk landscape, and in the sound of waves washing the pebble beach. However, his work and interests were never far from his mind, and at Cley he discussed problems with colleagues who called upon him, and did much writing and thinking.

Some personal characteristics

A deep interest in architecture, both ancient and modern, developed early in Cockcroft's life. He took every opportunity which presented itself to examine cathedrals and other buildings of architectural importance in Britain and abroad, and read widely about their origins and history. He was keen to see and understand modern buildings, especially when they incorporated new ideas in design or construction. His interest included problems of lighting, interior decoration and the proper design of furniture for comfort and appearance. He was well informed about contemporary sculpture and art, and, despite his innumerable activities, found time to read most of the important books of his time.

Early in his Cambridge career, Cockcroft adopted a very systematic approach to his various duties. From then till his death, he carried in his pocket a small black loose-leaf book, in which he noted every commitment and all information which interested him. His colleagues soon learnt that anything he undertook to do, which he entered in the book, would be attended to promptly. He kept all back pages as a sort of shorthand diary, so that he could always refer back to check dates, and even exact times, of any happening, or to refresh his memory of any occasion. He wrote in a small script which was almost illegible to those not familiar with it. Even those closest to him had difficulties at times in deciphering his letters and notes which, to the uninitiated, appeared to be in a mixture of script and shorthand. In the last year of his life he commenced the preparation of an autobiography. The small section which he drafted was about atomic energy, and was never checked by him after typing. He was clearly intending to write in great detail. The same meticulous accuracy is apparent in a report on Army Radar (18), which he wrote in 1945.

Cockcroft's ability to deal efficiently, and almost simultaneously, with a large number of totally different problems was aided by his economy of words and by never wasting time. Except in personal correspondence, or where necessary for technical reasons, he seldom wrote or dictated a letter of more than a few sentences, which were clearly expressed and left no doubt about his meaning. His reply to a request by a member of one of his teams for permission to take some particular action, was often simply, 'Yes'. If his colleague was not used to Cockcroft's inflections, he was apt to be in doubt whether he meant, 'Yes, I've heard what you have said', or, 'Yes. You may go ahead'. While he could relax completely while listening to fine music or walking, such diversions occupied only a small part of his time, and he soon returned to his desk. He was not interested in gossip or off-colour stories. Yet he was at ease with men from every walk of life, and a good listener, even if his thoughts were elsewhere. On any matter of interest to him he would ask pertinent questions, diligently probing till his understanding was complete. He could be moved to anger by foolishness, dishonesty or neglect of duty, but he seldom showed it. The general impression he gave in public was of reserve, tolerance and wisdom, but in private he encouraged the rebel and provoked activity and enterprise which was not orthodox. In matters of policy or action, he held very definite views, but he was never upset or disheartened for long by failure to persuade others that he was right, or by the necessity for compromise. His vision was always of the future, while never neglecting the present. These characteristics made him a great administrator.

Cockcroft wrote few scientific papers. He was a man of action rather than of ideas, and from 1935 onwards he devoted himself increasingly to the organization and administration of research and development in science and technology. In this field he displayed outstanding ability, but it was a characteristic of his achievements that he was always concerned with endeavours where the urgent need was for expansion. Wherever he was, he gathered round him a team of very able men and worked indefatigably to provide them with the conditions and equipment necessary for the tasks in hand. His integrity inspired trust both in those whom he led and in his superiors. He was aware in detail of almost all that went on in the large establishments under his command, encouraging all to give of their best and sharing in their pleasure in achievement.

Cockcroft's personal research will have its place in history, for it was one of the building stones of the nuclear age. His personal technical contribution, and his administrative work on radar in the Second World War, will be remembered as part of the scientific struggle which so strongly influenced the conduct of the war. His leading roles in atomic energy, notably at Montreal and in creating Harwell, were outstanding, and these also were enduring achievements. His public statements in the early 50's about the prospects for cheap nuclear power were technically accurate, and his great optimism was shared by scientists in other countries. However, the scale of the effort required to overcome the many technological problems, and the time necessary to build and operate pilot plants, were not understood by some governments or by the public generally, so that too much was expected too rapidly. The very success of A.E.R.E. in this field led, by 1959, to difficult long-range questions about the future of Harwell. By this time, Cockcroft had become Master of Churchill College, and others had to deal with these problems.

The many contributions which Cockcroft made to national and international science, through official and unofficial committees, and by giving advice behind the scenes, were extremely effective and influential. They took up a lot of his time, and involved a great deal of work. It is indeed remarkable that he was able to do so much in addition to the work for which he was more widely known.

Honours and distinctions

Cockcroft received many honours and other marks of distinction, of which the three most eminent were the Order of Merit (1957), the Nobel Prize for Physics, jointly with E. T. S. Walton (1951) and the Atoms for Peace Award (1961). He received the C.B.E. in 1944; was created a Knight Bachelor in 1948; and made K.C.B. in 1953.

Cockcroft received official recognition from several foreign countries: he was awarded the Medal of Freedom with golden palms (United States, 1947); the Chevalier de la Légion d'Honneur (France, 1950); Knight Commander of the Military Order of Christ (Portugal, 1955); and the Grand Cross of the Order of Alfonso X (Spain, 1958.)

He was awarded doctorates (h.c.) by many universities: Toronto (1945); Oxford (1949); London (1950); Trinity College, Dublin and Glasgow (1951); Australian National University, Melbourne and Sydney (1952); Cambridge, Manchester (1953); Birmingham (1954); Coimbra and St Andrews (1955); Leeds (1956); Delft and Leicester (1959); Dalhousie and Sheffield (1960); Temple (Philadelphia) (1961); Saskatchewan and Western Australia (1962); and Rhodes (Grahamstown) (1964).

He was elected Honorary Associate of the Manchester College of Technology in 1946, and President in 1961; and Honorary Fellow of the Tata Institute of Fundamental Research in 1964.

Cockcroft was elected to the fellowship of the Royal Society of London in 1936. He had become an associate member of the Institution of Electrical Engineers in 1927, and a member in 1941. He became a fellow of the Institute of Physics in 1933, President 1954-56, and an honorary fellow in 1962.

He was elected a fellow of the Royal Society of Arts in 1962. He became an honorary fellow of St John's College, Cambridge, in 1946. Other British institutions or societies which made him an honorary member were the Institution of Civil Engineers, the Institution of Marine Engineers, the Institution of Mechanical Engineers, the Institution of Metals, and the Royal Institution of British Architects. Overseas academies which honoured him with foreign membership were the American Academy of Arts and Sciences, the Australian Academy of Science, the Royal Danish Academy, the Royal Society of New Zealand, and the Royal Swedish Academy.

Cockcroft received several medals from learned societies or professional institutions. He was awarded the Hughes Medal of the Royal Society of London, jointly with E. T. S. Walton, in 1938; the J. A. Ewing Medal of the Institution of Civil Engineers in 1948; a Royal Medal of the Royal Society of London in 1954; the Faraday Medal of the Institution of Electrical Engineers in 1955; the Kelvin Medal, a joint award of the Engineering Institutions, in 1956; the Churchill Gold Medal of the Society of Engineers, and the Niels Bohr Medal, in 1958; and the Wilhelm Exner Medal in 1961. Cockcroft received the Honorary Freedom of Todmorden in 1946; and in 1958, he received the Freedom of the City of London on becoming an honorary member of the Salters Company.

On Tuesday 17 October 1967, at noon, a Service of Memorial and Thanksgiving was held in Westminster Abbey for John Douglas Cockcroft, O.M., K.C.B., C.B.E., F.R.S., First Master of Churchill College, Cambridge, 27 May 1897-18 September 1967.

Section II: Research and the Cavendish period

Cockcroft began his research at Cambridge along lines which sprang from his work with Miles Walker at the Manchester College of Technology. His abilities developed rapidly and he considered that his war-time service had greatly increased his maturity.

Cockcroft's first paper (2), with Miles Walker and others, appeared in 1925 and is an account of an application of the electronic valve oscillator, as a generator of a pure sine wave of variable frequency, to the dynamometer method of harmonic analysis of voltage and current wave forms at commercial power frequencies. The very complete analysis of the system and its limits of accuracy foreshadows the thorough approach to any problem which was to be so characteristic of the man. Three further papers by Cockcroft alone, (3, 4, 5) on the effect of curved boundaries on the distribution of electrostatic field round conductors, on the design of coils for producing very strong magnetic fields, and on the skin effect in rectangular conductors at high frequencies, demonstrate this ability applied to problems in electrical engineering. It is again obvious in the calculations (11) of the properties of the ingenious voltage multiplying circuit used, with Walton, to produce the high direct current potentials required in nuclear physics, and in a complete analysis, unfortunately not published, of the charged particle focusing properties of a spherically symmetrical electrostatic field, made for Oliphant. During the last war, the experience of this work enabled Cockcroft quickly to master problems of radar and know the limitations; and subsequently to become familiar with complex theoretical questions arising in the design of nuclear reactors.

Cockcroft found the atmosphere at Cambridge congenial. He was stimulated by lectures given by such men as Eddington, Milne, Fowler and Taylor, as well as by distinguished visitors. He enjoyed his contacts with J. J. Thomson who was still at work in the laboratory, with Aston, C. T. R. Wilson and Chadwick, and came to appreciate the skills of the technical staff, many of which he acquired for himself. His sympathy with technical assistants, and his appreciation of their essential contribution to research, established bonds with them which were to prove of immense importance in his subsequent career. Indeed, one of his most important attributes was to be his recognition, in all fields, of the specialized skills and knowledge of those who worked with him.

Engineering design in the Cavendish

After the usual 'kindergarten' period in the attic, learning the techniques of research in physics of those days, Rutherford asked Cockcroft to work with Kapitza, where his background of electrical engineering could be useful. He helped with the installation of the short-circuit type alternator which Metropolitan Vickers had made, to Kapitza's specifications, for producing pulses of very strong magnetic fields in air-cored coils. His paper in the *Philosophical Transactions* (5) shows how his combination of mathematical ability with engineering knowledge enabled him to design coils which would develop strong magnetic fields with maximum efficiency and minimum stress. These design considerations have provided the background upon which much of the modern work on coils for producing very strong magnetic fields is based. Cockcroft's correspondence with Kapitza, while the latter was abroad at various times, reveals how great a part he played in the development of Kapitza's work. He helped with the engineering aspects of the design of hydrogen and helium liquefiers, and the procurement of compressors, much electrical and mechanical equipment, and special materials.

Cockcroft has written (8):

'I was present at a remarkable interview with Rutherford when Kapitza persuaded him to raise money to build (a new laboratory) for the further development of this work. In due course the enormous grant of £15 000 (for the time) was obtained from the Royal Society for the building of the Royal Society Mond Laboratory, which has been of tremendous value in building up the school of solid state physics in Cambridge.'

He was associated closely with the design and construction of this laboratory, and with the engineering problems of the elimination of the old direct current motor-generating plant which occupied the site. At that time, the Cambridge electricity supply was anomalous, being 200 volts at 93 cycles a.c. A year or two later he supervised the change-over to standard frequency and voltage, and his proposal that the University might consider installation of its own electricity generating station resulted in substantially better terms for the supply of power.

Cockcroft's engineering ability was used in other ways in the Cavendish at this time. He designed (6) an ingenious electromagnet for Rutherford for the analysis of the energies of the groups of alpha particles emitted by naturally radioactive substances. This was in the shape of a double mushroom, with a central yoke round which the energizing coil was wound. It produced a highly uniform magnetic field over an annular ring, about 80 cm in diameter, using a weight of steel very small compared with the gigantic magnet of Cotton in Paris, with which alpha particles were first focused in a magnetic field, and it required only a few hundred watts, obtainable from a battery, to energize it. Much important work was done with this magnet. With Ellis & Kershaw (7), he designed a permanent magnet, with adjustable field, for beta-ray spectroscopy, using bars of cobalt steel with yoke and pole-pieces of mild steel.

Kapitza Club, atomic beams, and early particle accelerators

Kapitza had founded a club, in 1922, to discuss new ideas and developments in physics. It met, informally, generally on Tuesday evenings after dinner, in the college rooms of one of its members. Membership was limited, and Cockcroft counted himself fortunate to be invited to join and participate in the very lively discussions during and following the report by one of them on a subject of current interest. A talk was given sometimes by a distinguished visitor, and here Cockcroft heard such men as Bohr, Ehrenfest, Frank, Langevin, Born and Schrödinger describe their own work. The Kapitza Club was a great stimulus to Cockcroft. He recalled that on one occasion, in 1923, the Club discussed the Compton Effect and did not believe it.

During 1924 Cockcroft commenced some experiments of his own on the deposition from molecular beams of thin films on surfaces cooled to low temperatures, using the primitive vacuum equipment available then in the Cavendish. The results of this work were published in 1928 (9). He worked in a ground-floor room of the laboratory, which he shared from 1926 with T. E. Allibone, who had been seconded from the Research Laboratories of Metropolitan Vickers to develop methods of applying high voltages to vacuum tubes for the acceleration of charged particles to high energies. Rutherford was interested in the possibility of producing artificially more copious beams of very energetic particles, for nuclear bombardment, than were available as alpha particles from radioactive sources. Naturally, Cockcroft was interested in Allibone's work with high velocity electrons, which was greatly aided by the development by C. R. Burch, in the Research Laboratories of Metropolitan Vickers, of diffusion pumps using very low vapour pressure oils in place of mercury. He spoke to the Kapitza Club about methods which might be used to accelerate electrons. In 1927, E. T. S. Walton was assigned space in the laboratory to work on an idea which he had developed for the acceleration of electrons by a varying magnetic field. The room became very crowded, apt to be filled with the screech of spark-over of the high voltage generated by Allibone with a Tesla coil.

Beginning nuclear physics

In November 1928, a typescript of a paper by G. Gamow (1929), who was working with Niels Bohr in Copenhagen, was received in the Cavendish Laboratory. In an earlier paper, Gamow (1928) had been able to account for the emission of alpha particles by a radioactive nucleus by a wave-mechanical process of tunnelling through the potential barrier surrounding the nucleus, and had shown that the observed Geiger-Nuttall relationship between the energy of the alpha particle, and the life-time of the radioactive species, followed naturally. In the second paper, he showed that disintegration of light nuclei by bombardment with alpha particles was probably due to the inverse wave-mechanical penetration of the helium nucleus through the potential barrier into the interior of the nucleus. This idea aroused great interest in the laboratory. Cockcroft realized at once that this was very important for the possibility of producing nuclear transformations by bombardment with artificially accelerated particles. The probability of penetration of such particles into nuclei would be finite, though small, at bombarding energies much less than that corresponding with the height of the potential barrier. On the basis of Gamow's theory, Cockcroft calculated the probability of penetration of the positively charged particle of smallest mass, the proton, into boron and aluminium, for a series of bombarding energies from 200 000 electron-volts to 3 million electron-volts. He showed that protons with an energy of 300 000 electron-volts should penetrate into the boron nucleus, in a head-on collision, with a probability of about 1 in 1000. Assuming that penetration into the nucleus would result in a nuclear transformation rather than that the proton should escape, and realizing that 1 microampere of protons in a beam conveyed about 6×10^{12} particles per second, of which the order of one in a million would make a close collision with a nucleus of the target material, Cockcroft showed that many disintegrations should be produced in boron bombarded by a proton beam accelerated to 300 000 eV. He submitted a memorandum to Rutherford summarizing his calculations and suggesting that he should build equipment to accelerate protons through 300 000 volts.

In January 1929, Gamow spoke to the Kapitza Club, having already lectured in the Cavendish on his new theory. Allibone (1967) has recorded how he and Walton stood round while Cockcroft calculated the probability of transformations of lithium being produced by proton bombardment, following the lecture in the Cavendish, but these calculations have not survived. Oliphant recovered Cockcroft's memorandum from among Rutherford's papers after his death, and concludes that it was written late in 1928. This is in accord with Cockcroft's statement in the next paragraph.

Rutherford agreed that Cockcroft should endeavour to accelerate protons. It is clear that he set about this task with great enthusiasm, for he wrote (10): 'My laboratory notebook records that by December 1928, I was playing with the components of a high voltage vacuum accelerator.' This used an ancient induction coil as the source of high voltage and was too crude to give any result. However, he was able to persuade Rutherford to obtain a grant of £1000 from the University—a large sum in the Cavendish in those days—with which to buy a transformer for 300 000 peak volts (£500), and components with which to build rectifying and accelerating tubes.

Developing the high-voltage accelerating technique

Cockcroft was now joined by Walton, whose experiments with his primitive forms of betatron and linear accelerator had not borne fruit. At first (11) they followed rather closely the techniques devised by Allibone for applying high voltages to continuously exhausted glass tubes. With accelerated protons they looked for gamma radiations which might be produced in beryllium or lead targets, using a gold-leaf electroscope, but found no convincing evidence of any nuclear transformations at accelerating voltages up to 280 kV. The proton currents obtainable were small, and the ceiling of the room too shallow to make higher voltages possible. The experiment was moved to a much taller room, a lecture theatre with seating and fittings removed, and the opportunity was taken to redesign the equipment (12). Cockcroft worked out a modification of the Greinacher voltage doubling circuit, capable of extension to obtain almost unlimited high direct current potentials, which possessed the advantage that the accelerated beam could be used with apparatus earthed. He analysed the circuit for ripple and fall of voltage with increasing load, and tested his ideas with a model working at low voltage. Both rectifiers and accelerating tubes were made by fitting electrodes and tungsten cathode filaments on the axes of glass tubes, about 4 feet in length and 15 inches in diameter, the ends being ground square, and the vacuum seal to flat metal plates (galvanized iron sheets) being made with a low vapour-pressure Plasticine supplied by C. R. Burch. The cathodes were heated with car batteries mounted on top of the capacitor banks, and the high voltage required for the canal-ray tube, the source of protons at the top of the accelerating tube, was provided by a transformer and rectifier energized by a small alternator driven by a long insulating belt. It was all in the prevailing Cavendish tradition, but in place of string and sealing wax, it used glass tubes from Bowser petrol pumps, and Plasticine. There were many difficulties, particularly with the degassing of electrodes because of the low pumping speed of the vacuum pumps, but it worked. A steady potential of up to 600 000 volts was generated with a four-stage system, and applied to the accelerating tube. At first, the accelerating potential was determined by measuring the separation between two aluminium spheres of large diameter at which spark-over occurred. Later, this was replaced by observation of the current passing through a known high resistance immersed in oil.

Nuclear transformations observed, 1931

In Cockcroft's own words (8):

'At last we obtained a high energy proton beam and brought it out into the air through a window to check on its energy and range in air. After wasting a certain amount of time in this way, until prodded by Chadwick and Rutherford, we directed it on to a lithium target and at once observed, with a zinc sulphide screen, the bright scintillations which were obviously due to particle emission from the lithium.'

The scintillations were of the brightness expected of energetic alpha particles (13). Rutherford was called in to see them and, with infectious enthusiasm, described them as the most beautiful sight in the world. However, he demanded proof before the discovery was announced. Their identity as alpha particles was confirmed by the magnitude of the pulses produced in a shallow ionization chamber connected to an oscillograph through a linear amplifier, and by comparison with alpha particles from polonium, as well as by observation of the tracks produced in a Shimizu type, hand-operated expansion chamber. The range in air was found to be 8·4 cm, corresponding with an energy of $8{\cdot}6\times10^6$ electron-volts. The reaction was assumed to be:

$$^7_3\mathrm{Li} + ^1_1\mathrm{H} \rightarrow ^4_2\mathrm{He} + ^4_2\mathrm{He} + 17{\cdot}2\times10^6\ \mathrm{eV}.$$

The difference between the masses of the initial and product nuclear species, as determined by mass spectroscopic methods, was shown to correspond with the observed energy released in the reaction. Conservation of momentum requires that the two alpha particles escape opposite one another, if the momentum of the incoming proton is negligible. Rough coincidence observations by two observers, with scintillation screens and microscopes on opposite sides of a thin target of lithium, confirmed that this was so. The most striking confirmation that the interpretation of the reaction was correct, was obtained by P. I. Dee (Dee & Walton 1933), who set up his Wilson expansion chamber beneath a second accelerating tube, and obtained beautiful photographs of the tracks of the two alpha particles moving in opposite directions.

These first observations of a nuclear transformation produced by artificially accelerated particles pleased Rutherford enormously, and created at once world-wide interest and acknowledgement when published (13). Rutherford's dream of a new technique for investigating atomic nuclei materialized through Cockcroft's realization that bombarding energies of millions of electron volts were not necessary to enable particles to penetrate into the nuclei of light elements. It was this discovery which ushered in the new era of nuclear physics, and which gave impetus to the development of the cyclotron and other methods of accelerating particles to high energies. It was recognized by the award of the Hughes Medal of the Royal Society, in 1938, and of the Nobel Prize for Physics, in 1951, to Cockcroft and Walton, jointly.

Rutherford, wishing to exploit as fully as possible, in the Cavendish, the new field which Cockcroft and Walton had opened up, persuaded Oliphant to relinquish his work with positive ions, and join him in a programme to measure, as accurately as possible, the energies of the disintegration products of proton bombardment of the light elements. Cockcroft welcomed this expansion of such investigations and, with characteristic kindness, helped in every way possible to bring the new, lower voltage equipment into operation.

During this same year, 1932, Chadwick also working in the Cavendish Laboratory, discovered the neutron (Chadwick 1932). In their subsequent work Cockcroft and his colleagues looked for such particles as products of the nuclear transformations they went on to study. They examined the transformations produced by protons in other light elements (13), particularly boron, beryllium and fluorine, the energies of the particles emitted being consistent with the known masses of these nuclei, and they investigated the disintegration of some light elements by fast neutrons produced by deuteron bombardment (14).

Experiments with deuterons

In 1933, G. N. Lewis, from Berkeley, visited the Cavendish Laboratory and presented Rutherford with a small sample of concentrated heavy water. From this, deuterium gas was prepared and used for bombardment of lithium with deuterons (Oliphant, Kinsey & Rutherford 1933). The results were interesting enough for Oliphant to cable Cockcroft, who was then in the United States, asking that he obtain a further supply of heavy water from Lewis. He bought from Lewis two cans, containing about one gallon in all, of 2 per cent concentration of D_2O in ordinary water, for 10 dollars. He had some difficulty in convincing Customs that this was just water, and when he presented the precious material to Rutherford he was told that he should not have spent ten dollars without permission! Hartek, who was working with Rutherford and Oliphant at the time, concentrated the deuterium content by electrolysis, and Cockcroft and Walton used some of it for experiments on the disintegration of lithium, boron and carbon by deuterons (15). Following the discovery of artificially produced radioactive nuclei by Curie & Joliot (1934), Cockcroft, Gilbert & Walton showed (16), in 1935, that proton and deuteron bombardment of carbon and boron resulted in the production of radioactive nuclei. In a series of elegant experiments with Geiger counters and an expansion chamber with magnetic field, they showed that these radioactive species emitted gamma radiation and positrons, due to the production of ^{13}N and ^{11}C.

Cockcroft played a major role in clearing up a controversy which developed between the Cambridge physicists and those in Berkeley working with E. O. Lawrence with his cyclotron. Lawrence thought that there was evidence from his experiments that the deuteron was disrupted into a neutron and a proton when it collided with a target at high velocity. He reported this at the Seventh Solvay Conference, held in Brussels in 1933, and was disturbed that Rutherford, Chadwick and Cockcroft, who were present, were very sceptical. By careful experiments with a variety of targets, and especially by observations with a heated tungsten target, Cockcroft & Walton were able to show that the universally present proton and neutron groups observed by Lawrence and his co-workers were due to contamination. Oliphant, Kinsey & Rutherford showed that this contamination was deuterium deposited from the beam of ions. From their correspondence over this question, Cockcroft and Lawrence developed a great mutual respect and lasting friendship. (The controversy is reported in detail by Oliphant in 'The two Ernests', published in *Physics Today*, **19**, Nos. 9 and 10, 1966.)

A cyclotron at Cambridge

In 1933, following a tour of American laboratories working in nuclear physics, under the auspices of the Rockefeller Foundation, Cockcroft endeavoured to persuade Rutherford that the Cavendish Laboratory should possess a cyclotron to enable nuclear bombardment experiments to be pushed to higher energies than could be obtained by direct acceleration. Rutherford was not convinced, as he felt that there remained much work to do at the lower energies where more accurate measurements could be made. However, after the munificent gift of £250 000 to the Cavendish Laboratory by Lord Austin, in 1936, by which time the cyclotron had been developed into a more reliable tool, Rutherford agreed that one should be built in Cambridge. During a visit to the United States in 1937, at the invitation of the President of Harvard, where he gave a series of lectures on his work, Cockcroft again went to Berkeley, and obtained from E. O. Lawrence the drawings of his 36-inch cyclotron. Cockcroft organized the building of a cyclotron in Cambridge, incorporating some improvements, in the room where he and Walton had erected their high-voltage accelerator. He kept in touch with Chadwick, who was building a similar cyclotron in Liverpool.

In collaboration with Oliphant and Dee, Cockcroft was largely responsible for the refurbishing of the old library of the Cambridge Philosophical Society to house, initially, a one million-volt Philips high-voltage set, which used the Cockcroft-Walton method of voltage multiplication, and later a similar unit for two million volts. However, by the end of 1935, he ceased active participation in experimental work in nuclear physics, though he continued to be influential in matters of equipment and general policy. Cockcroft's last paper recording results obtained with the high-voltage equipment built with Walton, was written with W. B. Lewis (17). Magnetic analysis of the bombarding beam was introduced to remove the effects produced by unwanted ions, and the methods of detection and counting of product particles were improved greatly. An attempt to detect the unstable ^{8}Be nucleus was not successful.

The Mond Laboratory

In 1935, Cockcroft was asked by Rutherford to take over direction of research in the Mond Laboratory, following the resignation of Dr P. Kapitza. His first task was to supervise the duplication of the cryogenic equipment, and the removal of the original liquefiers, the short-circuit generator, and associated apparatus to Moscow. In 1936 he visited Kapitza at his Institute for Physical Problems in Moscow, and saw the equipment installed and in operation. In the Mond Laboratory he directed work on the properties of liquid helium at low temperatures, with J. F. Allen. However, Rutherford, who did not relish the task of rebuilding the Cavendish with the Austin benefaction, handed over to Cockcroft general responsibility for the design of the new wing, which was to house laboratories, workshops, offices and stores. In St John's College, and during the design and erection of the Mond Laboratory, Cockcroft had gained much experience of building construction. With a committee including Dee and others, which worked closely with the architect, W. G. Holford, the new laboratory was designed in detail.

*Supervisor and Junior Bursar, St John's College**

Cockcroft was appointed a Supervisor in Mechanical Sciences in the College in 1929, shortly after his election as a Research Fellow, and in 1931 he was appointed also a Supervisor in Physics. In both these capacities he continued to play an important part in the College teaching until 1939.

In 1933 he was elected Junior Bursar. The Junior Bursar was responsible for most of the internal, or domestic, administration of the College (apart from the Kitchen, which was in the charge of the Steward), including recruitment and management of staff and the maintenance of the College buildings and grounds. The six years during which he held the office were important in the history of the buildings. Apart from the reconstruction of the roof of the early seventeenth-century Library, which had been carried out a few years previously under his predecessor, Dr L. E. Shore, little had been done to the ancient buildings of the College for a long time. Soon after Cockcroft assumed office as Junior Bursar, the College began repairs with Sir Charles Wheeler as consultant, assisted by Mr Noel Dean of the Estate Management Branch in the University. The plan included the repair and partial rebuilding of the early sixteenth-century Gate House of the First Court and the colouring, under the direction of Professor E. W. Tristram, of

*These paragraphs were supplied by the Master of St John's College, Rev. J. S. Boys Smith, M.A.

the College Arms and their decorative field on its outer face, the repair of the brickwork and stonework of the Court, repair of the timbers of the roofs of the late sixteenth-century Second Court and the strengthening of the contemporary ceiling of the Combination Room in its northern range, and the repair of the timber roof of the sixteenth-century Hall, which, like the roof of the Library earlier, was severely attacked by the death-watch beetle. In addition to this important repair-work, most of the electric wiring of the College was renewed and the interior of Gilbert Scott's Chapel was cleaned.

The College began in 1938 an important scheme of new building. Cockcroft, as Junior Bursar, was immediately in charge, during the years 1938 and 1939, of the erection of the new Chapel Court and North Court to the designs of Mr Edward Maufe (now Sir Edward Maufe, R.A.). These were completed in 1940. By this time, however, the war had inevitably brought to a standstill the programme of repairs to the ancient buildings and the programme on the full scale, was only resumed some twenty years later.

To his work as Junior Bursar during this busy period Cockcroft brought his all-round competence, his administrative capacity, and his power of quick decision. The work was carried out concurrently with his College teaching and his distinguished scientific research. His election, in the summer of 1939, to the Jacksonian Professorship of Natural Philosophy from 1 October 1939 would in any case have meant that he would have had to hand over his College teaching and administration to others. He was in fact called to different and to wider national tasks, and he spent the whole period of his tenure of this Chair, till 1946, away from Cambridge.

Academic duties

The courses of lectures given by Cockcroft in Cambridge, especially those on electrodynamics, were well delivered and lucid. However, he assumed such high standards of competence in mathematics and physical reasoning, and covered so much ground, that while the better students profited greatly, others had difficulty in keeping up with him. He saw little point in proving the obvious or in treating elementary problems exhaustively, so that college supervisors had to work overtime to keep students abreast of the lectures. On the other hand, members of his class soon discovered the kindness behind his apparent reserve, and then they approached him readily, knowing that he would always find time to help them.

Cockcroft's correspondence for this period reveals that he was offered a number of attractive posts in academic institutions in both America and Britain, as a physicist and as an engineer.

Section III: Radar and the second world war

The story of the development of radar has been told many times, and the foresight of Sir Henry Tizard's committee, of which P. M. S. Blackett of the

Cavendish Laboratory was a leading member, in encouraging the work of R. A. Watson-Watt, has received just recognition. The great contributions to radar techniques made by T.R.E. under A. P. Rowe and W. B. Lewis are well known, and these, developed primarily for the Air Force, were basic to applications made elsewhere for naval and army use. However, the development of army radar systems, in which Cockcroft played an important part, was overshadowed by the more glamorous role which radar played in the air and on ships, and it is necessary to give here some account of the contributions made by the teams which Cockcroft led. This account is based on a paper, 'General account of army radar', written by Cockcroft in 1945 (18).

Early in 1938, Tizard spoke confidentially with Cockcroft about the new and highly secret radio technique, then known by the code letters R.D.F., for detecting enemy aircraft. 'These devices would be troublesome, and would require a team of nurses—would we—the Cavendish—undertake to come in and act as nursemaids, if and when war broke out. He talked also of wanting large powers at short wave lengths, and would we think about it.'

After Munich, R. H. Fowler and Cockcroft visited the radar development station at Bawdsey, on the East Coast, and were introduced to the secrets of radar, both ground-based and airborne. Following a further visit to Bawdsey in the spring, and a meeting in Cambridge with Watson-Watt, Cockcroft played a leading part in organizing the initiation of about 80 physicists into radar, various parties spending about a month at different coastal radar defence stations in September 1939. These visits were extremely successful and Cockcroft was able to persuade many of the leading physicists in the country to participate. They gained experience of operational radar and its deficiencies under war-time conditions. This action was one of Cockcroft's greatest contributions to the war effort, for a large proportion of the physicists so introduced to radar spent the war period in its development, and some of them made major advances.

Cockcroft himself had been persuaded by H. J. Gough, at that time in charge of scientific research for the Army, to join him in the application of radar to gunnery and related problems of coastal defence. Cockcroft threw himself into this work with characteristic energy and resourcefulness. The first task was primarily for the Admiralty. He and his able team built by hand three radar stations, one in the Shetlands and two in Fair Isle, and installed them in appalling conditions of gales and snow. These stations, designed to aid defences against submarines, were all in operation by the end of February 1940. It turned out that their greatest value lay in the detection of low-flying aircraft attacks on Scapa Flow. Difficulties were experienced in getting proper use made by the Services of the information obtained from these stations. In this, Cockcroft's tact and tenacity of purpose persuaded Admiral Somerville to intervene, with excellent results. Four more stations were erected in this vital area under Cockcroft's supervision. Thereafter, he withdrew from the islands to erect similar stations on the Thames Estuary and the East Coast to detect low-flying German aircraft sowing magnetic mines, which were devastating shipping. These stations were able to direct Naval minesweepers to the areas where magnetic mines had been laid, while shipping was able to avoid new minefields; and later they played an important part in defence against low-flying aircraft attacks upon Britain.

So successful were Cockcroft's early efforts that he found himself little hampered by the red tape and inter-departmental jealousies at headquarters, though, as Assistant Director of Scientific Research, under Gough, he could easily have been subject to the many frustrations of wartime. His quiet, determined manner broke through obstacles.

The Tizard Mission

In August 1940, Cockcroft became a member of Tizard's Mission to North America, the objective of which was to establish exchange of defence science information with the United States. Tizard had obtained authority from the Prime Minister to disclose all British developments. They took with them samples of equipment, including the magnetron generator of microwaves invented by H. A. H. Boot and J. T. Randall in Birmingham, and made at the General Electric Company's Research Laboratories at Wembley, a series of short-wave radio valves, and every technical report on radar, predictors, gunsights, rockets and jet-propulsion, which they could collect. Cockcroft acted as Tizard's deputy, both in preparations for the Mission and after arrival in America.

E. G. Bowen, a member of the Mission, remembers (Private communication to M.L.E.O.) an amusing episode on the voyage in *The Duchess of Richmond*. The ship carried a contingent of officers and men of the Royal Navy who were to pick up the first of the gift of fifty destroyers from U.S.A. The Navy men heard of the presence of eminent scientists on board and asked for a lecture on a subject of interest to them. Cockcroft was chosen for the task. The equipment and information carried by the Mission were considered to be too secret for discussion before a general audience, even in uniform, so he gave a delightful talk on atomic energy and the possibility of producing nuclear explosives. He ended by calculating the amount of nuclear energy potentially available in a cup of water, his unit being the energy required to blow a 50 000-ton battleship one foot out of the water.

The Mission was extraordinarily successful, most barriers to complete mutual trust being removed by the frankness of Tizard and the unassuming tact and great knowledge of Cockcroft; and especially by their disclosure of the microwave magnetron and its applications to radar. Cockcroft displayed a great capacity for making friends, forming close contacts with such influential men as Karl Compton, Ernest Lawrence and Alfred Loomis. Through them, he was influential in the establishment of the Radiation Laboratory at M.I.T., which was to become the counterpart of the radar development establishments in Britain. He made several visits to the National

Research Council in Ottawa, and established close liaison between British and Canadian microwave radar research and production.

Members of the Tizard Mission recall Cockcroft's unfailing good humour and enormous physical resources. Though the continuous strain on men already tired from their war efforts affected Cockcroft as much as the others, and he often looked to be at death's door, he carried on without flagging or becoming impatient.

Chief Superintendent, A.D.R.D.E.

Upon his return to England in December 1940, at the height of the night bombing by Germany, Cockcroft became Chief Superintendent of the Air Defence Research Development Establishment at Christchurch. He entered with enthusiasm upon the application of radar to the direction of anti-aircraft gunnery upon unseen targets. The G.L. equipment developed for this purpose was not always received with enthusiasm by anti-aircraft battery commanders. Cockcroft recalled wryly that one such commanding officer remarked heatedly that he had not joined the Army to become an electrician! Here again, by persistent visiting of gun-sites and quiet discussion, Cockcroft was largely responsible for its acceptance. A special school was established to train radar operators and maintenance men for this equipment, and mobile calibrating squads of experts improved its performance. By these means, the average rounds of A.A. fire required to shoot down an aircraft was reduced from 20 000 to 4000.

Cockcroft then spent a frustrating period in the endeavour to bring about the obvious change-over to the utilization of microwaves for gun-laying. It was realized that such equipment, if coupled to efficient predictors, could increase the accuracy by an order of magnitude, or more. Intolerable delays in production, and vacillating policy and indifference in high places, gave him many headaches. He was unable to persuade the War Office to agree to the provision of automatic following of a target, despite demonstrations that this resulted in an almost three-fold increase in accuracy, production facilities being already over-committed. However, automatic following had been developed in the U.S.A., and equipment was in production. Cockcroft was able to obtain an American G.L. on high priority, and this arrived in September 1943. He arranged for trials of this equipment, which were so impressive that A.A. Command pressed for orders to be placed. He had not obtained War Office authority for such trials, and was severely reprimanded for this breach of regulations. His advice that the equipment be obtained was not accepted by the War Office, despite the poor performance expected for A.A. gunnery against the flying bombs, which intelligence reports suggested might prove a grave menace to London. However, towards the end of 1943, during a visit to America with the Watt Mission, he discussed the problem with the United States authorities, and cabled home recommending the requisitioning of 200 sets of equipment. On his return, he was able to obtain the strong support of General Pile and Mr Duncan Sandys to overcome official inertia. The sets were ordered and arrived promptly. They proved themselves of vital importance in June, July and August 1944, when over 70 per cent of pilotless planes crossing the coast were shot down. In this they were aided greatly by the American proximity fuses discussed later.

The programme of development of microwave radar in Canada, initiated by Cockcroft during the Tizard Mission, bore valuable fruit at this time. There were many difficulties due to lack of liaison at high level, but these were overcome and Canadian equipment served well with A.A. Command in 1943.

Cockcroft's team developed microwave versions of coastal defence radar which became of increasing value in the war. In this work he had to contend with acute inter-Service jealousies, and lines of demarcation of responsibility for various aspects of the equipment, while the whole programme was much criticized by T.R.E. and the Air Ministry. There were unfortunate delays in decision making and manufacture which were particularly frustrating. Throughout the war, A.D.R.D.E. had to contend with a series of crash programmes to provide coastal defence equipment for Britain, the Mediterranean area, and then the Far East, including Australia. The various versions of this equipment proved their worth in the detection and location of E-boats, shipping of all kinds, and low-flying aircraft, as well as in the control of Britain's own ships. Somewhat similar equipment was developed and produced for use with coast artillery. The 3-cm version of this was extremely successful for fire control, especially when fitted with a display system which enabled ships to be seen in relation to shell-splashes on the screen of a cathode-ray tube. The sets at Ventnor recorded precisely the number and positions of convoys on D-Day, enabling an estimated 40 per cent saving in time required for turn-round. The Navy was reluctant to accept Cockcroft's assurances of the value of the system for gunfire control, but later co-operated whole-heartedly, using it in the Pacific war.

Further applications of microwave radar were developed, for field use by the Army, detecting and locating moving vehicles and tanks in darkness and enabling gunfire against them, determining the origin of mortar fire, and even observing the trajectories of mortar shells. From early in the Battle of Britain, various versions of radar equipment were produced by A.D.R.D.E. to enable searchlights to pick up enemy aircraft. It was hoped that this would assist visual interception by fighter aircraft, and visual following for anti-aircraft gunnery predictors. A great deal of effort went into this programme, but it had little value except when the enemy dislocated the lower frequency radar used for controlling the interception by fighter aircraft of night bombers, by distributing large quantities of streamers of aluminium foil (Window), which reflected longer-wave radio pulses. Oliphant recalls visits to searchlight stations made with Cockcroft at night in an endeavour to assess performance of the radar direction. Despite the extreme cold, problems of driving to the sites in the black-out, and the fact that the equipment was often unserviceable upon arrival, cloud cover appeared, or an enemy raid prevented the target aircraft from operating, Cockcroft did not lose his patience or determination to complete the project successfully. However, he concluded, by late 1943, that the value of searchlights against aircraft was dubious.

Radar equipment developed at A.D.R.D.E., which was light and mobile to give warning of air attack and to enable tactical control of aircraft interception with moving troops, did not prove successful, probably because it was designed and manufactured too hurriedly. Greater success was achieved in radar control of light anti-aircraft fire, especially with Bofors guns and against the V1 pilotless aircraft.

Early in 1940, A.D.R.D.E. began to take part in a programme, suggested originally at Bawdsey, that it might be possible to produce a very small and simple radio system which could be carried in the nose of an anti-aircraft shell, reflexions of radio waves from an aircraft firing the explosive charge when the shell was in its vicinity. A near miss would then become as effective as a direct hit. Such a proximity fuse required radio valves which would withstand the very high accelerations of the shell in the gun. No existing valves met these severe conditions. Cockcroft obtained a small diode from an unexploded bomb dropped on England by the Germans, and subjected it successfully to high accelerations in a centrifuge in the Biochemistry Laboratory in Cambridge. The diode proved to be so rugged that he arranged for development of similar valves in the U.K.

Cockcroft was much encouraged, when in America with the Tizard Mission, by work being done in Washington by Merle Tuve, who was endeavouring to develop a photo-electric proximity fuse. He was able to arrange with Tuve that he would develop a radar-operated version of the fuse suitable for use with British anti-aircraft guns. Great difficulties were experienced in the British project owing to the reluctance of the manufacturers to produce valves small enough in size or with sufficiently low cathode heating currents. The provision of a suitable small battery, with good shelf-life, was a major obstacle. Development of suitable valves and batteries went so slowly that it was June 1943 before successful trials could be carried out. Industrial development facilities in this field proved to be poor, and much of the work had to be carried out at A.D.R.D.E. Meanwhile, the American developments had gone well, and when intelligence reports indicated the imminence of German attack by pilotless aircraft and rockets, Cockcroft was able to discuss the provision of American proximity fuses with authorities in U.S.A. and press for their adoption in Britain. He has recorded (18) that he got little sympathy from the War Office, but that General Pile, of A.A. Command, was convinced, and arranged for a top-level request to be made to the U.S.A. The equipment arrived at the height of the V1 attacks, and the proximity fuses aided greatly the successful shooting down of these pilotless aircraft. Cockcroft has written:

'. . . the proximity fuse development was A.D.R.D.E.'s greatest disappointment. It was due in part . . . to the poor industrial facilities available.'

This disappointing experience impressed Cockcroft greatly, and led him to take a deep interest in industrial development in Britain after the war. He observed that British inventiveness was excellent at the basic stage, but that the subsequent industrial stages were often slow and ineffective.

Section IV: Cockcroft and atomic energy

Cockcroft was so influential in the British effort on atomic energy from 1939 to 1959 and he was so deeply involved in the policy making, organization and technical direction that it is impossible to understand his contributions without describing many of the main events in atomic energy during this period and referring to many names. He assembled at Harwell one of the largest and most brilliant technological teams ever seen in Britain; and many of them joined straight from the universities, attracted by exciting new fields of science and technology and by the name and philosophy of Cockcroft. Some of these men are still in the Atomic Energy Authority, or in the nationalized industries, but very large numbers are in the universities or in the private sector of industry. Once again, the characteristic of Cockcroft in attracting young people of the highest quality and providing an environment which quickly developed their potential must be classed as one of his most important influences.

Atomic energy in the Second World War

The story of the scientific and industrial effort made by the United States during the Second World War on the development of atomic energy for military purposes, and the assistance given by Britain, Canada and France, has been told in official histories; and parts of the story appear in various biographies and other books. (See, for example, *Britain and atomic energy 1939-45* by Margaret Gowing; *The New World 1939-46*, Volume I, History of the United States Atomic Energy Commission, by R. G. Hewlett and O. E. Anderson, Jr; *Canada's nuclear story* by Wilfrid Eggleston; *Les Rivalités atomiques* by Bertrand Goldschmidt; *The journals of David E. Lilienthal*, Volume II.)

The various accounts agree well on matters of fact, and all of them, to varying extents, give explanations of the political, military and commercial difficulties which grew as the American effort gathered its enormous momentum. Cockcroft was one of the most influential of the British scientists who, even before any exchange of information started with America, thought that a strong effort should be made by Britain, but in the early years of the war he was so completely engaged in radar that his contributions to atomic energy could only be advisory and administrative. The motive force in Britain came from a small number of outstanding theoretical and experimental scientists, some British born, some French and some who had become

British to escape from Nazi and Fascist oppression. These men worked on the basic scientific and technological problems of atomic energy and atomic explosives, and rapidly created a situation of formidable portent.

A military fantasy changed into a grim possibility when R. E. Peierls and O. Frisch wrote a memorandum in early 1940 about an atomic explosive device which assembled two pieces of ^{235}U. (J. Chadwick had already thought about the possibilities and had told Sir Edward Appleton that he was investigating the factors governing fast neutron fission.) The memorandum by Peierls and Frisch led to the formation of an official committee in the Ministry of Aircraft Production, with the name of the MAUD Committee, and the first meeting was held in June 1940, although two informal meetings had been held in April 1940. The Committee met almost invariably in the Royal Society premises at Burlington House, and the original members were G. P. Thomson (Chairman), J. Chadwick, J. D. Cockcroft, M. Oliphant and P. B. Moon; but soon P. M. S. Blackett, C. Ellis, W. N. Haworth and a representative of the Director of Scientific Research at M.A.P. were added, with B. G. Dickins as secretary. Later on, F. Simon joined the Committee. The work of the MAUD Policy Committee and of the technical sub-committee, and their various ramifications, are best understood by references to the books already quoted, especially that by Margaret Gowing.

Another of the decisive events of atomic energy occurred when Tizard led the mission to the United States in September 1940 (see Section III). On his way to Washington, Tizard spent a week in Ottawa where he saw C. J. Mackenzie, O. Maass and many others. R. H. Fowler was already in Ottawa as scientific liaison officer, and Fowler had been briefed by the MAUD Committee. G. C. Laurence had started work in March 1940 at the Ottawa laboratories of the National Research Council, in an attempt to make a neutron multiplying system from natural uranium oxide and carbon. Fowler had told Laurence of the experiments started by H. V. Halban and L. Kowarski in Paris, and being continued by them at Cambridge on a heavy water-uranium assembly. Cockcroft was in the Tizard Mission mainly as a radar expert, but he was of course particularly well qualified to handle the atomic energy side. Cockcroft was joined in Washington by Fowler, and they attended a meeting of the Briggs Uranium Committee, which President Roosevelt had created in the autumn of 1939. Tizard returned to the United Kingdom in October 1941, but Cockcroft and Fowler stayed on for a few weeks, to continue making arrangements for the exchange of information on scientific research for war, including atomic work.

The response of the British Prime Minister, the reorganization of responsibilities under Sir John Anderson, Lord President of the Council and then Chancellor of the Exchequer, the creation of the atomic energy directorate under W. Akers in the Department of Scientific and Industrial Research, headed by Appleton, the effect of the MAUD Committee reports and British government actions on the United States and Canada, the remarkable growth of the Manhattan District Project, and the political, commercial and uranium procurement difficulties involving Britain, Canada and the United States, are well described from different viewpoints in the official histories to which reference has been made. Cockcroft does not re-enter the story again until November 1943.

In the summer of 1942, Britain had tentatively suggested to Canada that some 'British' scientists and engineers (some of whom of course were French) should be transferred to Canada to work on a heavy water-uranium programme. Canada wanted to know what American reactions would be. On 5 August 1942, Anderson asked Dr Vannevar Bush how the Americans would view the transfer of the Halban team from Cambridge to Canada; and Bush said that he would welcome the arrangement. On 24 September 1942, Gordon Munro (Deputy High Commissioner for the United Kingdom in Canada), accompanied by Halban, called on C. J. Mackenzie, President of the National Research Council, at Ottawa, to propose officially the transfer of the Cambridge team. By the end of the year, steps had been taken to use laboratory accommodation in the unfinished Medical Wing of the University of Montreal. The outlook, however, was not encouraging and without the help of the United States in acquiring essential materials, little progress could be made. Meanwhile, relationships between the United States and Britain on atomic energy were at a low ebb.

The Quebec Agreement in August 1943, and the move of Chadwick to Washington to take charge of British atomic energy matters in the British Mission led to a great improvement. Major-General L. R. Groves, who was in charge of the United States project, and Chadwick, soon reached agreement. So far as the Anglo-Canadian effort was concerned, a heavy water pile of moderate but adequate size was to be recommended, with American help. There was an understanding between Mackenzie, Chadwick and Groves that a British or Canadian scientist would be put in charge of the Montreal laboratory. Chadwick, in December 1943, had already seen Cockcroft and explained what he hoped would be agreed for Montreal and suggested that, in that case, Cockcroft should consider leading the Montreal laboratory. Chadwick took Cockcroft to see Groves, and Cockcroft then visited Montreal. Mackenzie was well pleased by the possible acceptance of Cockcroft. Groves said that the choice was a matter for Chadwick and Mackenzie.

The Combined Policy Committee in Washington on 13 April 1944, with Mr H. L. Stimson in the chair, accepted the proposal of a heavy water pile in Canada, built with American help.

'It took another five weeks for Groves and Chadwick to set the ground rules. The guiding principle was to exchange only information essential to constructing and operating the Canadian pilot plant. It included the fundamental physics of a heavy water pile and such findings as corrosion, water treatment and properties of materials as were necessary to construct the one in Canada. It specifically excluded, however, all construction details on Hanford and the methods of separating plutonium and plutonium chemistry and purification.' 'The scientists in Canada were upset when they learned that they were denied data on the chemistry of plutonium. As a gesture in their direction, Groves agreed to permit a limited amount of irradiated uranium in the form of slugs from Clinton to go to Montreal so that the group there could work out independently the methods of plutonium separation and purification.' (Hewlett & Anderson, *loc. cit.* p. 283.)

Cockcroft reached the Montreal laboratory on 25 April 1944. A few days earlier, as a result of the meeting of the Combined Policy Committee, arrangements had been made with the Americans to come to Canada and advise on the choice of a site for the heavy water reactor and plant, but the decision to choose the Chalk River site was not made until late July 1944, after Cockcroft had seen several possible sites, and after he had visited the Chicago Metallurgical Laboratory, the Argonne Laboratory near Chicago and the Clinton Laboratory, near Knoxville.

Cockcroft's presence in Montreal and the support he received from Chadwick in Washington had their effect; and under his calm but energetic guidance the laboratory, with its mixed British, Canadian and French staff, gained a firm sense of purpose. Cockcroft took a keen interest in the planning and layout of the Chalk River site. The design and development of the 10 MW heavy water reactor NRX, and its back-up zero energy assembly ZEEP, were vigorously pursued, and construction began in the autumn. Cockcroft and many of the staff moved from Montreal to the new town site at Deep River towards the end of 1945. Chemical processes began to be developed for recovery of uranium from the irradiated fuel as well as for separation of uranium-233 from irradiated thorium oxide rods in the reflector. The primary separation processes for plutonium were worked out, but only on a semi-micro scale, using the American slugs from Clinton. By the time he left Canada in the autumn of 1946, the reactor was almost complete, the laboratories were fully occupied and the town had become a settled community. The NRX heavy water reactor later proved to be one of the most valuable research reactors in the world because of its relatively high neutron flux, and it also became the forerunner of successful developments in Canada on the use of atomic energy for power purposes. The layout of the Chalk River site and of the community have stood the test of time and are widely considered to be a testimonial to the vision and philosophy of Cockcroft.

During the spring and summer of 1945 great pressure was building up in the United Kingdom to bring back Cockcroft as soon as possible to start the post-war effort in Britain on atomic energy research. The decision to create a British atomic energy research establishment had effectively been made in April 1945, and in July 1945 Anderson wrote to Cockcroft and offered him the Directorship of the establishment. Anderson explained the position to Mackenzie who was deeply disturbed.

Atomic energy in post-war Britain

Early in the summer of 1945, Oliphant and Cockcroft suggested to

Anderson that a 'permanent' R.A.F. station would make a suitable site for the proposed establishment on atomic energy research. Oliphant made a survey and in October 1945 Cockcroft visited possible sites near Oxford and recommended Harwell. Anderson's Advisory Committee on Atomic Energy agreed and the Air Ministry gave immediate consent (9 October 1945).

The first post-war government in Britain was led by Mr C. R. Attlee as Prime Minister. Attlee endorsed the decision to offer Cockcroft the directorship of Harwell. In November 1945, Cockcroft received the formal letter from Sir Oliver Franks, Permanent Secretary in the Ministry of Supply. The salary was £2000 per annum for a period of five years in the first instance. This not very generous offer was, however, accompanied by an assurance that, subject to such rules for safeguarding military information as the Minister might give from time to time on what might or might not be published, it was the intention that the Establishment should have the same freedom as regards exchange of views and the publication of results as other institutions such as university research laboratories. Cockcroft accepted appointment on these terms as from 1 January 1946; but recognizing his responsibilities in Canada, he also remained director of the Chalk River and the Montreal laboratory for nine months, until W. B. Lewis succeeded him there. During this period, Cockcroft was constantly commuting between Canada and Britain. Attlee persuaded Viscount Portal of Hungerford to become Controller of Atomic Energy (Production) in the Ministry of Supply, and announced his appointment on 29 January 1946. C. Hinton was invited to become Deputy Controller of Atomic Energy (Production). In accepting the formal offer from Franks, Hinton made the condition that if it were possible to evolve civil applications for nuclear power, the engineering development of these should be the responsibility of the Production organization. Hinton asked his colleague W. L. Owen to join him. Their first task was to create the organization to design, build and operate the uranium metal plant, a plutonium production pile and the chemical separation plant.

The motive behind the atomic energy programme was military. Britain had just come through a war in which technical innovation had swung the balance from side to side, sometimes almost decisively. The atomic bomb, appearing at the end of the war in the Far East, appeared militarily to be of a different order. A military threat henceforth could only be stabilized by an equal counter threat. These at any rate were the thoughts of those engaged on atomic energy and Cockcroft seemed to share them. However, no arrangements were made at that time about an ordnance programme. Experience in America had shown that a minimum of several years was required to establish a nuclear technology and produce fissile material. If Britain was to make atomic bombs, the ordnance programme could be started later.

The top level chain of command was exceptional. Cockcroft was not under Portal and reported to Franks. Portal, Cockcroft and Hinton were all in the Ministry of Supply, but Portal had direct access to the Prime Minister, and could see the Chiefs of Staff whenever he pleased, because of his earlier position. The high administrative civil servants, although sometimes thinking that a more normal chain of command would have been better, bore these arrangements with a good grace. The machinery and the resources of the Ministry of Supply, and through this Ministry of other Government departments, were deployed to meet the requirements coming from atomic energy and were fully used.

Portal took over a set of offices which could be made especially secure in Shell-Mex House. The area was usually called the Cage. He was joined by M. Perrin, who with Akers had been lent by Imperial Chemical Industries to Tube Alloys; F. How, an under-secretary in the Ministry of Supply, became Secretary to the Atomic Energy Office and his job was to make administrative arrangements between atomic energy and the rest of the Ministry and Whitehall.

Portal formed two committees and usually took the chair at both: when he was unavoidably absent, Cockcroft took the chair. These were the Atomic Energy Council, whose membership included Cockcroft, Hinton, Perrin and How; and a much larger body, the Atomic Energy Technical Committee whose membership included the Council and senior members from Harwell and Risley as well as many of those who had played important parts in the war-time effort and who were mostly back again at a university.

Harwell—early days 1946-1950

Possession of the Harwell site and facilities was taken on 1 January 1946, and soon staff began to move in from Canada, from the Manhattan District laboratories in the United States and from laboratories in Britain. The first Division Head to arrive at Harwell was H. W. B. Skinner and he acted as Cockcroft's local deputy. Cockcroft was well informed on the new appointments and took an active part in finding good candidates.

The initial programme of the establishment included:

(1) A low-powered graphite moderated pile (GLEEP) to be used mainly for testing the purity of uranium metal and graphite for future reactors. (GLEEP was commissioned in 1947.)
(2) A 6-MW (thermal) graphite moderated research reactor (BEPO), to be designed by the Industrial Group at Risley. (BEPO was commissioned in 1948.)
(3) An electromagnetic separator for uranium isotopes to produce small quantities of ^{235}U.
(4) A Van de Graaff accelerator to produce 6-MeV protons for nuclear data work.
(5) A synchrocyclotron to produce protons of energy 180 MeV.
(6) A 'hot' laboratory for radio-chemistry.
(7) Office accommodation and some general-purpose laboratories, to be obtained by converting existing buildings.

Some of the early planning of the development of the Harwell site was done at Montreal and Chalk River, and the detailed planning of the hot laboratory was mostly done at Montreal. The construction of the buildings and facilities at Harwell was the responsibility of the Ministry of Works and a special team was put at Harwell. The Director-General, Sir Charles Mole, spent a lot of time at Harwell and did much to ensure rapid and effective progress. Cockcroft visited Harwell on a stormy day in January 1946 when the rain was coming down at the typical angle of 45°. He approved suggestions put to him by Mole on the siting of major facilities and he inspected the site for 200 prefabricated houses. He also inspected various sites at Abingdon for the construction of permanent houses for staff returning from Canada and the United States.

The alterations to existing buildings and the construction of new buildings and houses required an ever-increasing number of industrial workers. Industrial relations were in the capable hands of the Chief Engineer, H. Tongue, but Cockcroft soon became known to a great many workers through his Saturday morning visits. He spoke to the industrial staff from a temporary platform in the hangar and told them about the programme and its importance, and quickly gained their confidence.

Some technological problems were of great urgency because procurement action and plant design and construction had to start without knowing how long the problems would take to solve. Two such problems concerned graphite and the chemistry of irradiated fuel.

The graphite for BEPO and the plutonium piles needed to be of exceptional purity, especially as regards certain elements, determined by nuclear considerations. Cockcroft had formed early in 1945 a graphite committee in Canada; J. V. Dunworth led this work. Early in 1946, Cockcroft arranged for measurements to be made in ZEEP of the cross-section of Canadian graphites coming from the Electro-metallurgical Corporation plant at Welland, Ontario. These tests indicated a preference for a particular petroleum coke as raw material and the need to eliminate the metallurgical coke used in commercial graphitizing furnaces. The work led to the use of Canadian graphite in BEPO and, initially, in Windscale.

At Harwell Cockcroft put J. M. Hutcheon in charge of a programme to develop suitable production here, with co-operation from a number of industrial firms and Government and University laboratories. This work, with the particular help of the Shell Company, led to the replacement of residue cokes by distillate cokes as starting material. Trial quantities of these cokes, first of 500 tons and later of 1500 tons, were made at Shell refineries and converted to graphite, first in a small pilot plant built and operated by British Aluminium Co. at Kinlochleven, Scotland, and then in the plants at Welland and the associated company, British Acheson Electrodes, at Sheffield.

This graphite proved to have a cross-section about 20 per cent lower than the previous nuclear grade and was satisfactory in other respects. It became a standard material for the Windscale, Calder and the Magnox reactors, and was known as P.G.A. (pile graphite grade A).

The second technological area was related to the design and construction of the chemical separation plant at Windscale to separate plutonium and uranium from irradiated fuel, and deal with the fission products. The initial designs of this plant had to be based on the semi-micro-scale work at Chalk River done on the Clinton slugs, but fuller information was needed. Cockcroft arranged that a team of British chemical engineers would build a pilot extraction tower at Chalk River and the development of the butex process was done at Chalk River by a Harwell team led by C. R. Nicholls, using the first irradiated fuel coming from NRX for their experimental work.

Hinton's original remit on the plutonium production pile was to build one resembling the Hanford piles and using similar siting criteria. A possible site was found but it was so remote that rapid progress would not have been possible and the costs would have been high. Attention was therefore turned to the possibility of using gas cooling rather than water cooling, a possibility which had been mentioned in the Smythe report. Collaborative work between H. H. Gott and E. H. Lee at Risley and J. Diamond at Harwell progressed to the point where it became practicable with less demanding siting criteria to use finned cans in an air-cooled reactor which was essentially a scaled-up version of BEPO and using only an amount of uranium which would be available. The required plutonium production needed two such reactors, and the decision was made to build the reactors at Windscale. J. W. Kendall was to start designing them immediately his office had completed BEPO. A small effort was to be continued at Risley on a CO_2-cooled graphite moderated power reactor, in collaboration with Parolle (the subsidiary of C. A. Parsons and Company). Cockcroft organized a small supporting research effort at Harwell on a CO_2-cooled power reactor.

The duality of atomic energy

The gravity of the Cold War in the late spring of 1947 caused the Chiefs of Staff to consult Portal about a nuclear weapons programme. Portal made some proposals and saw the Prime Minister. W. G. Penney, Chief Superintendent of Armaments Research in the Ministry of Supply, was asked to plan an ordnance programme, and he joined the Atomic Energy Council. The urgent task of the British atomic energy production programme was about to become the production of a small number of atomic weapons.

The growth of the three major groups under Cockcroft, Hinton and Penney was rapid, but meanwhile the Cold War became even more serious. The Chiefs of Staff asked for an expansion of the weapons programme, and in late 1947, Portal and the Atomic Energy Committee decided to accelerate diffusion plant development with the construction of a major plant in view. Hinton persuaded Portal to try to bring in a large firm from British industry as the major contractor but the response was unsatisfactory and the Industrial group was then given the task of designing and building a diffusion plant at Capenhurst. The I.C.I. work on membranes and flowsheets, done under contract with I.C.I. Billingham was carefully assessed at Risley and the decision was made to set up a pilot unit at Springfields to test a single stage. Owen chaired the design committee of which Cockcroft was a member. Harwell and the development laboratory of Risley energetically resumed work on compressors. Harwell gave considerable support on the technology of diffusion plant but the formidable large-scale engineering and system problem was concentrated at Risley, Springfields and Capenhurst. Meanwhile, uranium procurement remained a serious problem.

Portal decided in 1951 that he could relinquish his post as Controller, and he was succeeded by Lieut.-General Sir Frederick Morgan. Perrin returned to industry.

The election of October 1951 brought the Conservatives back to power under Winston Churchill. Cherwell became Paymaster-General and Mr Duncan Sandys became Minister of Supply. There was a lot of jockeying for position in the atomic energy field and Churchill did not resolve the matter by announcing in the House of Commons on 14 November 1951 that the Paymaster-General would advise him on atomic energy questions. The Minister of Supply, in whose Department the atomic energy project was located, and whose Permanent Secretary was the accounting officer for the Ministry, including atomic energy, remained strongly entrenched.

Cherwell and Sandys agreed that Cherwell should set up an Atomic Energy Council, consisting of Morgan, Cockcroft, Hinton, Penney, How and a secretary, and the Council met in Cherwell's office under his chairmanship.

The expansion of the weapons programme required by the Chiefs of Staff would not be fully met by the addition of a diffusion plant. For some time, a tentative scheme for increasing plutonium production had been based on replicating the Windscale piles, but a more attractive route was seen. The small effort at Risley on a CO_2-cooled power reactor had been picked up by a composite team centred at Harwell and led by B. L. Goodlet, with participation by the Ministry of Works, the Central Electricity Authority and Babcock & Wilcox. R. V. Moore, under Goodlet, had produced by 1952 an exciting conceptual design for a CO_2-cooled, graphite moderated, natural uranium power reactor called PIPPA; and Hinton and Cockcroft decided that the design could be modified to a reactor whose primary purpose would be to make plutonium but which would also be used to generate substantial quantities of electricity as a by-product. Cockcroft readily agreed that Moore should be transferred to the Production group to expedite the detailed designing. Hinton then proposed to Cherwell's Council that a dual-purpose reactor station of the modified PIPPA type be built at Calder Hall, contiguous to Windscale, primarily to make plutonium for the military programme but also to supply electricity to the national grid. Probably the most important technological decision made by Cherwell's Council was to recommend to the Government in early 1953 that a single such dual-purpose reactor be built at Calder Hall. Soon after design work began, it was decided to build a pair of reactors rather than one. The justification for the reactor was primarily military, but for the first time in Britain, the visions of cheap nuclear power began to have some practical endorsement. The first electricity was fed into the grid in the summer of 1956, only 3½ years after approval for construction was given.

Uranium supplies: the fast reactor

Uranium supplies were never far from the minds of those leading the British atomic energy effort. Nothing was ever stopped because there was insufficient uranium, but each increase in the military programme required by the Government posed new supply problems. One of the advantages of the Calder reactors was that they were more economical in the overall use of uranium for making plutonium for the military programme than were the Windscale reactors. If, as seemed conceivable, the Calder reactor was going to lead to commercial nuclear power stations, the uranium demand would increase much further. Exploration was proceeding vigorously in several countries but the balance of supply and demand might at any moment swing strongly in favour of the producer. Attention began to turn in 1951-52 towards the fast reactor because this system was supreme in its overall economy of natural fuel materials. Cockcroft planned a programme of measurements of nuclear cross sections at Harwell. At his request, enough plutonium was to be borrowed from the military programme to enable Dunworth in 1952 to start designing a small fast reactor zero energy assembly at Harwell called ZEPHYR. Hinton took charge of a design committee at Risley to look at some of the design problems. However, an industrial programme did not start until 1954 when a paper on fast reactors by J. M. Kay, G. R. H. Geoghan and D. R. Poulter had been thoroughly discussed. The outcome was encouraging, and by then it was realized that there would be the Magnox programme of power stations which would in due course have a considerable plutonium production. The Government accepted a recommendation from the newly formed Atomic Energy Authority to build a large experimental fast reactor at Dounreay, and construction began at the end of March 1955. By then, the world resources of uranium began to appear plentiful for a decade or two and the Atomic Energy Authority was placing several advantageous long-term contracts.

The Atomic Energy Authority

Cherwell had never wholly supported the arrangements which placed atomic energy in a government department. Indeed, when Attlee was Prime Minister, Cherwell tried to persuade him that an independent body under broad government control would be more efficient; but after considering an analysis by How of the pros and cons, Attlee ruled in February 1951 that the Ministry of Supply arrangements should continue.

Later that year, with the Conservatives in power, Cherwell renewed his efforts, at first not successfully. However, a small Cabinet committee to examine the matter was set up, and this committee was strongly influenced by the performance expected from the Calder reactors. Radioactive isotopes, although much less important, also promised to have important civil applications. The Cabinet Committee recommended in January 1953 that a small committee should prepare a detailed scheme for the transfer of responsibility to a non-departmental organization and work out the most suitable form for the new organization. The Prime Minister announced in the House of Commons that the Government had appointed a committee consisting of Lord Waverley, Sir Wallace Akers and Sir John Woods to devise a plan for the organization of atomic energy.

Waverley, Akers and Woods visited the atomic energy sites, talked with Cockcroft, Hinton and Penney, discussed the problems with government ministers and officials and consulted the Opposition and some industrialists. They recommended the formation of the Atomic Energy Authority. The drafting of the necessary legislation by How and the parliamentary lawyers closely followed their proposals and became law in the Atomic Energy Act of May 1954.

Cockcroft in the Authority: long-term reactor policy

The Minister made responsible for the Atomic Energy Authority was the Lord President of the Council, who at that time was the Marquess of Salisbury. He appointed Sir Edwin Plowden as Chairman. Cockcroft, Hinton and Penney were appointed as full-time technical members and Sir Donald Perrott became member for finance and administration.

The work-load on the newly formed Atomic Energy Authority was enormous and increasing. While the titles of the full-time technical members were clear, the Member for Research (Cockcroft) and the Member for Engineering and Production (Hinton) did not work solely or even mainly as functional members, with Authority-wide responsibilities matching these titles. Cockcroft remained the Director of Harwell, until B. F. J. Schonland succeeded him in this post in 1958; and Hinton, in addition to his Membership, was also Managing Director of the Industrial Group with Owen as the Deputy Managing Director until 1957. Harwell wanted to do much more than research, but the Industrial Group had created applied research and development teams under L. Rotherham to work with their designers and engineers on their projects. Harwell had undertaken the design and construction of its heavy water experimental and materials test reactor DIDO (commissioned in 1956) and several back-up water facilities, and PLUTO was to follow. Cockcroft created an interest in DIDO in Australia and in Denmark, and in due course copies were built in these countries, and fuel elements were provided and re-processed in Britain.

Harwell was bursting with ideas of possible new thermal reactor systems, some of them using heavy water, but by then a scheme for a dual-purpose plant to make heavy water and generate electricity using geothermal steam in New Zealand had been shown to be uneconomic. A light water pressurized system called LEO, using enriched oxide fuel had been assessed and the early development work done at Harwell on oxide fuel paved the way for important later developments with ceramic fuel. Other thermal neutron systems which were being studied included the sodium-cooled graphite moderated, the homogeneous aqueous, the liquid metal fuelled and the organic moderated and cooled, or organic moderated, and the high temperature converter system, using dispersed fuel. The Authority was already committed to a large development, design and operating programme on fast reactors, centred on the Dounreay site. The situation was getting out of hand, and in 1956 the Authority set up the Committee on the Reactor Programme, chaired by W. Strath, to review the position and make suggestions about concentrating the programme.

Cockcroft considered that it was the duty of the Research Group to study advanced reactor concepts and to test the most promising ideas in small experimental reactors. There was no prospect of building more reactors at Harwell. Dounreay was a possible site, but it was remote and staff was not easily attracted. Cockcroft recommended to the Atomic Energy Authority in 1957 that a new experimental reactor establishment, to be part of the Research Group, should be built in Dorset at Winfrith. The proposal was controversial but Cockcroft's view prevailed. Construction at Winfrith started in 1958, and within a year reactor physicists and engineers began to move from Harwell. A number of zero energy facilities were built, and others were to be moved from Harwell and rebuilt, with improvements.

At about the same time as the proposals for an experimental reactor site at Winfrith were being prepared by Cockcroft, he had begun to favour a high temperature gas-cooled converter system as the natural long-term development in Britain for thermal neutron reactors. In the shorter term, the Industrial Group had made excellent progress with the advanced gas-cooled reactor (AGR) and were preparing to start construction work on a prototype power station at Windscale by late 1958. The Research Group wanted the Authority to build an experimental HTR at Winfrith but the Industrial Group opposed the proposal mainly on the grounds that the Authority did not have sufficient available effort. The proposal was, however, approved when Cockcroft secured international support from O.E.C.D. countries for the collaborative Dragon project at Winfrith (see Section V).

Later on, Cockcroft's plan of Winfrith as an experimental reactor site was endorsed by the siting there of the large zero energy critical facility ZEBRA for work on fast reactor core physics, and by the siting there, in 1962, of the 100 M.W.E. demonstration nuclear power station called the Steam Generating Heavy Water Reactor (SGHW).

Cockcroft accepted the Mastership of Churchill College, and resigned as full-time Member for Research in the Atomic Energy Authority, in 1959. However, he wished to continue spending as much time as possible keeping in touch with developments in the Atomic Energy Authority, and as part of the arrangements which were made, he became a part-time Member of the Authority. He continued as a part-time Member until his seventieth birthday and he took a particular interest in fast reactors, plasma physics and isotopes.

C.T.R.—Harwell and Culham

The period when Cockcroft was Director of Harwell saw the start and growth of thermonuclear research in Britain. Before the Second World War, astrophysicists had postulated that exothermic fusion reactions between the nuclei of light elements were the source of energy radiated by the stars. After the war, speculation began on the possibility of fusion processes as a controlled source of energy. Experiments were started independently at the universities of Liverpool (J. D. Craggs), Imperial College (G. P. Thomson) and Oxford (P. C. Thonemann). All sought to achieve the conditions of high temperature and density necessary for demonstrating thermonuclear fusion by using high-current gaseous discharges. Some results of this early work were published in 1951-52.

The work attracted govenment interest and financial support, with two consequences. To enable greater resources to be brought to bear, the work at Imperial College was moved to the research laboratories of Associated Electrical Industries at Aldermaston, and the work at Oxford was moved to Harwell, where the group was later joined by some of the Liverpool scientists. Second, thermonuclear research was officially classified, because of its possible relation to nuclear weapon development. Research on controlled thermonuclear fission also began at A.W.R.E. Aldermaston in 1952.

The Harwell work grew steadily in scale and effort. The main experimental approach was the pulsed high current toroidal discharge, in which gross instabilities of the current channel were first observed, and later subdued by the application of steady magnetic fields. On the theoretical side, an improved understanding was gained of the properties of the plasma state of matter and the mechanism of plasma instabilities. As a result of this progress, work began in 1955 on the construction of a large (1 metre bore) toroidal apparatus, later called ZETA, in which it was hoped to demonstrate the practicability of thermonuclear fusion.

Not until the United Nations Conference on Atomic Energy at Geneva in 1955, when H. Bhabha, the President of the Conference, predicted that a method would be found for liberating fusion energy in a controlled manner within two decades, did the United States and Britain reveal that they were active in the field. The first scientifically documented statement from the Soviet Union came in April 1956, when I. Kurchatov lectured at Harwell, at Cockcroft's invitation, and gave a full account of work in Moscow on high current linear discharges in deuterium.

The veil of international secrecy was then gradually lifted. Partly through Cockcroft's efforts, full Anglo-American co-operation started in October

1956. Joint conferences were held on both sides of the Atlantic in 1957, and results of neutron production in stabilized pinches were published (19). By the time of the second Geneva Conference, in September 1958, on the Peaceful Uses of Atomic Energy, all security restrictions on C.T.R. had disappeared, apparatus was on view and large open discussions took place without any restrictions.

In July 1957 a C.T.R. Advisory Committee was formed, with Cockcroft as chairman, to guide the British research programme and the committee remained in existence until 1962. During this period the construction of a separate central C.T.R. laboratory, free from security restrictions, was decided upon, where scientists of any nationality could take part in the British programme. The Atomic Energy Authority considered Winfrith as a possible site, but in 1959 decided to have a new and completely open site at Culham.

Radiological protection

The hazards to human health inseparable from the development of nuclear energy, and its military potential for mass destruction, were matters of great concern to Cockcroft. As soon as he was appointed in 1944 to Montreal, he arranged that some leading British specialists should work in the laboratory on the biological effects of ionizing radiation. They were particulary concerned with the maximum permissible levels of exposure of staff to radiation, especially to neutrons. The same thought was in Cockcroft's mind when he arranged with Sir Edward Mellanby that the Medical Research Council would install a unit working on the biological aspects of radiation adjacent to the Harwell establishment, under J. F. Loutit.

Cockcroft associated himself, along with many other prominent scientists in the atomic energy field, with a body formed in the early months of 1946 called the Atomic Scientists' Association. The Association aimed at the influencing of public opinion and Government in the direction of working towards international agreement on the abolition of atomic weapons under international safeguards. The Association also sought to preserve the freedom of scientists to discuss and pursue researches over the widest possible areas. In November 1946 Cockcroft accepted the invitation of the Council of the Association to become a Vice-President, along with a number of other distinguished scientists including Mott, Blackett, Cherwell, Peierls, Oliphant, Simon, Massey and Thomson. The Association published a monthly newsletter which had a considerable influence on the Atomic Energy Act 1946.

Soon after his appointment as Director of Harwell, Cockcroft commissioned early in 1946 a study of the applications of stable and radioactive isotopes in medicine. This involved a review of the work done in the United States and led to the rapid formulation of plans for the production of these materials at Harwell.

The Medical Research Council, with Mellanby as Secretary, formed a committee under Sir Lionel Whitby on Medical and Biological Applications of Nuclear Physics. The Tolerances Doses Panel in 1949 and the Protection Sub-Committee in 1950 were formed. Cockcroft was a member of all three; some of his Harwell staff were members or sometimes went with Cockcroft to support him at particular meetings, notably Catherine Williams and W. G. Marley.

Cockcroft helped to organize three important tripartite conferences between the United States, Canada and Britain on permissible doses of ionizing radiation at Chalk River, Canada, in 1949; at Buckland House, Berkshire, in 1950; and at Harriman, New York, in 1953. These conferences led to a near standardization of the permissible levels of exposure to radiation and radioactive substances in the atomic energy projects of the three countries, and enabled levels to be set which were very little different from those which obtain today, although there is now a mass of biological data to support them. The Protection Sub-Committee was the forerunner of the Medical Research Council's present Committee on Protection against Ionizing Radiations, which continues to exercise a general oversight on the recommendations of the Council concerning protection against ionizing radiations, and of which Cockcroft was the Chairman at the time of his death.

Cockcroft started at Harwell in 1950 a programme of monitoring for radioactive fallout from nuclear test explosions. He set up the Technical Irradiation Group at the Grove airfield near Wantage to develop the technology and the use of large sources of ^{60}Co from which sprang the processes for sterilizing medical supplies.

Cockcroft was a member of the Medical Research Council Committee on the Hazards to Man of Nuclear and Allied Radiations, chaired by H. Himsworth. This Committee issued two reports (in 1956 and 1960) which were milestones in the evaluation of the hazards to the population as a whole from the increasing uses of ionizing radiations and from radioactive contamination of the environment from nuclear test explosions.

In the later years of his life, Cockcroft was a member of the Nuclear Safety Advisory Committee of the Ministry of Power, a Committee which was responsible for assessing safety factors in the choice of sites for nuclear power stations in this country. Although earlier siting policy had necessarily been extremely cautious, operating experience of nuclear power stations and the accumulation of additional data were enabling the Committee to recommend relaxations.

Section V: International relations in science

Cockcroft believed profoundly in the international brotherhood of man, and throughout his life he worked unceasingly to improve international relationships through contacts between scientists. He loved travelling and there was nothing he enjoyed more than visiting scientific laboratories and hearing about a piece of research from the person at the bench. He was just as attentive to a research student as he was to a senior professor. He must have visited many hundreds of laboratories all over the world, and lectured in most of them. To the end of his life he was travelling and seeing for himself with the same enthusiasm as he had always shown. There is no complete record of the places he visited, but he himself mentioned in the notes he left at the Society, as especially important to him, the visits he made to Kharkov, Leningrad and Moscow in 1932, and to the United States in 1933, with a grant from the Rockefeller Foundation, where in particular he visited E. O. Lawrence in Berkeley.

Anglo-American collaboration in atomic energy

President Truman, Mr Attlee and Mr MacKenzie King, at the end of 1945, agreed in Washington a three-power Declaration on atomic energy. They proposed the creation of a United Nations Atomic Energy Commission, to make specific proposals for controlling atomic energy to ensure its use only for peaceful purposes, and for 'extending between all nations the exchange of basic scientific information for peaceful uses'. The three leaders also reaffirmed their wish for full and effective co-operation between their three countries, through the existing Combined Policy Committee and Combined Development Trust. Nevertheless, differences of view were immediately revealed in the drafting of detailed instructions for future Anglo-American collaboration. These effectively blocked the progress of technical exchange. By the spring of 1946 'it had become practically if not legally impossible for American officers to give fresh authorizations for the exchange of information' (*The New World—a history of the U.S.A.E.C.*, Hewlett & Anderson, p. 493, etc.). Under the MacMahon Act passed in August 1946, 'basic scientific information in specified fields could be freely disseminated: related technical information was to be controlled by a Board of Atomic Information. Dissemination was subject to the proviso that such information was not of value to the national defence.' Cockcroft's visits to the U.S. Atomic Energy establishments had to cease, and were not resumed until April 1947 when he visited Brookhaven.

British relations with the Canadian atomic energy project continued good and much information useful to the British project was derived from work at Chalk River. Cockcroft also maintained a good link with Carroll Wilson, the General Manager of the U.S.A.E.C.

In November 1947, a British Publications and Declassification Committee was formed to co-ordinate aspects of classifying or declassifying British atomic energy information. The work of this Committee resulted in recommendations which were taken to the American-British-Canadian Tripartite Conference on Declassification, a purely scientific body without political representatives. Cockcroft frequently took the chair. The recommendations of the Tripartite Conferences had to be ratified by Governments but were never seriously challenged.

A beginning was made by agreement to lift secrecy restrictions on the research reactors GLEEP and BEPO at Harwell, and the Canadian ZEEP and NRX. In December 1947, further high-level political discussions took place in Washington, this time with Cockcroft present, and in January 1948 an exchange of technical information was agreed in nine specified areas. This was part of a deal to allocate uranium to the United States in a greater proportion than the 50-50 basis then in force. (See *Journals of David E. Lilienthal*, Vol. II, p. 266). As a result of these negotiations, some British technical missions were able to visit the United States, but only a few of the nine areas were in fact activated.

In 1950, the Fuchs case caused a great setback in relations with the United States atomic energy projects, and even the limited collaboration then existing with the United States Atomic Energy Commission was reduced. As soon as investigations into Fuch's conduct began to show alarming possibilities, Cockcroft was warned. He recorded in his personal notes, 'This came as a tremendous shock to me and I had to live with him for the next few months.'

Cockcroft visited the United States in 1951 and was able to tell the U.S. Atomic Energy Commissioners something of the British atomic energy programme. A Washington visit by Churchill and Cherwell later the same year helped to re-open the way to better collaboration, especially as Britain had some exclusive information of its own to offer. By 1953, for a number of reasons, the Americans were prepared to revise the MacMahon Act and exchange information on industrial applications of atomic energy with Britain, Canada and Belgium. There is no doubt that the re-establishing of the flow of information between Britain and the United States had been helped appreciably by Cockcroft's determination to achieve a continuous exchange of scientific information in non-sensitive areas, and by his fostering of permissible working relationships with scientists at the U.S.A.E.C. laboratories.

Commonwealth projects

There had been close ties between Harwell and some of the Commonwealth countries, in the non-classified atomic energy field, from the earliest days when some Australian and New Zealand staff were working at Montreal.

In the late forties some Australian and New Zealand groups worked on GLEEP under an arrangement made through Cockcroft.

By 1952, the Australian and New Zealand staff at Harwell had returned home and Australia was beginning to consider studying nuclear energy for power production in that country. Both Australian and New Zealand scientists leaned heavily on Cockcroft's personal advice: he accepted an invitation to visit them in 1948 and again in 1952.

Geneva conferences on the peaceful uses of atomic energy

President Eisenhower addressed the General Assembly of the United Nations on 8 December 1953, on the atomic dilemma. He stressed the reasons why an acceptable solution to the atomic armaments race must be found. He made constructive proposals. The governments principally involved should make immediately and continue to make from their stockpiles of fissile material, contributions to an International Atomic Energy Agency under the aegis of the United Nations, to be used only for peaceful purposes. The speech was widely acclaimed, and the peaceful uses of atomic energy became a matter of great importance internationally and politically. The Cold War was no longer so cold, and the Soviet Union and the West were looking for means of improving their relationships. The peaceful uses of atomic energy gave a possible forum, having the features for which the political leaders were looking. The technological countries were becoming involved in nuclear programmes for peaceful purposes, and atomic energy seemed likely some day to become vital to the development of the less developed countries. Leading atomic scientists, among them Cockcroft, strongly supported the idea of a United Nations Conference on the Peaceful Uses of Atomic Energy. The Secretary-General of the United Nations, Dag Hammarskjold, was enthusiastic. The Soviet Union and the countries of the West could all make important contributions to an exchange of information, and no one country was going to emerge as having a clear lead over the others. The atomic energy scientists and engineers everywhere would gladly meet together to hear what everybody was doing. Soundings were taken through diplomatic channels and the response was uniformly favourable.

The General Assembly of the United Nations, in December 1954, unanimously resolved that an international technical conference should be held under the auspices of the United Nations on the means of developing the peaceful uses of atomic energy through peaceful co-operation.

The precise date and place were left to the Secretary-General and an Advisory Committee composed of representatives of seven countries to decide. Cockcroft was nominated by the British Government to represent the United Kingdom.

H. J. Bhabha was nominated by the Government of India to represent India. The biographical memoir of Bhabha (*Biog. Mems. R.S.* **13**, p. 35) describes the Conference and Bhabha's part. Cockcroft led the British delegation.

The Conference, held in August 1955, was an unqualified success, and a great deal of information on the civil uses of nuclear power was published for the first time. In a report to *Nature* in September 1955, Cockcroft wrote: 'The Conference has been more successful than we have dared to hope from such a large gathering. It has been a meeting ground for innumerable friends from all parts of the world. It has enabled us to discuss how best we can help other countries, and has done a great deal to re-establish the normal pattern of communication in the scientific world.'

Cockcroft also led the British delegation to the second United Nations Conference on the peaceful uses of atomic energy, held in Geneva in

September 1958. At the end of the conference, he gave a brilliant summary of the proceedings. He did not inject his own opinions, but the way in which he made an integral summary of the main facts and opinions expressed at the conference was a masterly expression of his personal judgement. Reading his summary ten years after it was made, the most promising nuclear systems were correctly assessed. The estimates of the economics of nuclear power have proved sound; but not enough allowance was made for the improvements in the economics of conventional power stations. The fuel cycle summary was well and accurately stated. Fusion was seen to be a long and difficult problem—20 years (i.e. 1978) was the earliest time by which we would know whether an economic fusion power station is practicable. The biological sections of the summary, including isotopes and health and safety have developed almost exactly on the lines predicted.

Geneva: control system on nuclear tests

Another extremely important international conference had started two months earlier, also in the Palais des Nations at Geneva. Between 1954 and 1957, various attempts at formulating disarmament plans had been made by the United States, the Soviet Union and others. One of the major items was the possibility of a ban on nuclear test explosions.

In 1958, the Soviet Union, the United States, the United Kingdom, France and four other countries agreed that an East-West conference of experts should be called on nuclear test control. Dag Hammarskjold made all United Nations facilities at Geneva available, and sent a Deputy Director General to the Conference as an observer. The Soviet side was led by Dr E. Federov and the Western side by Dr J. B. Fisk. Penney led the British team and Cockcroft was the alternate leader. The Conference made great progress in spite of many scientific uncertainties and other difficulties, and after eight weeks of very hard work made a unanimous report. The *bon mot* of the Conference, which everybody enjoyed, was 'let us not get this mixed up with science'. The report was endorsed and accepted by the three powers which at that time possessed atomic weapons, and in due course, the partial test ban treaty was signed in Moscow by the United States, the United Kingdom and the Soviet Union. Many other countries quickly signified their adherence.

Cockcroft and CERN

After the Second World War, Cockcroft wanted to see improved experimental facilities for nuclear physics research becoming available in Britain. At Harwell, under his direction, the first post-war proton accelerator, a 180 MeV synchrocyclotron, was completed in 1949. On the mainland of Europe, at the same time, at a meeting of the European Cultural Conference in Lausanne, the idea of creating a European International Research Institute was first advanced, and nuclear physics was suggested as the most appropriate subject for such an institute. Cockcroft anticipated that the cost of experimental facilities for high energy nuclear physics, particularly the cost of the particle accelerating machines, would soon outstrip the budgets allocated to pure scientific research by the individual countries of Europe, and that only by combining together could these countries afford the next generation of machines. He therefore used his considerable standing as an international scientist to support the notion of a European high energy nuclear physics laboratory. During the period 1949 to 1953, when the shape of the future CERN was evolving, Cockcroft gave active support, and together with B. Lockspeiser quietly pushed the scheme forward both in Britain and on the Continent. He allocated three of his Harwell staff, J. B. Adams, G. K. Goward and M. G. N. Hine, to work part-time on the design of a projected European proton synchrotron, and when, in 1953, the Interim CERN came into existence, he sent them to Geneva to join other European scientists on this project.

The convention of CERN, which established that organization officially, was finally ratified in 1954, and Cockcroft and Lockspeiser became the two British delegates to the CERN Council. During the whole construction period of the CERN laboratory at Meyrin, Geneva, from 1954 to 1960, Cockcroft remained on the CERN Council and a member of the Scientific Policy Committee of CERN: and the solid growth and ultimate success of that organization owes a lot to his guidance and unfailing encouragement. His personal friendship with other European scientific leaders, Amaldi, Bohr, Heisenberg and Perrin, all members of the CERN Council during this period, together with his reputation in the field of nuclear energy, made his influence in CERN's affairs very powerful indeed, and he never failed to use it to the benefit of European science.

European Atomic Energy Society

Meanwhile, in 1954, as a result of informal discussions between Cockcroft and scientists well known to him in several European atomic energy centres, a small society was formed of which he became the first President and Chairman of its Council. This body published no proceedings, but existed to promote exchange between Europeans of ideas in nuclear research and engineering for peaceful purposes.

I.A.E.A.

The International Atomic Energy Agency (the I.A.E.A.) was formed in July 1957 and Vienna was the city chosen for the headquarters. The Agency was authorized by its statutes 'to make provision for materials, services, equipment and facilities to meet the needs of research on, and development and practical applications of, atomic energy for peaceful purposes including the production of electric power, with due consideration for the needs of the under-developed areas of the world'. Cockcroft was a member of the

Scientific Advisory Committee advising the Director-General. This Committee was able to formulate policy on sound scientific lines with the minimum of political controversy.

CENTO

Cockcroft took a leading part in the formation of a CENTO Institute of Nuclear Science, which was opened in Baghdad in March 1957, and trained about 60 Middle East scientists in nuclear techniques; later, the centre was moved to Tehran. Cockcroft was the British representative on the Scientific Council, and made personal visits to some of the centres to see the work they were doing.

Relations with U.S.S.R.

Although there had been some visits to Harwell by scientists and others from Soviet Bloc countries (notably Mr Bulganin and Mr Khrushchev in 1956), return visits by British scientists were not made until Cockcroft visited Poland in 1957, at the invitation of the Polish Academy of Sciences. In 1958 he visited the Soviet Union to see work on plasma physics and controlled thermonuclear reactions. He was able to take the opportunity to meet again his old friend Kapitza. This re-opening of scientific relations with the Soviet Union was to Cockcroft one more step forward in the re-establishment of the world-wide scientific community.

Adviser on science abroad

On many occasions, Cockcroft was called upon to give advice to governments and institutions in member countries of the Commonwealth, and in some of the newly independent nations, on questions of the organization of science, and of research and training in science and technology. He was consulted by Australia, Ghana, India, New Zealand, Pakistan and South Africa. His constant aim was to encourage these countries to play a full part in the work of the international Scientific Unions, and in international conferences. His interest did not end with a visit, for his subsequent correspondence was considerable, and later on he entertained a constant stream of visitors in the Lodge of Churchill College.

*Cockcroft and Pugwash**

Cockcroft at various times made substantial contributions to Pugwash. His advice was sought about the British membership of the Continuing Committee, the body responsible for organizing the conferences and guiding the movement. In 1959 he became a member of the Organizing Committee for the 9th and 10th Conferences, which were held in Cambridge and in London.

* The series of informal international conferences on science and world affairs, initiated by Bertrand Russell. (See J. Rotblat, *Pugwash—the first ten years*, Heinemann, 1967.)

Cockcroft was elected to the new post of President of the Pugwash Conferences on Science and World Affairs, at the large Conference held at Ronneby in September 1967, at which extensive plans for new Pugwash activities were adopted. In undertaking the Presidency, Cockcroft gave expression to his deep concern about the special implications of the progress of science and technology. He gave one of the keynote papers on 'The control of the peaceful uses of atomic energy'. The paper was precise, informative and stimulating, and was used as the basis for the first Pugwash Symposium on this topic, held in London in April 1968. At Ronneby he worked, with obvious enthusiasm, on plans for raising funds and implementing the new programme of Pugwash activities, but his death ten days later abruptly ended these endeavours.

Section VI: Science policy and education

Tizard, at the end of 1946, accepted an offer which effectively made him the top scientist in the Scientific Civil Service. He became the Scientific Adviser to the Ministry of Defence and Chairman of both the Defence Research Policy Committee and of the Advisory Council on Scientific Policy. R. A. Clark's *Tizard* describes Tizard's work in these important jobs. The tremendous strain of the war years, followed by these heavy duties, took their toll, and Tizard began to show the effects of overwork. In 1949, he wrote to the Minister of Defence (Emmanuel Shinwell) suggesting that plans should be made about his successor, and he suggested Cockcroft. Well before the fall of the second post-war Labour government in 1951, it was becoming generally agreed that Cockcroft would succeed Tizard. Cockcroft even went so far as to start negotiations for the lease of a house in Walton Street.

When the Government fell, to be followed by a Conservative administration, Cherwell, as Paymaster-General and Churchill's close personal adviser, changed these plans. A. R. Todd became Chairman of the Advisory Council on Scientific Policy (A.C.S.P.), on a part-time basis, with S. Zuckerman continuing as Deputy Chairman, also on a part-time basis. Cockcroft, then a scientific civil servant in the Ministry of Supply, became the titular chairman of the Defence Research Policy Committee (D.R.P.C.), with F. Brundrett as the deputy. Cockcroft also became Scientific Adviser to the Ministry of Defence, on a part-time basis. These latter arrangements were unsatisfactory in every way. Rapid changes were taking place in defence and atomic energy and even Cockcroft could not carry two such heavy jobs at the same time. Cockcroft held these Defence posts from April 1 1952 to 31 July 1954.

So far as the civil side is concerned, the story is much more satisfactory. Cockcroft replaced Chadwick on the Advisory Council on Scientific Policy when the latter retired in April 1951. He remained a member till 1963, part of the time representing the Atomic Energy Authority and part of the time in his own right as a distinguished scientist, from the Civil Service or from the Universities. He was also a member of the Scientific Manpower Committee during the period when the Committee produced its first estimates of the balance between supply and demand for trained scientists and engineers.

Cockcroft was a valuable member. He did not intervene on all matters, but when he did he made a considerable impact on the outcome of the discussion. Zuckerman recalls that some time in the mid-1950's A.C.S.P. became concerned about the deleterious influence of undue specialization in science in the school sixth forms, and the urge to specialize which was provided by entrance and scholarship examinations in Oxford and Cambridge. The Council was divided in its views, some members regarding the spur provided by the older universities as an essential element in the maintenance and raising of standards. Cockcroft, while recognizing the significance of this influence, nonetheless felt that the raising of standards in the older universities implied an intolerable pressure on sixth forms, and he argued that nationally we lost more through the deterrent effect of high standards of entrance and scholarship examinations than we gained. Hinshelwood, who was on the other side of the fence, asked Cockcroft and Zuckerman when either had last looked at any entrance papers. The answer, not surprisingly, was not for a long time! A few days after this particular meeting, Zuckerman received from Cockcroft a batch of entrance and scholarship papers with a covering letter of a single sentence in his neat, small hand-writing—'I couldn't get in, could you?'

NIRNS: The Rutherford and the Daresbury Laboratories

Cockcroft quickly assembled after the Second World War strong teams of physicists and engineers working at Harwell and Malvern on particle accelerator design and development. Their first task was to equip Harwell with the machines needed for the atomic energy research programme, and by the end of 1949 the 170 MeV synchrocyclotron and the 4 MeV electrostatic generator were operating. Small betatrons, electron synchrotrons and microwave linear electron accelerators were also built. Cockcroft took a personal interest in an important Harwell project which sprang from this work, a powerful pulsed neutron source (Poole & Rae 1960) using photoneutrons from an electron linear accelerator multiplied in a sub-critical fissile assembly, and using beam tubes of various lengths with choppers to get velocity discriminations.

Cockcroft realized that nuclear research could not progress properly in the universities without substantial outside help—and not only financial help, because the necessary accelerators demanded specialized scientific and engineering effort beyond the resources of most universities. The subject was developing rapidly in the United States, and Cockcroft felt that our effort should be improved. The first post-war round of university accelerators was financed by D.S.I.R., but several of the bigger projects benefited greatly from design and development made available by Cockcroft at Harwell and Malvern.

Section V has described the part played by Cockcroft in CERN. Cockcroft was for many years a delegate of the British Government at the Council of CERN as well as Chairman of the Nuclear Physics Sub-Committee of D.S.I.R. He foresaw the need for a national centre at an intermediate level of energy to serve the British universities. Largely on his advice, but with the support of most of the high energy physicists in the country, a decision was taken in 1957 to create the Rutherford High Energy Laboratory adjacent to the Harwell site. The 7 GeV proton synchrotron, Nimrod, was chosen for the laboratory, from designs already prepared by accelerator specialists at Harwell. The initial staff of the new laboratory came from Harwell, and Harwell provided the supporting services. The Atomic Energy Authority acted as the prime contractor during the construction, and the funds were supplied through a separately controlled sub-head of the Authority's Vote. The governing body of the laboratory was established by Royal Charter as the National Institute for Research in Nuclear Science, with Lord Bridges as Chairman, and with strong university representation as well as members drawn from the Authority. In this way the independence of the laboratory, and the interests of universities, were guaranteed, while preserving proper financial control and excellent support through the administrative and technical resources of the Authority, Cockcroft was one of the principals in this ingenious and effective scheme, and served on the Board of the Institute from its foundation until it was absorbed into the Science Research Council in the reorganization of Civil Science in 1965. Throughout this time he was Chairman of the Institute's Physics Committee, which was the main channel of external scientific advice to the Institute and the laboratory and, for example, generated and guided the proposals which led to the foundation of the second national high energy physics laboratory at Daresbury, in 1962. He continued to take a direct interest in the work of these laboratories until his death, by chairing consultative meetings of senior physicists and by frequent visits.

Churchill College

Cockcroft became the first Master of Churchill College in October 1959, but from January 1957 he had been giving help and advice to a group of people whose efforts eventually led to the foundation of the College. The story of how Churchill College came to be founded can certainly be traced back at least to 1950. Only the major events can be mentioned here.*

In March 1950, a number of prominent British industrialists agreed to seek support for the formation of an institute for advanced technological postgraduate training, offering a two- or three-year course for 75 men per year chosen from the British Commonwealth. The necessary finance was

* Most of the information about the events leading to the formation of Churchill College has been provided by Mr A. F. W. Humphrys.

to be provided by industry. An appeal letter to companies was drafted to raise £1·3M of which a third had been promised by four companies. The scheme never came to fruition, though after many vicissitudes, part of what it set out to achieve, and the industrial drive and money behind it, went, as will be seen, into Churchill College at Cambridge eight years later.

In April 1955, Sir Winston Churchill was on holiday in Syracuse after resigning as Prime Minister and handing over to Sir Anthony Eden. With him were Cherwell and Mr John Colville. Cherwell had impressed on Churchill the striking superiority of the efforts which both the U.S.S.R. and the U.S.A. were making to train scientists and had interested him in the advantages of a technological education similar to that provided at the Massachusetts Institute of Technology. Churchill wanted to see a similar institute created in Britain. Churchill asked Colville to consult suitable people on how to achieve this purpose most effectively, and gave him permission to make free use of his name.

As a result of Colville's activities and the support he received, a meeting of prominent industrialists was held at Imperial Chemical House in September 1956 to consider proposals for a £10M scheme, in Sir Winston Churchill's name, to finance the industrialists' 1950 scheme and also pay for Churchill Fellowships. This scheme was considered too nebulous and was turned down. Meanwhile, in the United States, Mr Carl Gilbert, with the knowledge of Colville, was considering whether money could be raised in America to help found an institute of the M.I.T. type at Oxford or Cambridge. The use of Churchill's name would act as a magnet for contributions.

Colville was finding a consensus of opinion among a number of leading Cambridge scientists, including J. R. Baker, Cockcroft, W. R. Hawthorne and Todd for a new Cambridge college where a high proportion of the junior members, both undergraduate and postgraduate, would be scientists or engineers.

Colville went to see Churchill. Churchill agreed with the proposal, although he regretted that his name was not to be associated with an institute nearer in concept to M.I.T. Churchill expressed an initial preference for Oxford, but Cherwell persuaded him that Cambridge would be a better choice.

B. W. Downs, as Vice-Chancellor of Cambridge University, sought and obtained influential support within the University. Cockcroft and Todd, both in the United States in the summer of 1957, discussed the suggestion with the Ford and Rockefeller Foundations and obtained encouraging responses. At a meeting at the Lodge of Trinity College, Cambridge, in November 1957, it was agreed that Lord Adrian, the new Vice-Chancellor, would put the proposal of a new College to the Council of the Senate of the University. The Council duly approved the outline plan in principle and the way was clear for planning in Cambridge and in London. The Shell company agreed to provide, free of all expense, a secretary and the facilities for launching a major appeal to industry.

Agreement was reached that the ratio of students and Fellows in the sciences and the arts was to be 70/30, but there were to be no students or Fellows in medicine or agriculture. There were to be no women, in spite of a plea by Lady Churchill to the contrary. The college was to be large—360 undergraduates, 180 advanced students and about 60 Fellows, including Research Fellows. Rooms in college were to be provided for nearly all students, and most Fellows if the funds for so large a college could be raised. The name suggested for the college was Churchill College. Churchill gave his assent: he was deeply gratified that the college was to be a national memorial to himself, and he considered it an original idea that such a memorial should be built in his lifetime.

Lord Godber persuaded Lord Weeks to assist in consulting leading industrialists as to the feasibility of launching a successful appeal. Complete secrecy was maintained and the appeal was launched in May 1958. The response was generous. The Trustees formed an Executive Committee, an Educational Committee, a Building Sub-Committee, and an Appeal Committee. The University passed the necessary Grace to bless the conception of Churchill College.

Churchill requested that the Mastership should be made a Crown appointment, but it was agreed by the Trustees that the first appointment should be made by Churchill personally.

Cockcroft accepted the Mastership of Churchill College in the summer of 1959, and he took up residence in October. No better person could have been chosen to develop the idea of a new college of this kind. His contacts with the people on both sides of the Atlantic who administered the Ford and Rockefeller Foundations, and his own connexion with the Wolfson Foundation were of the utmost importance to the college. Not less important was his vision of Churchill as a college which should be a centre of new ideas in scientific education, and which, through its contacts with scientists throughout the world, would add a new dimension to scientific research at Cambridge. Here again his wide interests were of the utmost importance to the College, and to the University. He travelled extensively during the first few years of his Mastership, and also occupied in that period the position of Chancellor of the Australian National University. Scientists from all parts of the world were frequently to be found dining at the college on his right hand in Hall. At the same time, he did not neglect the problems of scientific and mathematical education at home, and was always ready to serve on committees or attend conferences of dons and schoolmasters who were concerned with modernizing syllabuses and teaching methods. During these early years of the life of the college, his own activities illustrated and helped to carry out the function which he saw the college might perform. It is a mark of his quality that so much of his early vision was in fact realized.

In August 1966, the University of Cambridge constituted Churchill College a full College of the University, signifying that the financial provision was adequate and that the Governing Body had full control of the funds. However, Cockcroft arranged that one of the original purposes in the minds of those who worked to create Churchill College should be preserved. An advisory committee, composed mainly of leading industrialists, advised the Master and the College. One of the first matters to be discussed and agreed, was that a number of Industrial Fellow Commoners, from industry and the trade unions, should be appointed to stay at the College for a time and work in the University.

The University of Manchester Institute of Science and Technology

Cockcroft expressed great pleasure and a genuine sense of honour when the Institute where he first graduated invited him in 1961 to succeed Lord Chandos as President. The functions of the President are mainly honorific, but he had always maintained a lively interest in the affairs of the Institute, and as President he visited the Institute several times each year, talked to the students and staff, and gave helpful advice on current problems.

The Council of the University of Manchester Institute of Science and Technology, at its meeting of 26 September 1967, recorded its deep sense of loss on the death of the President, Sir John Cockcroft, and offered its sincere condolences to Lady Cockcroft and her family. In the Minutes of Council recording the death, it said, 'He brought to this, our highest office, an unostentatious dignity, informed authority and the warmth of his personal charm. His detailed knowledge of affairs and events in the Institute was sustained not alone by periodical briefings but by a systematic and careful reading of minutes and documents which came into his hands, with the result that his senior officers found him ever prepared for consultation and advice. The Institute gratefully recognizes in him one of its greatest sons.'

The Australian National University

Among Australian universities, only the Australian National University appoints a distinguished visitor as its head. Cockcroft succeeded Lord Bruce as Chancellor in 1961. He had visited Canberra and was already an honorary graduate of the University. With Lady Cockcroft he spent some weeks each year in the University. The University showed a warm interest in the foundation of Churchill College and sent wood to be fashioned into a refectory table for its Hall.

The Pro-Chancellor, Dr H. C. Coombs (now Chancellor), Governor of the Reserve Bank, writes:

'I remember Cockcroft, in his farewell lecture as Chancellor of the Australian National University, stressing his profound belief that international collaboration is the life-blood of science: and I am sure it was the practical expression which the University gave to that belief which attracted him to it. In 1952, he had opened and given his name to the main building of the Research School of Physical Sciences; and he found in that School, and elsewhere in the University as it developed, that same mingling of staff and students from all parts of the world which, later, found further expression in Churchill College. This was the flavour of Cockcroft's Chancellorship: there was an essential sympathy between his own belief in international collaboration and the ethos of the University he served for four years.'

The many friends he made in the University were looking forward to a further visit early in 1968. His contributions to its work and its growth, while in England as well as in Australia, had earned their lasting gratitude.

We have received substantial help in preparing this Notice. In particular we acknowledge our indebtedness to Lady Cockcroft, Mrs L. H. Arnold, Miss G. M. C. Dixon, Miss J. M. Pye, Dr J. B. Adams, Dr T. E. Allibone, Dr E. G. Bowen, Rev. J. S. Boys Smith, Sir James Chadwick, Mr J. R. Colville, Professor P. I. Dee, Dr J. V. Dunworth, Mr M. Fishenden, Lord Hinton of Bankside, Mr A. F. W. Humphrys, Dr J. M. Hutcheon, Mr J. F. Jackson, Dr W. B. Lewis, Dr A. McLean, Dr C. J. Mackenzie, Dr K. McQuillen, Dr W. G. Marley, Mr J. S. Morrison, Mr J. Oriel, Sir Leonard Owen, Mr M. W. Perrin, Dr T. G. Pickavance, Professor J. Rotblat, Professor R. Spence, Dr P. C. Thonemann, Lord Todd, Dr F. A. Vick, Professor E. T. S. Walton, Sir Solly Zuckerman; and the United Kingdom Atomic Energy Authority. The photograph is by Tita Binz of Mannheim.

M. L. E. Oliphant
Penney

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