

UNITED KINGDOM
ATOMIC ENERGY
AUTHORITY

THIRD
ANNUAL REPORT

1956—57



LONDON
HER MAJESTY'S STATIONERY OFFICE

THREE SHILLINGS NET

UNITED KINGDOM
ATOMIC ENERGY AUTHORITY

THIRD
ANNUAL REPORT

For the Period
1st April 1956—31st March 1957

*Presented to Parliament in pursuance of Section 3 (5)
of the Atomic Energy Authority Act, 1954*

*Ordered by The House of Commons to be Printed
23rd July 1957*

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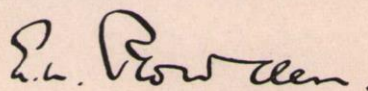
United Kingdom Atomic Energy Authority,
St. Giles Court,
London, W.C.2.
12th June, 1957.

SIR,

I have the honour to submit, in accordance with Section 3 (5) of the Atomic Energy Authority Act, 1954, the third Annual Report of the United Kingdom Atomic Energy Authority. This Report covers the period from 1st April, 1956, to 31st March, 1957.

I have the honour to be, Sir,

Your obedient Servant,



Chairman.

The Rt. Hon. Harold Macmillan, M.P.,
Prime Minister and First Lord of the Treasury,
10, Downing Street,
S.W.1.

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UNITED KINGDOM ATOMIC ENERGY AUTHORITY

THIRD ANNUAL REPORT

1956—1957

CHAPTER I

INTRODUCTION

1. During the year 1956-57, there were several major developments in the United Kingdom's nuclear power programme, and increased attention was given to the application of nuclear energy to marine propulsion. On the defence side, two weapon trials were held, and preparations were made for the Christmas Island tests to be made in 1957. Important steps were taken towards ensuring the United Kingdom's future uranium supplies both for defence and civil uses.

2. In the international sphere, the principal activities were of a multi-lateral rather than a bilateral nature. The Statute of the International Atomic Energy Agency was signed by the representatives of seventy-two countries on 26th October, 1956; the Organisation for European Economic Co-operation continued to study possibilities of joint European effort in the nuclear field; while the "Messina" Group of countries concluded the drafting of the "Euratom" Treaty.

3. The practical achievement of nuclear power was celebrated by the opening of the Calder Hall station by Her Majesty the Queen on 17th October, 1956. A few days earlier, tenders had been submitted to the Central Electricity Authority and the South of Scotland Electricity Board, and in December contracts were placed for the erection of the first two English nuclear power stations. Provisional arrangements were also announced for the construction of the first Scottish station and a possible third English one. On 5th March, 1957, the Minister of Power announced the revised nuclear power programme, under which the amount of nuclear capacity to be in operation by the end of 1965 is to be raised from the "White Paper" bracket of 1,500-2,000 MW to 5,000-6,000 MW. A fifth industrial team (Atomic Power Constructors Limited) was formed during the year.

4. Plans were developed, in collaboration with the Admiralty, for the building at Dounreay of the land-based prototype of a reactor for submarine propulsion. The design of this prototype is being prepared by the Vickers-Rolls Royce-Foster Wheeler group (see paras. 94 and 95); the Authority are assisting with the provision of basic nuclear data, and also in the development of fuel elements. In his speech on the naval estimates on 5th March, the Parliamentary Secretary to the Admiralty announced the formation of a Committee to study the application of nuclear energy to marine propulsion. Representatives of the Authority are members of this Committee.

5. Public interest in nuclear energy was again demonstrated by the large number of visits to the Authority's establishments. There were 3,757 visitors to Harwell in the course of the year, of whom 429 were from the Commonwealth and 665 from foreign countries. Excluding the opening ceremony, 1,069 people visited Calder Hall during the same period, of whom 151 were from the Commonwealth and 193 from foreign countries.

6. The Authority were honoured to receive Her Majesty the Queen and His Royal Highness Prince Philip, Duke of Edinburgh, at Harwell on 1st March, 1957. Other distinguished visitors to Harwell were H.R.H. Princess Margaret on 11th April, 1956; H.M. King Feisal II of Iraq; Marshal N. A. Bulganin, Chairman of the Council of Ministers of the U.S.S.R.; Hamid El Hag Chouderi, Pakistan Foreign Minister; Herr Walter Stain, Bavarian Minister of Labour and Social Welfare; Mr. N. S. Khrushchev, First Secretary of the Communist Party of the Soviet Union; Academician A. V. Topchiev, General Scientific Secretary of the Praesidium of the Academy of Sciences of the U.S.S.R. and Academician I. V. Kurchatov. Sixty-eight Peers and M.P's. visited the Establishment on 30th May, 1956. Distinguished visitors to Calder Hall included Herr Balke, the Federal German Minister for Atomic Affairs; the Rt. Hon. Aubrey Jones, M.P., Minister of Fuel and Power; the High Commissioners for Canada, Australia, New Zealand, Rhodesia and Nyasaland, and Pakistan; the "Three Wise Men" of Euratom, M. Louis Armand, Dr. Franz Etzel and Professor Francesco Giordani; Academician I. V. Kurchatov; and ten members of the House of Lords and House of Commons.

7. The Calder Hall opening ceremony on 17th October, 1956, was attended by guests from thirty-nine nations and press representatives from all parts of the world. In addition to the large number of distinguished guests a crowd of thousands watched the ceremony from the public enclosure.

8. During the year the Nuclear Energy Trades Association Conference was formed by the following five trade associations: the British Chemical Plant Manufacturers' Association, the British Engineers' Association, the British Electrical and Allied Manufacturers' Association, the Scientific Instrument Manufacturers' Association and the Water-Tube Boilermakers' Association. Members subsequently admitted are: The British Industrial Measuring and Control Apparatus Manufacturers' Association and the Society of British Aircraft Constructors Ltd. The Conference's objectives include the formulation of commercial and export policies, the dissemination of technical information, facilitating the participation of industry in the atomic field, collaboration with overseas countries, and arrangements for publicity.

9. The Financial Secretary to the Treasury announced in the House of Commons on 14th February that a National Institute for Research in Nuclear Science had been constituted under the chairmanship of Lord Bridges. The Governing Board of fifteen includes three representatives of the Authority—Sir John Cockcroft, Sir Donald Perrott and Dr. Schonland.

CHAPTER II

MEMBERSHIP, FINANCE AND ACCOUNTS

Authority Membership

10. The appointment of Sir Luke Fawcett as a part-time Member of the Authority was renewed by the Lord President of the Council for one year from 1st August, 1956. The Members of the Authority are listed in Appendix I.

Finance

11. The estimate of the Authority's expenditure in 1956-57 was presented to Parliament on 15th February, 1956, and was approved for the net sum of £68,242,000. Further expenditure of £3,735,000 was also approved by Parliament as a Supplementary Estimate on 21st March, 1957. The additional

funds were needed largely to meet increases in wages and salaries as a result of national wages awards and the application to the Authority's staff of the findings of the Royal Commission on the Civil Service. Other factors were increases in loans for uranium production, in expenditure on stores and research and development contracts, and in prices and costs generally. Against the gross additional requirement of £4,120,000 there were additional receipts of £385,000.

12. The actual cash expenditure for the financial year 1956-57 will be included in the Appropriation Account of the Atomic Energy Office. This account, after examination by the Comptroller and Auditor General, will be presented to Parliament and published.

13. On 19th February, 1957, an Estimate of the Authority's expenditure in 1957-58 was presented to Parliament. This showed £98,769,000 as the net sum required, an increase of nearly £27,000,000 over expenditure in 1956-57. Constructional work accounts for over £20,000,000 of this increase, and a general expansion in the Authority's staff and activities for the balance.

Accounts

14. The Authority maintain records adequate to meet the requirements of Parliamentary accounting; and, in addition, a commercial system of accounting is maintained to provide information for management and to enable accounts to be prepared in the commercial form directed by the Treasury under Section 4 (3) of the Atomic Energy Authority Act, 1954. Commercial accounting is now in operation in all groups of the Authority. The transitional problems in connection with the change-over from government department to statutory authority have largely been overcome. The Authority recognise that in compiling the statement of assets and liabilities taken over on 1st August, 1954, some degree of estimating was necessary in dealing with the valuation of buildings, plant, equipment, etc., which had been acquired by H.M. Government over a period of many years; and the possibility of errors of duplication or omission, not insignificant in themselves but small in relation to the total figures, cannot be precluded. Final confirmation of the figures must be achieved over a period during which adjustments of a marginal nature may be necessary.

15. A Balance Sheet as at 31st March, 1956, was submitted to the Comptroller and Auditor General and will in due course be presented to Parliament* (the Operating Account is withheld from publication in the interests of national security). The Accounts included, for the first time as a separate item, the Principal Non-Industrial Superannuation Scheme. This is a contributory scheme, the employee contributing 6 per cent and the Authority 8 per cent of salaries. The scheme is regarded as notionally funded by H.M. Exchequer, and apart from a small amount in respect of fully paid insurance policies, the funds are treated as deposited with H.M. Exchequer at interest. Provision was made in the Authority's 1955-56 accounts for an amount of £250,000 towards the deficiency which may be disclosed by the first actuarial valuation of the scheme at 31st March, 1960.

* Ordered by the House of Commons to be printed on 10th May, 1957, and now on sale at Her Majesty's Stationery Office (price 6d.). The Balance Sheet, together with the Authority's foreword, is reproduced at Appendix III.

CHAPTER III

RAW MATERIALS

16. Responsibility for the procurement of uranium and other special materials for the nuclear power programme lies with the Atomic Energy Authority.

17. The requirements of such a programme, taken together with the United Kingdom's military requirements and what is known of the civil demands of other countries, would, a few years ago, have seemed impossible to satisfy. That this is no longer so can be more readily understood in view of the withdrawal, on 12th December, 1956, as a result of the Tripartite Declassification Conference (see paragraph 212), of the ban on publication of figures showing the production, grades and reserves of uranium subsequent to 30th June, 1955. Within a few weeks of the declassification of this information the U.S.A., Canada and South Africa had published comprehensive figures under all these heads. These, together with the figures recently published by France, showed that total free world production of uranium at the end of the year under review was about 13,000 short tons per annum of U_3O_8 . This figure does not cover the, as yet, unpublished production in Australia, the Belgian Congo and Portugal.

18. The rate of production of uranium oxide in the free world has increased many times in the past decade and is expected to be about 40,000 tons per annum by 1959.

19. The Authority's requirements are assured for some years ahead. Nevertheless, more uranium from more mines will be required to feed the programme in the later 1960's. Indeed, it is clear that demand for uranium will increase throughout the 1960's. The advent of more advanced types of reactor in the 1970's, leading to increased burn-up and the introduction of thorium into the fuel cycle, should enable the nuclear power programme to be expanded without a proportional increase in the need for virgin uranium, but it is essential that vigorous prospecting should continue. Consequently, the Authority decided that they should play a greater part in stimulating prospecting in suitable areas by giving both long-term production guarantees and specific technical assistance.

20. On 27th March, 1957, an understanding was concluded between the Authority and the Federal and Territorial Governments of the Federation of Rhodesia and Nyasaland under which the Authority undertook that they would be willing to buy in the Federation chemical concentrates containing 500 short tons of uranium oxide per annum. Contracts will be offered covering a ten-year period from the coming into production of a mine, provided that the end date of the period does not extend beyond 1972. The Authority gave the Federal Government an assurance that the prices to be offered for such concentrates will be reasonable in the light of world conditions at the time, having regard to the principles on which prices for uranium have been negotiated elsewhere. In addition to the above offer to buy concentrates the Authority expect shortly to publish the terms on which they will buy uranium ores up to an annual total of 100 tons of contained uranium oxide. This offer will be framed to meet the needs of small producers and will remain open for a period of seven years. The Authority have also offered to the Federation, free of charge, geological assistance in the search for uranium. The Federal and Territorial Governments, in return, have given to the Authority a first option on any exportable supplies of uranium.

21. Arrangements were in hand, as the year ended, for a similar type of guarantee by the Authority to buy chemical concentrates, containing up to 500 short tons per annum of uranium oxide, from existing or future mines in certain of the Colonial and Dependent Territories. As with the Federation, this offer will be open until 1972.

22. The Authority's office at Salisbury, Southern Rhodesia, continued to give advice and assistance to prospectors throughout the Federation. Arrangements were made to open a similar office at Dodoma in Tanganyika to serve Kenya, Uganda and Tanganyika. Reconnaissance surveys were undertaken during the year of the promising Buller Gorge occurrence in New Zealand and of parts of Swaziland. Towards the end of the period, reconnaissance work was undertaken in West Africa and British Guiana on the Authority's behalf.

23. Where the volume of prospecting for radioactive minerals, undertaken by individuals or mining companies, is inadequate, the Authority intend from time to time, by agreement with the Governments or other authorities concerned, to undertake prospecting work; they will not, however, enter into any mining operations on their own account. Two experimental airborne surveys were undertaken during 1956, one in Northern and one in Southern Rhodesia. These surveys provided encouraging evidence of the efficacy of the latest types of electromagnetic apparatus and Harwell scintillation counters. During the year manufacturers of electronic equipment produced an improved form of ratemeter which will assist the prospector on foot. These ratemeters weigh only about three pounds and conform to a specification laid down by the Electronics Division at Harwell; they work on torch batteries, which have a long life in the field. The Authority are in course of providing to the Colonial Geological Surveys, on extended free loan, one of these instruments for every geologist in the field. Two specially adapted instruments were provided for the British Antarctic Expedition.

Existing Contracts—Combined Development Agency

24. No supplies from new sources have been received during the year. The material arriving at Springfields still consists of concentrates from the Belgian Congo, South Africa, Rum Jungle and Radium Hill. The new contract with Union Minière du Haut-Katanga for the supply of uranium ore and concentrates from the Shinkolobwe mine, the negotiation of which was referred to in the Second Annual Report (para. 22 (b)), was signed on 10th September, 1956. During the year four more South African mines came into production. The Authority entered into a loan agreement with one additional gold/uranium producer. This brought the total number of such agreements to 28. During the year the Combined Development Agency opened an office in Sydney, Australia.

U.K. Contracts

25. Canada

An announcement was made of the arrangement whereby the Authority will purchase, during the next five years, uranium to the value of about \$115m. from the Canadian Government Agency (Eldorado Mining and Refining Co., Ltd.), which in turn has entered into purchase contracts with Canadian mining companies. Supplies from Canada to meet the Authority's needs after 1962 were under negotiation at the end of the period. The co-operation of the United States Atomic Energy Commission, which has options on certain Canadian output, has been of great assistance to the Authority.

Australia

Progress in bringing the Mary Kathleen mine to production has continued. Prospects in the South Alligator Region of the Northern Territory have not developed as was hoped.

Central African Federation

Production of uranium commenced at the treatment plant at the Nkana mine. This small plant will be used in connection with the Authority's offer to buy parcels of ore from small producers in the Federation.

Thorium and Beryl

26. The Authority have continued to make small purchases of thorium, and the Salisbury Office has assisted in the evaluation of a deposit of monazite found at Monkey Bay on Lake Nyasa. A consistent demand for thorium for atomic energy purposes is, however, still a number of years ahead. During the year interest in beryl grew because of the likelihood of the use of beryllium as a fuel canning material for the natural uranium, graphite-moderated reactor. Beryl purchases have been increased.

Technical Services

27. The Authority's raw materials procurement programme continues to be supported by the Electronics Division and the Mineral Dressing Laboratory at Harwell, by the Radiochemical Laboratory at Teddington and by the Atomic Energy Division of the Geological Survey. During the year the Authority agreed to a major expansion of the Radiochemical Laboratory; in addition, the Authority have begun to recruit a small geological staff to assist in the prospecting programme.

CHAPTER IV

PROCESSING PLANTS

Uranium Production and Fabrication

28. At Springfields, the increased rate of production of uranium metal to meet the needs of Calder Hall as well as those of the Windscale piles has been maintained, and the requirements of the diffusion plant for uranium hexafluoride have been met. Concentrates from the Radium Hill and Rum Jungle mines in Australia have been received and will shortly be processed.

29. Since mid-1956 the batch ether extraction process for the purification of concentrates and works residues has been replaced by continuous solvent extraction. This plant operated according to flow sheet from the start-up with considerably fewer commissioning problems than are usually encountered on this type of plant, and led to a useful reduction in costs.

30. The use of magnesium in place of calcium as a reducing agent for uranium tetrafluoride was introduced early in the year. Some trouble was experienced initially in producing satisfactory bars from the magnesium-reduced billets, but careful investigation established the reason for this and enabled a considerable improvement to be made. Although cartridges produced from magnesium-reduced metal are proving quite acceptable, a detailed study is being undertaken to establish a complete explanation of the changes in behaviour resulting from the use of magnesium, since they

appear to be due, at least in part, to minor variations in the impurities of the uranium. The use of the new reducing agent has resulted in a substantial economy in this part of the process.

31. In the early part of the period, the major effort in the cartridge manufacturing section was directed to the production of the initial fuel charges for the Calder Hall reactors. Their greater length (40 inches compared with 12 inches for the Windscale rods), and the use of magnesium alloy instead of aluminium for the canning material, introduced a number of problems. After some initial difficulties, however, the output of the plant reached the desired level and the charges were delivered in accordance with the programme. From May, 1956, to February, 1957, only three in approximately 10,000 cartridges developed leaks while in the reactor. This shows that the standard of manufacture and inspection was extremely high.

32. Improvements have been made to the bars for the Windscale cartridges by subjecting the metal to the various heat treatments given to the rods used for the Calder Hall reactors. In addition to providing fuel elements for Calder Hall and Windscale, the supply for BEPO has been maintained and a number of overseas orders have been met.

33. Facilities for manufacturing highly enriched fuel elements for the Authority's high flux research reactors and for the fast breeder reactor are being provided at Dounreay and some plant is already in operation. The first charges of enriched fuel elements for DIDO and LIDO have been made at Harwell (see para. 126).

Production of Fissile Material

34. The extension of the facilities at Capenhurst to provide additional quantities of uranium enriched in the 235 isotope, which was announced in the Second Annual Report (para. 36), has continued during the year.

35. The existing plant has operated well and has met the various requirements for enriched material. Because of the criticality risks involved, the plant for converting the enriched uranium hexafluoride to metal was built at Windscale, as this factory has experience of these problems. This plant has operated reliably and has produced metal in accordance with the programme.

36. The reactors at Windscale, which have now been producing plutonium for over six years, have continued in operation with only minor maintenance. In addition to fulfilling the programmed requirements for plutonium, special radioactive isotopes have been produced in them. Facilities have also been provided for an extensive series of tests. These included trials of the fuel elements for the Calder Hall reactors under the working conditions to which they would be exposed.

37. New decanning facilities have been installed for processing the Calder Hall fuel elements after irradiation. Means for dividing the rods into lengths which can be handled by the charging mechanism of the chemical separation plant have also been provided.

38. The plants for handling the irradiated cartridges have worked satisfactorily and the plutonium production programme has been achieved. The first large sources of caesium-137 have been extracted from the fission product solution which is separated from the uranium and plutonium in the first stage of the primary separation plant. Besides providing highly radioactive sources which have important medical uses, the removal of this long lived isotope is a first step towards reducing the storage facilities required for this extremely radioactive fission product solution.

CHAPTER V

THE AUTHORITY'S CALDER HALL REACTOR PROGRAMME

Calder Hall "A"

39. The first reactor at Calder Hall, on which tests were starting at the beginning of the year under review, was handed over for operation in May, 1956. Charging began on 17th May, and the reactor became divergent on 22nd May. The critical size of the reactor, which is the amount of uranium needed to maintain a chain reaction, was less than had been calculated, thus indicating that the neutron economy would be better than predicted by theory and exponential experiment. Loading was completed early in June and by 2nd August the reactor was producing 10 megawatts of heat.

40. The first turbine was commissioned on 20th August and from then on electricity was generated for domestic consumption at a gradually increasing rate. On 17th October, H.M. the Queen pulled the switch which diverted the electricity from use in the Authority's premises at Calder Hall and Windscale into the Central Electricity Authority's distribution grid. In her speech at the opening ceremony the Queen said: "Today . . . we are present at the making of history . . . Atomic scientists, by a series of brilliant discoveries, have brought us to the threshold of a new age . . . It may well prove to have been among the greatest of our contributions to human welfare that we led the way in demonstrating the peaceful uses of this new source of power. I congratulate all those who have shared in this fine project . . ." For the first time, electricity from a full scale nuclear power station was being delivered to a national distribution system.

41. The fuel elements in the Calder Hall reactors are stacked vertically one on another, six in each channel. This means that the lower the place occupied by a fuel element in the channel, the greater is the load it has to bear. It was realised that this might cause bowing in the lower placed elements, but the risk was accepted in view of the greater simplicity of this arrangement over a system in which each fuel element was separately supported. Moreover, the cooler conditions at the bottom of the reactor would mean that the lowest cartridges were stronger than those nearer the centre, and therefore better able to support the greater load. In fact, tests indicated that the relationship of load and temperature was such that the conditions producing the greatest amount of bowing would be towards the centre of the reactor. About the time when the reactor went into operation, research at Harwell showed that the intense radioactivity in the reactor was likely to increase the amount of bowing. This might lead to difficulty in removing the fuel elements, and a further series of tests was made which confirmed the theory and indicated the size of the effect. Accordingly, the reactor was shut down for a period in November and typical channels were unloaded. The removed fuel elements were examined and the results confirmed the predictions of the tests. The rate at which the bowing would increase had been calculated and this confirmation indicated that the planned irradiation of the first charge could be achieved with safety. This level was reached early in February, 1957, and the reactor was then shut down for re-charging. Between November, 1956, and February, 1957, suitable supports were developed for fitting to each fuel element to prevent excessive bowing, and these have been fitted to the second charge.

42. As stated in the previous chapter, during the period from May, 1956, to February, 1957, only three of the 10,000 cartridges in the reactor developed faults, and these were quickly detected by the equipment provided for this

purpose. The only feature which has proved less satisfactory than was hoped for has been the gas-tightness of the coolant circuit. The leakage of the carbon dioxide has been higher than the estimated figure, but this presents no hazard and does not add materially to the cost of operating the plant. The leakage can be reduced to the anticipated level by ensuring a sufficiently high standard in the engineering details of the later reactors at Calder Hall and Chapelcross.

43. Generally, it can be said that operating experience at Calder Hall has been satisfactory. The plant has gone into operation with less trouble than might reasonably have been expected, and it has worked reliably at the designed conditions of power level and temperature; these have indeed been exceeded with satisfactory results for appreciable periods.

44. The second reactor of Calder Hall "A", programmed six months behind the first, passed its testing period satisfactorily. It was handed over for operation at the end of November, 1956.

45. By 31st March, 1957, Calder "A" had exported 107,825,000 kWh of electricity, almost entirely from the first reactor.

Calder Hall "B" and Chapelcross

46. The additional reactors, two at Calder "B" and four at Chapelcross, for combined plutonium and electricity production, are due to go into operation in 1958 and 1959.

47. The first reactor on the Calder "B" station was structurally complete at the end of the period, and is now being fitted out with the many plant items required. The pressure vessel had been stress relieved and pressure tested, and preparations were in hand for laying the graphite structure. The heat exchangers had all been lifted into position and the tubing and testing of the first one were complete. Tubes were being installed in Nos. 2 and 3. The installation of equipment such as blowers was going ahead.

48. On the second reactor the octagonal biological shield, with its steel lining, was complete and installation of the pressure vessel sections had started. The structural steelwork of the blower houses and control building, which is built on to the main shield, will shortly be completed. All four heat exchangers had been fabricated and awaited lifting on to their stools.

49. The turbine hall structure was complete, including the foundation blocks for the turbo-alternators. Installation of the condensers had started. The first of the turbo-alternators was almost ready to be moved into place.

50. The first of the two new cooling towers was externally complete, while the shell of the second had reached a height of about 100 feet. Progress on the various ancillary buildings was in accordance with the programme.

51. At Chapelcross the past year has seen a great advance in the construction of the station. In April, 1956, only foundation work had been done; by April, 1957, the biological and thermal shields of the first reactor had been completed, together with the heat exchanger bases. The biological shield of the second reactor was almost complete. The lifting of pressure vessel sections into the first reactor had started and the remaining sections were in course of fabrication. The first heat exchanger was ready for lifting into position.

52. Good progress was made on the welding of the pressure vessel sections and the fabrication of the heat exchangers for the second reactor. The third and fourth reactors are programmed to follow at a later date, and the concrete foundations were being laid.

53. In the turbine hall the first two turbo-alternator bases were completed, the first cooling tower shell was constructed to the 120 foot level and work had begun on the ponds and foundations for the second. The office and stores buildings made good progress. The work in general kept pace with the programme.

CHAPTER VI

THE NUCLEAR POWER PROGRAMME

The White Paper Programme

54. Calder Hall and Chapelcross are dual-purpose nuclear power stations designed for the production of plutonium for the military programme as well as for the generation of electricity; they are owned and operated by the Atomic Energy Authority. The White Paper "A Programme of Nuclear Power",* published in February, 1955, outlined a provisional programme for the construction for the electricity authorities of nuclear power stations designed primarily for the generation of electricity, though they would also produce by-product plutonium. This plutonium will not be of the same quality as that produced for military purposes, but could be used in more advanced types of power reactors. The White Paper suggested that, if all went well, nuclear generating capacity owned and operated by the electricity authorities might by 1965 total some 1,500 to 2,000 MW in 12 nuclear stations.

Technical Progress

55. Since the publication of the White Paper technical progress in some directions has been more rapid than was expected. This has made possible a much bigger size of station than was foreseen two years ago.

56. Tenders for the first two nuclear power stations to be built for the Central Electricity Authority at Berkeley, Gloucestershire, and at Bradwell, Essex, were received by them in October and contracts were awarded in December. The Berkeley station, which will have an output capacity of 275 MW, will be built by the A.E.I./John Thompson Nuclear Energy Co. Ltd.; the Bradwell station will be built by the Nuclear Power Plant Co. Ltd., and will have an output capacity of 300 MW. Provided the Minister of Power gives his consent, the C.E.A. also plan to build a third nuclear power station at Hinkley Point, Somerset. They are negotiating with the English Electric/Babcock and Wilcox/Taylor Woodrow group for the construction of this station. The South of Scotland Electricity Board are seeking the consent of the Secretary of State for Scotland to the construction of a 300-320 MW nuclear power station at Hunterston in Ayrshire; this station is to be built by the G.E.C./Simon-Carves Atomic Energy group. These stations are all much bigger than the 100-150 MW capacities for the early nuclear power stations envisaged in the White Paper.

57. The principal technical innovation which has made possible this increase in output has been the development of techniques for welding thick steel plate. At Calder Hall, the pressure vessel containing the reactor is made of 2" steel plate; the first nuclear stations to be built for the electricity authorities will have pressure shells of 3" steel plate. This will permit an increase both in the size of the reactor and in operating pressures and temperatures. Numerous other improvements to the designs have been made. It will, for instance, be possible to charge and discharge fuel elements under load without having to shut down, as is necessary at Calder Hall.

* Cmd. 9389.

The Revised Programme

58. Towards the end of 1956 a detailed re-examination of the nuclear power programme was made by the Ministry of Fuel and Power in collaboration with the Central Electricity Authority, the South of Scotland Electricity Board, the Atomic Energy Authority and the Government departments concerned. The review showed that technical developments had made possible a substantial improvement on the original White Paper programme and that a total output capacity of up to 6,000 MW might be achieved by the end of 1965. In the light of the general fuel situation the need for a greatly expanded nuclear power programme was accepted by Her Majesty's Government. On 5th March the Minister of Power, Lord Mills, announced that nuclear power stations with a total of between 5,000 and 6,000 MW output capacity would be in operation by the end of 1965. In a full year's operation, 6,000 MW of nuclear generating capacity, which would amount to some 15 per cent. of total capacity, would, when operating at high load factor, save about 18 million tons of coal. Thus nuclear power stations would be generating about a quarter of the total U.K. output of electricity.

59. On the same day on which the Minister of Power gave details of the revised programme, the Northern Ireland Government announced that the Electricity Board for Northern Ireland would commission a 150 MW nuclear power station in 1963 or 1964.

Capital Costs

60. The 1955 White Paper estimated expenditure on the 1,500-2,000 MW nuclear power programme at about £300 million. This figure included £60-£70 million for expenditure by the Atomic Energy Authority on ancillary plant and prototype development. As stated in the recent White Paper "Capital Investment in the Coal, Gas and Electricity Industries",* the capital cost of the 6,000 MW programme is estimated at £742 million for nuclear power stations with a further £177 million for initial fuel charges. The Atomic Energy Authority's capital expenditure is not expected to be very different from the 1955 estimate.

61. The total capital investment of the electricity authorities in the ten years up to and including 1965-66 as a result of embarking on a nuclear power programme on the scale proposed will be about £750 million more than if all generating capacity to be installed or to be put in hand were conventional plant. However, since the technology is new, it is to be expected that the capital cost per kW of nuclear power will fall rapidly and progressively; there are in fact already prospects that future nuclear stations will have significantly lower capital costs per kW than those for which contracts already have been placed or shortly are to be placed by the electricity authorities. Moreover, there should eventually be some offsetting saving of investment resources by the coal and oil industries; this is because the capital investment that, in the absence of a big nuclear programme, would have been incurred in making available additional supplies of these fuels, should not now be needed.

Electricity Costs

62. As stated above, capital costs per kilowatt of nuclear generating capacity, particularly for the early stations, will be high. Fuel costs will, however, be much lower than for conventional stations. The cost per unit of electricity generated in the early nuclear stations (when used for base

* Cmnd. 132.

load) is expected to be only slightly higher than the cost of electricity generated in the most advanced conventional plant that could have been commissioned at about the same time, assuming present coal and oil prices. The cost of power from the later nuclear stations will fall and should soon be fully competitive with that from conventional plant.

The Role of the Atomic Energy Authority

63. Though the nuclear power stations designed primarily for the generation of electricity will be owned and operated by the electricity authorities, the Atomic Energy Authority have a four-fold interest in their construction.

64. In the first place the Authority are carrying out an extensive programme of research and development into nuclear power. This programme, reviewed in detail in Chapters VII and VIII, embraces the more advanced stations that will be built in later stages of the programme and also work on nuclear physics data. In particular it involves the development of fuel elements that will be of immediate relevance to the early stages of the nuclear power programme.

65. Secondly, the Authority are acting as technical advisers to the electricity authorities for the nuclear side of the new power stations. The Industrial Group of the Authority have set up a separate organisation for this service.

66. Thirdly, as stated in Chapter III (para. 16), the Authority are responsible for procuring adequate supplies of the special materials—primarily uranium and graphite—needed for the nuclear stations. As stated by Lord Mills when announcing the revised nuclear power programme, the 5,000 MW—6,000 MW programme is flexible and the exact size will depend on technological development, the trend of capital costs, and the availability of physical and financial resources. The Authority are, however, making arrangements for the supply of sufficient uranium for 6,000 MW of nuclear capacity by 1965; and steps have been taken to ensure that manufacturing capacity for graphite will be sufficient to meet the requirements of the expanded programme.

67. Fourthly, the Authority will process the uranium concentrate and fabricate it into fuel elements for sale to the electricity authorities. They also will buy back from the electricity authorities the irradiated fuel elements for separation of the plutonium.

68. The prices charged for the fuel elements will be calculated on a commercial basis. The price paid for the irradiated fuel elements will be calculated with reference both to the estimated value of plutonium as a fissile material for use in advanced reactors and to the cost of processing the irradiated fuel.

After 1965

69. The revised programme announced by the Minister of Power does not look beyond 1965. However, in the light of this increased programme up to 1965 it is reasonable to expect that the total nuclear capacity in commission by 1975 should be larger than the 10,000 to 15,000 MW indicated in the 1955 White Paper.* Much will depend on the success achieved by the Atomic Energy Authority and industry in their development programmes in reducing capital costs per kW; this is of first importance for the reason that since capital costs of the early nuclear stations will be high, they will be economic only if they are operated at a high load factor. ("Load factor" in this sense is a measure of the actual use made of a power station.) But the

* Cmd. 9389.

demand on the electricity supply system, and hence the load factor, is such that only a limited number of power stations are able to work at full capacity throughout the year. This means that, for the stations with lower load factors, overheads (including capital charges) must be spread over a smaller number of units generated. Thus nuclear stations will be at a disadvantage compared with conventional plant when operated at low load factor, unless the capital cost per kW of nuclear stations can be reduced to a level approaching that for conventional plant. The higher the proportion of total generating capacity accounted for by nuclear plant, the greater becomes the importance of achieving a substantial reduction in capital costs.

CHAPTER VII

THE REACTOR RESEARCH PROGRAMME

70. The primary objective of the Authority's Reactor Research and Development Programme is the development of reactors offering the prospect of producing the cheapest power possible for this country's nuclear power programme. In addition to this, the Authority are investigating reactor systems suitable for ship propulsion and for power generation in smaller power stations particularly suited to meet export demands.

71. In Chapter VI (para. 72) of the Authority's Second Annual Report, reference was made to "the three successive stages of the country's nuclear power programme". The reactor research programme of the Authority has been under constant review, and in the light of developments within the past year the concept of three successive stages has been abandoned in favour of the concept of a more flexible pattern of development.

72. The gas-cooled, graphite-moderated system, which has been adopted for the country's first commercial power station, continues to show even greater potentialities than at first thought. It follows from this that the choice of the next system to be developed to the prototype stage for use in large land-based power stations must be made on the basis of standards more exacting than it was previously thought would be appropriate. As indicated below, work on the investigation of the sodium-graphite system is still continuing, and the Authority are not yet in a position to determine whether the system has sufficient advantages over the gas-cooled system to justify the construction of a prototype reactor.

73. Some of the more advanced systems previously listed under Stage Three show greater potentialities for early development than others. Of the types referred to in the Second Annual Report as Stage Three systems, work is continuing on all four, though at different rates. A decision has been taken to build a high-temperature zero-energy critical assembly and good progress continues to be made on the experimental fast reactor at Dounreay. The homogeneous aqueous and liquid-metal-fuelled systems will probably require much more research and development work before they are suitable for incorporation in a nuclear power programme. As indicated below, work on these systems is being devoted mainly to an examination of the technological problems involved.

74. The Authority are assisting in the development of the pressurised water reactor for submarine propulsion. They are also examining possible systems for surface ship propulsion, reference to some of which was made in last year's Report. These systems include the organic-liquid-moderated

reactor, a scaled-down version of the gas-cooled, graphite-moderated reactor, and a heavy-water, gas-cooled reactor.

75. This chapter summarises the work being done on the various systems to which reference has been made above. Chapter VIII explains in more detail the research and development work that is being done in connection with the development of these reactor systems.

The gas-cooled, graphite-moderated reactor

76. The gas-cooled, graphite-moderated reactor is likely to provide the basis of the United Kingdom nuclear power programme for many years to come. The Authority believe that there are considerable possibilities for further development of this type of reactor which should lead to a substantial lowering of capital costs. For this reason they continue to give high priority to study of the technological problems involved.

77. One objective is to increase the operating temperature of the fuel elements from 400°C. to about 600°C. This would allow the efficiency of conversion of heat to electricity to be increased, and the electrical output of a two-reactor station to be raised from its present level of 300 megawatts to about 800 megawatts. This increase of temperature would call for ceramic fuel elements in place of the present metallic elements, and for a canning material capable of withstanding the high temperatures. Uranium oxide ceramic fuels and beryllium canning are being developed for these purposes. Samples of these fuels will be irradiated in the materials testing reactors of the Authority.

78. The reaction between carbon dioxide and graphite at the higher temperatures and under conditions of intense radiation is also being examined, as this may be a limiting factor to the temperatures attainable.

79. A joint programme of research with industry on the reactor physics problems of more advanced forms of this reactor has been arranged. This will include a study of the consequences of using ceramic fuels and of changing the geometrical form of the fuel elements to achieve higher heat ratings.

80. The good neutron economy of the gas-cooled reactor has indicated that it should be feasible to redesign the reactor to make it suitable for smaller outputs of the order of 30 megawatts of electricity; the reactor size (even using natural uranium) and capital cost would be appreciably less than Calder Hall. A feasibility study of this is being carried out.

The sodium-cooled, graphite-moderated reactor system

81. The Authority are studying a graphite-moderated reactor cooled with liquid sodium as a possible successor to the gas-cooled reactor. The use of liquid sodium would allow the amount of heat extracted per ton of uranium to be increased several times over the gas-cooled reactors now being built for the Central Electricity Authority, though the advantage over later gas-cooled reactors would be less. A zero energy reactor, NERO, has been constructed to study the physics of advanced graphite-moderated reactors. This will provide information on the sodium-cooled reactor as well as on gas-cooled systems.

82. Hot liquid sodium attacks graphite, so the two must be separated by a metal of low neutron absorption such as zirconium. The compatibility of hot liquid sodium with zirconium and other metals of the reactor is being studied in test rigs. Experiments have shown that it is essential to keep the oxygen content of the sodium down to a few parts per million.

83. The fuel costs of this reactor are likely to be appreciably higher than those of gas-cooled reactors, as some enrichment will be needed. Engineering studies are being carried out to determine how far the capital costs can be reduced compared with the gas-cooled system. It will then be possible to decide whether the economic advantages over the improved gas-cooled reactor are sufficient to make the sodium-cooled reactor worth developing.

The Fast Breeder Reactor

84. Good progress has been made on the design and construction of the Dounreay fast breeder reactor, which is expected to start operation in 1958. The zero energy reactor ZEUS at Harwell has been used to study the neutron physics of various core designs.

85. The Dounreay reactor is essentially a reactor experiment. It will be used to get experience of operation of a fast reactor, and to try out various types of fuel element. The Authority expect to carry out experiments with the Dounreay reactor for some years before proceeding to the design of a prototype. The programme could lead to construction of commercial fast reactors during the 1970's when substantial supplies of plutonium fuel are likely to be available from the civil power programme.

The High-Temperature, Gas-Cooled Reactor

86. High priority is being given to the development of a thermal breeder reactor working on the uranium-233/thorium cycle* and using a ceramic uncanned fuel able to withstand temperatures of the order of 800°C. The fissile and fertile materials and a moderator are to be combined in a semi-homogeneous system; the heat developed will be transferred by high pressure gas. The system offers promise of high ratings, high thermodynamic efficiencies, and low fuel costs.

87. A high-temperature zero-energy critical assembly is to be built for the purpose of examining the physics of this and similar high temperature systems and it is hoped that it will be possible to construct a reactor experiment to come into operation in 1960. In the meantime development and testing of fuel elements are proceeding in loops† in the BEPO and DIDO reactors and preliminary results are encouraging.

88. If successful, different forms of the reactor might be used for large and medium power stations and for ship propulsion.

The Homogeneous Aqueous Reactor System

89. This reactor system also aims at achieving breeding by using the uranium-233/thorium fuel cycle. In the form studied to date the uranium-233 fuel would be used as uranyl sulphate dissolved in heavy water. This solution is contained in a zirconium core vessel which is surrounded by a "blanket" containing a slurry of thorium. The heat developed is removed by circulating the hot core and blanket fluids. Fission gases and some other fission products are removed continuously, thus improving neutron economy and safety.

90. Up to a point, the reactor system can be considered as a combination of a reactor and a chemical plant, and the problems which arise are essentially concerned with the chemical engineering design of the plant, and with the materials of construction. The circulating core fluid is highly corrosive and highly radioactive so that corrosion may lead to damage to the plant,

* In this system fissile uranium-233 is burnt in the core and some of the neutrons released are captured in thorium to produce further supplies of uranium-233 by nuclear transmutation.

† Materials and components for reactors are tested under conditions simulating those expected in operation, in special independent circuits called loops which are exposed to the neutron flux within the reactor.

while any leakage of the core fluid would be dangerous and repair work very difficult. Irradiation effects within the core itself accentuate these difficulties. Special care in the design of plant items which would ordinarily be regarded as conventional in chemical engineering must be exercised.

91. The Authority will concentrate their effort on the technological problems of the system; zero energy studies are proceeding, using an approach-to-critical experiment known as ZETR.

Liquid-Metal-Fuelled Reactor Systems

92. Liquid-metal fuels may be used in thermal breeder systems operating on the uranium-233/thorium fuel cycle and may also have possible applications in advanced fast fission systems based on the plutonium/uranium-238 cycle. In its most interesting form the thermal system consists of a core of uranium-233 fuel dissolved in liquid bismuth; this is surrounded by a blanket containing a thorium slurry. The system has the advantage over the aqueous homogeneous reactor that it would operate at a lower system pressure and at higher temperatures, but it has problems of its own.

93. The most important of these are concerned with the compatibility of the liquid metals with the components of the reactor, and with the chemical processing of the liquid fuel. Loops are being constructed to study corrosion and mass transfer. For some time to come the Authority's work will be concentrated on the technology of various forms of the system, one of which is being given high priority in its application to the fast breeder reactor.

Ship Propulsion

94. The development of a pressurised-water reactor for the propulsion of submarines is, by agreement with the Authority, being undertaken by the Admiralty, who have placed development contracts with Vickers Nuclear Engineering Ltd. As stated in the Second Annual Report (para. 173) this company brings together Vickers Ltd., Rolls Royce Ltd. and Foster Wheeler Ltd.

95. The Authority are collaborating in certain aspects of the work. They are responsible for the physics of the system, for the development and fabrication of fuel elements, for corrosion studies, and for provision of facilities for the testing of components and the study of shielding problems. The reactor requires the development of a technology quite different from that of the gas-cooled reactor. A zero energy assembly for the study of the physics of the core is being built by industry and will be installed at Harwell by July, 1957. Several loops (each a complex and costly experimental facility) have been built for the study of corrosion and heat transfer problems. The LIDO swimming-pool reactor is being used for studies of shielding. The prototype naval reactor will be built at Dounreay.

96. The reactor will use enriched uranium fuel elements in a non-corroding alloy and good progress has been made with their development.

97. As already mentioned (para. 4) the Authority are represented on an Admiralty Committee for the study of the use of reactors for the propulsion of merchant ships. The problem here is to reduce the cost of nuclear propulsion to a level comparable with conventional costs using oil fuel. Present oil fuel costs are about 0.5 pence per shaft horsepower hour. Nuclear fuel costs well below this will be achieved in the large output graphite-moderated, gas-cooled stations of the electricity authorities. These have the advantage of using natural uranium as a fuel, which is comparatively cheap, but it is not yet clear whether the system they employ can be economically competitive when scaled down for ship use.

98. It may well turn out that the problem of marine propulsion divides itself into two separate fields. The large ship which spends most of its time at sea, such as a tanker, might be powered by a scaled-down version of the Calder Hall type of reactor; this would involve comparatively little development effort and offers the greatest chance of being competitive in the near future. For smaller ships it will probably be necessary to develop a new type of reactor and two systems are being studied with this object. The first is an organic-liquid-moderated reactor which might be built in small sizes to give outputs of the order of 20,000 shaft horsepower or less. It has the advantage over the water-moderated reactor of having a lower system pressure and few if any corrosion problems. Like the pressurised-water reactor, however, it calls for enriched fuel. On the other hand the organic liquid becomes less radioactive when irradiated than water, and so the shielding of the external heat exchanger circuit can be reduced or even eliminated.

99. The stability of a number of organic liquids under irradiation is being studied with a Van de Graaff generator and in loops. The liquids form polymers at a low rate but these may not prove an embarrassment, since they can be removed continuously and the cost of replacing the organic liquid is not likely to be high.

100. A heavy-water, gas-cooled reactor is the second possibility for ship propulsion. It would have the advantage of using a fuel of lower enrichment than the organic-liquid reactor, and the technology of fuel elements and heat removal would be similar to that already developed for large power reactors. A study of this system is being made.

101. The Authority will decide during the present year which of these reactor studies should have priority for the ship application. The next step would be to build reactor experiments or small power units to test the first systems selected.

Nuclear Power Units of Medium Output

102. It seems probable that a large part of the export demand for nuclear power would be for units of 30 MW or less. Power units of the type being considered for ship propulsion may prove to be suitable for this role, and the studies being done on them will indicate whether this is so or not. The Authority will also decide during the coming year whether it is necessary and possible to devote effort to the development of an export reactor in addition to that on reactor development for ship propulsion.

CHAPTER VIII

RESEARCH AND DEVELOPMENT

Research and Materials-Testing Reactors

New Reactors

103. During the year three new reactors were commissioned at Harwell. The first was the 100 kW swimming-pool reactor LIDO, which was commissioned in September. Experiments with a mock-up in a small water tank early in the year enabled the reactor to be assembled and run up to design power quickly. The main purpose of this reactor is research into shielding, particularly the development of light-weight shields; it is being used in connection with the naval reactor.

104. The second reactor to be commissioned was DIDO, the high-flux materials-testing reactor cooled and moderated by heavy water. Again design and construction were accelerated by the use of results obtained in zero energy assemblies in DIMPLE. DIDO is a much more complex reactor than LIDO and develops a hundred times as much heat (10 MW instead of 100 kW). For this reason commissioning took longer. The reactor diverged on 7th November and was formally opened by Sir Cyril Hinshelwood, President of the Royal Society, on 21st November, 1956. An important use of DIDO will be to test samples of materials such as moderators, coolants and fuels for other reactors in special loops. These loops have to be exceedingly reliable and, principally for this reason, their design, manufacture, and out-of-pile testing, has proved to be a difficult task. It is unlikely that the larger loops will be operating before the summer of 1957. In order to provide data for predicting the neutron fluxes to which fuel elements will be exposed in loops, mock-ups of both loops and elements have been tested in DIMPLE and the fluxes in them measured.

105. The third reactor was NERO, which went into operation on 23rd February, 1957. This is a zero-energy graphite-moderated reactor which has been built for investigations into the physics of the more advanced types of graphite-moderated reactor now being studied by the Authority. Enriched fuel is used, so the reactor is considerably smaller than any other graphite-moderated reactor at Harwell. It will be possible to simulate a sodium coolant in NERO, and data will be obtainable for both gas-cooled and liquid-metal-cooled reactors.

106. Work proceeded during the year on the two PLUTO materials-testing reactors at Harwell and Dounreay.

Earlier Reactors

107. BEPO, the 6 MW graphite-moderated, air-cooled, veteran reactor at Harwell, continues to be fully utilised for a very wide range of purposes. Besides routine production of radioisotopes and training experiments for Reactor School and other students, over sixty experimental holes are in use. Loops on an engineering scale now operating in the reactor include a replica of a Calder Hall channel, a water-cooled channel operating at medium pressure, and a loop in which an organic liquid moderator is circulated.

108. Experiments with the other Harwell reactors, DIMPLE, ZEPHYR and ZEUS, and with the loops in BEPO, are described elsewhere in this Report. The Authority's reactors, as at 31st March, 1957, are detailed in Appendix IV.

Technology of Some Proposed Reactor Systems

Gas-Cooled, Graphite-Moderated Reactor Systems

109. The Calder Hall loop in BEPO has been used to study the complex reaction between carbon dioxide, graphite and carbon monoxide. The investigations include an examination of the effect upon losses in weight of graphite along the channel of varying the temperature, pressure and other conditions. Some experiments on carbon balance will be made in the higher flux of DIDO.

110. The rating of gas-cooled reactors could be improved by using hydrogen instead of carbon dioxide as coolant. The reaction of hydrogen with graphite and with fuel materials is being studied in BEPO.

111. The Research and Development Branch (R. and D.B.) of the Industrial Group is studying methods for improving fuel elements and reducing the cost of manufacturing them. The manufacture of fuel and canning alloys of higher strength appears to be feasible. Fabricated cans would be cheaper than the present ones, which are machined from extruded stock; one improvement has been the design of a seal which does not require a specially shaped end.

112. In collaboration with industry, R. and D.B. is investigating the development of steels for pressure vessels which will operate at higher temperatures and pressures. Preliminary experiments at Harwell have shown that neutron radiation embrittles some steels at ordinary temperatures; different types of steel are therefore being studied to determine their suitability as structural materials in reactors.

Fast Reactor Systems

113. The zero-energy plutonium-fuelled, fast reactor ZEPHYR has been used to study materials alternative to natural uranium for the blanket or reflector. The materials studied have been thorium (because in it uranium-233 is made), lead (because it may be useful for shielding light-weight reactors), and graphite (because it introduces some slow neutrons into the system).

114. ZEUS, the zero-energy version of the Dounreay reactor, has been used to obtain physical data needed for the final design and operation of the Dounreay reactor. In addition, many nuclear data useful to the design of future fast reactors have been obtained. The core of ZEUS is roughly a 2 ft. right cylinder, and contains about 4 cwt. of uranium-235 and 12 cwt. of uranium-238. This core is surrounded by a blanket of natural uranium weighing 65 tons. Measurements have shown that, for each uranium-235 atom fissioned, more than one uranium-238 atom is converted into plutonium. The breeding ratio is not however as high as that of ZEPHYR.

115. R. and D.B. work has been concerned particularly with fuel elements for the Dounreay reactor. Production line techniques for making enriched uranium billets have been specified. Conditions have been established for alloying uranium with chromium, which improves the creep strength and minimises swelling on thermal cycling, and for casting the alloy into tubes within close dimensional tolerances. Production processes have been established for making tubes from several exotic metals, e.g. starting from metal powder, niobium tubes have been made, and a process has been developed for recycling niobium scrap, a matter of economic importance since the metal is very expensive.

116. R. and D.B. has also brought into operation a plant for separating boron-10 from natural boron. This isotope, which absorbs neutrons of intermediate energies reasonably well, is needed for making control rods for the reactor.

Homogeneous Aqueous Reactor Systems

117. Measurements with zero-energy critical assemblies (called ZETR) with solutions of both fissile isotopes of uranium (uranium-233 and uranium-235) in light water have been completed. Valuable information was obtained in these experiments about the slowing down of neutrons in light water and about the nuclear constants for the uranium isotopes. The study is being extended to solutions in heavy water for which purpose a new apparatus has been built.

118. Chemical work has included investigations into the stability of uranium and plutonium solutions at high temperatures and pressures and

under high radiation flux, and into the behaviour of thorium oxide slurries. The effects of radiation on the corrosion of steel and zirconium have been studied. The R. and D.B., Industrial Group, has designed a separator for removing gas from the circulating fuel, and has studied fuel flow in several possible arrangements of the core.

General Reactor Technology

Fuel and Fuel-Element Technology

119. The trend in development of fuel elements for advanced reactors has been towards ceramic, rather than metallic, elements because the evidence now available indicates that ceramics may be more suitable for high temperature operation. Thus uranium dioxide has been irradiated in the Chalk River reactor in conditions that resulted in the temperature at the centre of the fuel exceeding $2,000^{\circ}\text{C}$; nevertheless the material kept its size and shape well. This fuel could be used in either gas-cooled or liquid-cooled reactors. A technique for manufacturing uranium dioxide, cheaper than the conventional one, has been developed which produces high-density specimens to accurate dimensions in a single operation.

120. Ceramics generally have the disadvantages that their resistance to sudden temperature changes and their heat conductivity are both low. These disadvantages are reduced in cermet, i.e. dispersions of ceramic materials in a metal matrix. Cermets studied have included uranium dioxide in aluminium and in steel.

121. The techniques for canning fuel elements in beryllium have been refined and consolidated. A number of beryllium-canned fuel elements have been fabricated and tested out-of-pile, and some are now undergoing in-pile tests.

122. From a long-term point of view plutonium is an important fuel because it will be produced in quantities by the first nuclear power stations. But this element is also an awkward material partly because of its metallurgical behaviour and partly because it is exceedingly toxic. For the first of these reasons, coupled with the high heat rating to be expected from pure fissile material, it is probably impracticable to use pure plutonium in metallic form as a fuel; therefore work has been concentrated on investigating the alloying properties of this element and developing techniques for fabricating plutonium-bearing metallic and ceramic fuels. Whilst much remains to be done, sufficient is already known for a variety of possible fuels to be designed.

123. Studies of the fundamental properties of plutonium, its alloys and ceramic compounds, have been extended and it is proving possible to interpret these results theoretically with more confidence.

124. Liquid-metal fuels containing uranium have been studied in connection with the liquid-metal-fuelled reactor. These fuels may be in the form of solutions (e.g. uranium in bismuth or lead) or slurries (i.e. suspensions of dense solid particles in a less dense fluid). The solid particles in a slurry tend to separate from the liquid with the result that the pipe in which the slurry is circulating may become plugged. Methods for preventing this effect, including the use of ultrasonic vibrations, have been investigated with encouraging results.

125. Another difficulty associated with liquid-metal fuels arises from the fact that most of the component elements in steel (iron, chromium, and especially nickel) dissolve in bismuth and lead; this leads to a transfer of steel in the containing vessel from the hotter to the cooler parts of the system. The factors controlling this process have been established and

techniques for reducing it examined. Alternatives to steel have been investigated ; most of them are difficult to fabricate.

126. Improved processes have been developed for fabricating "conventional" fuel elements. These elements consist of a rod or plate of fuel material enclosed in a metal can, an apparently simple structure which is in fact complicated to design and manufacture, especially when the use of enriched fuel makes it essential to avoid waste of expensive material during manufacture and to simplify the chemical processing of used fuel. The aluminium-clad fuel plates used in DIDO are typical in their use of enriched uranium and the manufacturing processes used at Harwell for making these have been greatly improved. Charges of an earlier, Mark I, design were made at Harwell for LIDO and DIDO and also for the Indian swimming-pool reactor. Charges of Mark II elements have been made for DIDO and for Associated Electrical Industries Limited's research reactor Merlin.

Moderator Materials

127. Research on special grades of graphite for future reactors is being done at Harwell. An experimental plant has been commissioned and used to make specimens of about the same size as the graphite blocks used in industrial reactors. Methods of increasing the density and decreasing the permeability of graphite are being studied.

128. Research into methods of manufacturing heavy water has been concentrated on the hydrogen-distillation and the dual-temperature chemical-exchange processes. In the first of these, hydrogen gas is cooled to its liquefaction temperature of -253°C and then distilled in a column, when the heavy hydrogen (deuterium) is separated from the light. An engineering design study of the process has been undertaken in collaboration with a firm of consultants and experimental work done on the development of reversing heat exchangers. A closed cycle form of the process is also being developed in which the stripped (light) hydrogen from the distillation unit is brought into contact with natural water, from which it picks up more deuterium by chemical exchange ; this enriched hydrogen is then fed through the separation process.

129. A theoretical design study of the dual-temperature chemical exchange process between sulphuretted hydrogen gas and water is nearing completion, and a new method of heat recovery has been developed which makes the process more attractive for operation in this country. A new form of the exchange process between liquid ammonia and hydrogen is also being studied.

Other Reactor Materials

130. Zirconium is of interest for canning fuel elements, but it suffers from the disadvantage that its creep strength is low. Several alloy additions capable of increasing creep resistance have been found which are acceptable on nuclear and other grounds. Techniques for fabricating and welding these alloys are being developed.

131. Some of the neutron-absorbing materials used in reactor control rods form helium when they absorb neutrons. It has become apparent that the accumulation of this gas in the material may have an effect similar to, and as serious as, the corresponding effect in fuel elements of accumulating fission-product gases. The problem is particularly acute in high-flux reactors. It has therefore been decided to undertake a general survey of control materials and an experimental investigation of methods for improving them. As one possibility, cermetts of boron carbide and steel have been made and

are being tested. Alternative materials are alloys (including ternary alloys) of silver and cadmium, several of which have been fabricated and tested.

The Effects of Radiation on Materials

132. The effects, often dramatic, of neutron radiation upon the fuel and other materials used in reactors are vitally important to the development of nuclear power, and research into them has for long absorbed a great deal of effort. The increasing interest in more highly rated reactors has necessitated an extension of this research programme, particularly in respect of enriched fuels and fuels irradiated to high burn-up. The work is being undertaken as a joint effort between Harwell and R. and D.B., Industrial Group. Samples are irradiated in the Harwell, Windscale, and Calder Hall reactors and also, with the co-operation of Atomic Energy of Canada Limited in the NRX reactor at Chalk River. After irradiation, these highly radioactive samples are manipulated in various ways and precise measurements are made on them. Development and construction of the facilities necessary for these post-irradiation examinations are demanding a major effort.

133. Work on the chemical analysis of irradiated samples has shown that the chemical behaviour of many fission products is conditioned by the fact that they are formed as daughter products of the rare gases. This observation has led to the development of new techniques for studying the evolution of fission products in fuel elements.

Chemical Processing of Fuel Elements

134. Fuel elements removed from a reactor have to be treated chemically to separate neutron-absorbing fission products and secondary fissile material from unburnt fuel. This chemical processing forms an important element in the cost of nuclear power.

135. Solvent extraction processes are used at present for treating fuel elements from the Windscale and Calder Hall reactors and similar processes will be used for the fuel elements from the first Central Electricity Authority reactors. Plant requirements for these have been studied by a joint working party from Harwell and R. and D.B., and flow-sheets proposed; although the plant has been conceived as primarily for uranium fuels, the possibility that later reactors might be spiked with plutonium* has been borne in mind.

136. In aqueous processes such as the foregoing, the fuel is treated in solution and must be converted to metal before it can be used. Processing costs might be reduced if the fuel could be kept in metallic form throughout. This might be done by high-temperature methods, e.g. by melting the spent fuel and removing fission products as slags. A project, known as Hotspur, for studying these methods has been set up at Harwell. A special laboratory suite has been designed and built in which uranium and plutonium at activities up to 1,000 curies can be melted and treated entirely by remote control. The work has included the study of related techniques and materials. Assessments of the economics of the process have been made.

137. The Hotspur programme is supported by a study of methods for fabricating extracted fissile material, which will be radioactive, into fuel elements.

Physics Data for Reactors

138. Although many of the basic nuclear data needed for thermal reactors have been determined, the shift in the emphasis of current studies to highly irradiated fuel elements has shown that, in this field, the information available

* A plutonium-spiked reactor is one which contains plutonium-bearing fuel elements separate from the uranium fuel elements.

is by no means adequate. To fill the gaps, experimental measurements are being made supported by full use of recent advances in nuclear theory. Valuable international co-operation in nuclear data measurements has been established during the year with Canada and the U.S.A. through the Tripartite Nuclear Cross-section Committee. A successful conference was held at Harwell during the summer of 1956.

139. The best nuclear data are valueless if the neutron spectra (the relative numbers of neutrons having different energies) in reactors are not known. Novel methods have been developed for measuring these spectra, which are often too complex to calculate; these methods have been applied to sodium-cooled, graphite-moderated systems, ordinary water and heavy water assemblies with enriched fuel, and the naval reactor.

140. Reactor designers also need to know, for neutrons of various energies, the scattering law of different moderators, i.e. the probabilities that neutrons will be turned through different angles. As a result of a study at Harwell, the Authority have agreed to collaborate with Canada and the U.S.A. to obtain this information from experiments using the NRX reactor. The extensive calculations needed to apply this information will be made by the Argonne National Laboratory of the U.S. Atomic Energy Commission.

Fundamental Research

141. Although the greater part of Harwell's research is concerned with the technology of reactors and the processes associated with them, about a fifth of the effort has been devoted to work that is usually described as fundamental research, that is research to establish and broaden knowledge about the bases of the sciences from which technology is developed. Sometimes the subjects of this research are not obviously related to technology, and always the choice of which to pursue involves an important element of judgment. The aim in choosing which research to pursue is to ensure that, when new technical problems arise in project development, the fundamental scientific knowledge on which to base a solution is available. If it is not, the problem will have to be tackled by means of ad hoc investigations. This is nearly always a more costly way of obtaining a solution.

142. One field of fundamental research which has been greatly affected by the development of nuclear reactors is the study of the physics of solids. Reactors provide a quite new and complex environment for solids, the effects of which are as important for a fundamental understanding of the properties of solids as for the technology of atomic energy. Studies at Harwell have enabled the behaviour of graphite under neutron irradiation to be deduced from a knowledge of its crystal structure and have led to a successful correlation between neutron-induced damage and changes in the electrical properties of the graphite. Experiments have also been carried out on the growth of graphite under irradiation and the storage of energy which occurs due to the displacement of atoms.

143. Reactors have also made practicable a valuable new technique for solid state studies called neutron diffraction, in which beams of neutrons are used to explore the atomic architecture of solids; this work has ranged from a study of the shapes of molecules in organic chemicals to a search for a fuller understanding of the nature of magnetism in metals and alloys. This reactor-inspired work is backed by general theoretical studies based upon the application of the methods of theoretical chemistry to solids regarded as very large molecules.

144. Metallurgical studies of uranium under irradiation have shown that the metal loses its elasticity and flows like an extremely viscous liquid under

applied stresses. The theory of this so-called "Cottrell effect" has been developed; rates of flow calculated on the basis of the theory agree with experimental observations. Irradiation-induced creep has been observed in fuel elements removed from the first Calder Hall reactor, where steps have been taken to render its effects innocuous.

145. Another group of experiments has been concerned with the microscopic bubbles of rare gases which are formed in several metals, particularly uranium, when they are irradiated at high temperatures. These bubbles cause the metal to swell. It has been possible to measure the gas pressure inside the bubbles by squeezing the metal and measuring the shrinkage of the bubbles. These experiments have a bearing on the practical problem of swelling in fuel and other metals.

146. Neutron irradiation also induces hardening and embrittlement in metals, and experiments indicate that this effect is caused by collisions between fast neutrons and metal atoms, which occur inside the metal crystals and knock the atoms out of position. A detailed investigation is being made to ascertain the movements of these displaced atoms and their effect on the atomic processes of plastic deformation and fracture in metals. With the sensitive techniques recently developed, it is possible to detect this hardening unambiguously after the metal has been only fifteen minutes in BEPO.

147. In nuclear physics a group working on cosmic rays is studying the variation with time (from day to day and month to month) in the occurrence of big showers of cosmic ray particles. The time variation of the showers is connected with the paths taken in the galaxy by the enormously energetic particles from outer space which cause the showers. The cosmic ray work has stimulated interest in the Cherenkov radiation given off when fast charged particles move through a refracting medium. Physicists at Harwell were the first to use this radiation to detect single particles, a method that is now used widely.

148. Some time ago nuclear physicists developed, initially for cosmic ray work, a precision proportional counter, filled with helium-3, which was a great advance in detectors for neutrons in the medium energy range. The counters have more recently been used to study the radiation emitted by mesonic atoms, i.e. atoms in which the electron in the innermost energy level is replaced by a negative π -meson*. The counters have also been used to measure neutron spectra in the reflector of a fast reactor and to study certain energy levels of the uranium-238 nucleus about which surprisingly little was known.

149. Among the important fundamental researches in chemistry carried out in recent years have been studies of practically all the radioactive heavy elements from polonium to curium. The work on polonium is particularly noteworthy and has contributed the major part of present knowledge of this element. Although discovered sixty years ago, polonium is so rare in nature that it had never been isolated in weighable amounts until the advent of the nuclear reactor enabled it to be made by irradiating bismuth. It is a highly radioactive element, and therefore requires safe-handling equipment such as is available only at laboratories like Harwell. Over twenty of the thirty compounds of polonium now known have been prepared and identified at Harwell, and a good deal of its fundamental chemistry has been established. The rather surprising result is that more is now known about the chemistry of polonium than about that of radium, which has been available in gram quantities for more than fifty years.

* A π -meson is one of a group of fundamental particles called mesons, most of which have masses intermediate between those of the electron and the proton. Mesons decay radioactively with very short half-lives.

150. The chemistry of uranium also has engaged much attention; an interesting part of this work has been concerned with the behaviour of uranium dioxide. This compound is non-stoichiometric, that is, its composition can be varied slightly, without changing its crystal structure, by taking up additional oxygen. The amount of this uptake, its variation with temperature, and the mechanism by which it is produced at different temperatures, have all been studied. This is of considerable technological interest. During the past year the instantaneous absorption of oxygen on the surface of uranium oxide at the temperature of liquid air has been studied, and its amount measured and related to uptake at other temperatures.

151. For research on heavy elements, substantial quantities of thorium, uranium, and plutonium have been available for some time, but recently gram quantities of protoactinium, neptunium, and americium have been, or are being, prepared. A specimen of the neptunium has been reduced to the metal. Protoactinium is being obtained from the residues of uranium extraction at Springfield, and neptunium from liquors from the spent-fuel treatment plant at Windscale. Americium is being separated on the laboratory scale from irradiated plutonium. In addition, specimens of the rarer isotopes of thorium, uranium, and plutonium have been prepared, including thorium-230, uranium-236, plutonium-238, and plutonium-242. There has been close collaboration with the U.S.A. in this field (including exchange of staff) and the association has been most beneficial.

152. Developments in the technique of chemical analysis by neutron activation have led to interesting results in pure as well as applied chemistry. This technique has been investigated in other laboratories, especially in America, but the Harwell work has been outstanding. The principle is simple. A sample containing minute traces of an element which it is required to determine, is irradiated with neutrons, usually in a reactor; at the same time a standard containing an accurately known amount of the same element is irradiated. The neutrons activate the element and the amount present is determined by comparing the radioactivity induced in the sample with that induced in the standard. The method is extremely sensitive; for example it has been used, in connection with the manufacture of transistors, to determine an impurity which was present in a semiconductor in concentrations as low as one part in ten thousand million (copper in silicon). Recently the technique has been applied to determine with hitherto unobtainable accuracy, the minute traces of gold that occur in sea-water. These experiments have settled a long-standing scientific controversy by confirming the conclusion of Haber, reached some thirty years ago, that most of the gold is associated with particulate matter. Another recent application has been to the analysis of cosmic spherules, i.e. minute particles believed to come from outer space which are found in deep-sea sediments; using neutron activation it has been possible for the first time to analyze these materials quantitatively for iron, cobalt, nickel and copper.

The production of a controlled thermonuclear reaction

153. Research has continued at Harwell into ways of obtaining power from controlled thermonuclear or fusion reactions. The objective is to heat isotopes of hydrogen to temperatures in the region of $100,000,000^{\circ}\text{C}$. at which the nuclei fuse to form heavier nuclei, releasing energy in the process. The central problems to be solved are those of heating the hydrogen to the required temperature, and of isolating the hot gas from the walls of its container, and maintaining it at temperature long enough for the heat energy released in fusion to exceed that needed to heat the fuel.

154. In one method being studied, a very large current is passed through a tenuous gas; the current heats the gas and at the same time generates a magnetic field which constricts the hot gas into a narrow channel so that it does not touch the walls of the containing tube. The fundamental properties of a discharge of this kind have been studied in toroidal tubes of various sizes. Measurements have been made of the temperatures of both ions and electrons in different parts of the discharge using several different methods, including spectroscopy and centimetre radio waves; with both methods, temperatures of several hundred thousand degrees have been recorded in the hot gases. The magnetic field of the discharge, and the nature of the radiation emitted, have also been studied. Considerable advances have been made in understanding the mechanism of the discharge.

155. Theory and experiment have both shown that the current channel in these discharges is unstable, so that the hot gas wriggles about the axis of the discharge tube, striking the walls from time to time. These instabilities are similar to turbulence in a gas or liquid. As a result of them, the gas is cooled on striking the tube walls and some vaporisation of the walls leads to contamination of the hot gas by atoms of the material of the walls. On the other hand the violent motion of the gas actually assists in raising its temperature. A promising method of controlling instabilities is the use of magnetic fields generated by external conductors. These magnetic fields are trapped by the highly conducting gas and eliminate some modes of instability. The detrimental effects of these instabilities form the major barrier to the successful production of a fusion reactor and are consequently being studied extensively.

156. A major piece of experimental apparatus for investigating discharges on a much larger scale has been designed and built in collaboration with an industrial firm. Construction is almost complete. It is hoped with this equipment to reach temperatures at which fusion reactions can be detected.

157. During the year collaboration on research into controlled thermonuclear reactions was established with the United States under the agreement for co-operation on the civil uses of atomic energy between the governments of the U.K. and the U.S.A. Several visits have been exchanged by parties of scientists from the two countries and the resulting interchange of ideas has been mutually beneficial.

Particle Accelerators

158. It is well known that research in nuclear physics requires machines capable of accelerating charged particles over a very wide range of energies, from a few hundred keV to thousands of MeV. One valuable machine at Harwell is the 4 MV electrostatic generator. To extend the programme of research on nuclear structure for which this machine is used, a new generator is being developed in collaboration with the Weapons Group, who are to have a similar machine, and with an industrial firm, to give particles of energies up to 12 MeV. The increase in energy is obtained by using two 6 MeV electrostatic generators in tandem; particles are accelerated as negative ions in the first half of the machine and then, having had some electrons stripped from them in their passage through a common high voltage terminal, as positive ions in the second half. In this way a total energy of 12 MeV is achieved without generating a voltage higher than 6 MV.

159. A larger machine whose construction is well advanced is the 50 MeV proton linear accelerator. The first stage, which will accelerate protons to

10 MeV, is almost complete ; the later stages are being manufactured by an industrial firm and should be finished by the end of 1957. A programme of nuclear research, using the proton beams which will be produced by the accelerator, is being prepared.

160. This 50 MeV machine is the pilot section of a larger, 600 MeV, accelerator which was studied in detail some three years ago (see First Annual Report, para. 102). As the design study neared completion it became apparent that, by the time it could be operating, this 600 MeV machine would not mark a sufficient advance over other machines for its construction to be justified. Attention was therefore shifted to a new type of proton synchrotron for an energy of 6,000-7,000 MeV (6-7 GeV) with an intensity in the beam considerably greater than that of existing machines. This design is now well advanced. Protons will be accelerated to 15 MeV in an improved linear accelerator, whose design will be based on experience with the 50 MeV machine already mentioned, and injected for the main part of the acceleration into a magnet ring 120 ft. in diameter which will weigh 6,000 tons. Design of the magnet and special buildings with heavy shielding has reached the stage at which tenders can be sought when approval to proceed is given. If it is decided to build it, this machine will be one of the main tools of the National Institute for Research in Nuclear Science.

Second Establishment for the Research Group

161. As stated in the Second Annual Report (para. 13), Harwell has almost reached the maximum size that is compatible with efficiency of management and with the resources of the surrounding countryside ; nevertheless the needs of research and development continue to grow.

162. The Authority consequently decided to set up another major research establishment to which new research projects could be directed, and to this end well over 70 possible sites throughout England and Wales were examined. After carefully considering all the factors involved, which included amenity values and effects upon local economy as well as water supplies and disposal of effluents, the choice fell upon a site at Winfrith Heath, in the county of Dorset. Following many months of technical investigations to establish in detail the suitability of the site, and of negotiations with the Dorset County Council and other statutory bodies, the County Council approved the proposal by 71 votes to 16 in November, 1956. Subsequently, a public enquiry into the proposal was held at the direction of the Minister of Housing and Local Government. After considering the evidence of the enquiry, the Minister finally gave planning permission in February, 1957, subject to conditions regarding approval by the County Planning Authority of the layout of the site and of individual buildings, and regarding provision of screens of trees.

163. The Authority's choice of this site was influenced by the fact that the land possessed no agricultural value and did not appear to be subject to common rights. Investigation, however, has brought to light the fact that certain commonable rights appear at one time to have been exercised, and although there is little evidence that these rights have been exercised during recent years it is necessary that steps should be taken to extinguish them before development can take place. At the end of the year under review, the necessary procedure was being set in motion.*

* The Government presented the Winfrith Heath Bill in the House of Commons on 21st May, 1957.

CHAPTER IX

ISOTOPES AND IRRADIATION PROGRAMMES

164. Sales of radioisotopes continued to increase during the year. The total value of sales was about £541,000, of which £154,000 was from the Isotope Division at Harwell, and £387,000 from the Radiochemical Centre at Amersham. The total represents an increase of 12 per cent. over the preceding year. The proportion exported was 56 per cent. Exports went to 52 countries, among the principal buyers being Canada, France, Germany, Japan, the U.S.A. and Sweden. An exhibition of isotopes from the Radiochemical Centre was staged at the International Congress of Radiology held in Mexico City in July, 1956. New catalogues were published during the year by both Harwell and Amersham.

Production of Radioisotopes

165. There will be a substantial increase in the quantity of radioisotopes produced by irradiation in nuclear reactors when the new high flux reactors DIDO and PLUTO are brought into use for isotope production. Fission product caesium-137 is being separated in an experimental plant at Windscale and several large sources have been made; in addition a certain amount of strontium-90 has been produced. The demand for these sources far out-runs present production capacity and the Authority are therefore considering the design and construction of a plant to separate very much larger quantities of caesium-137 and strontium-90.

166. The demand for certain minor isotopes made in a cyclotron, particularly sodium-22, continues to exceed the supply notwithstanding the help given to the Authority by the University of Birmingham in allowing their cyclotron to be used for this purpose.

167. Special irradiations in BEPO continue to increase. Of particular interest is the use of sintered yttrium oxide grains for medical purposes. The number of antimony-beryllium neutron sources manufactured for training centres has increased also.

Large Sources of Radiation

168. Two sources of 1,200 curies of caesium-137 have been made for teletherapy work. One of these is already in use at the Royal Marsden hospital. Cobalt-60 for industrial and medical uses has been sent in quantities of 100-500 curies to fourteen countries, including Japan and Australia. A number of hospitals and universities have been equipped with cobalt-60 sources; 5,700 curies were specially capsuled for the Wantage Radiation Laboratory.

Technical Irradiation Development

169. The Grove Airfield site, which is now known as the Wantage Radiation Laboratory, has been occupied in part by the Technological Irradiation Group. In one hangar two large concrete shields have been built to contain 10,000 curie sources of cobalt-60 and the first of these has been loaded with 4,500 curies. Another eight smaller shields have been built to accommodate sources of 2,000 curies each and four sources of about 200 curies have been fitted. A 4 MeV linear accelerator has also been installed. Close collaboration with industry is maintained, and eight firms have seconded staff to work at the Laboratory.

170. Radiation introduces a new variable in chemical reactions, widening the choice of temperature and pressure required to produce a reaction;

novel products can consequently be prepared. Chemical reactions are being studied under various conditions of radiation to explore the possibilities opened up by this new situation.

171. Radiation can be used to sterilize biological material with the advantage that no heating is required. Experiments have been made on heat-sensitive materials, including drugs, bones and arteries used for surgical transplants, and a range of food products. There is also a small programme of research on radiation effects on plant genetics and the control of insect pests. All of this work is being done in collaboration with the many Government research bodies concerned in the different fields.

New Applications of Specific Isotopes

172. Many new applications of specific isotopes continue to be evolved. Some representative ones are cited here.

173. The radioisotope iodine-131 is widely used for clinical investigations and diagnosis, but for some purposes its half-life is unnecessarily long and a shorter-lived iodine isotope is desirable. A suitable alternative is iodine-132, but its half-life of 2.26 hours is too short to permit transport to any distance from the production centre. This difficulty is overcome by using the fact that this isotope is a daughter of the much longer lived (77 hours) tellurium-132. A service has been started during the year by which tellurium is separated from fission products, purified, and supplied as telluric acid solution; a simple distillation procedure has been devised by which a hospital can obtain iodine-132 from this solution over a period of at least a week from the date of despatch.

174. The movements of pebbles on beaches and under coastal waters have been traced using natural pebbles in which holes have been drilled and filled with resin pellets "labelled" with barium-140 and lanthanum-140; movement of pebbles after putting them into the sea is traced by portable detectors. This method of labelling is somewhat tedious and methods for impregnating the surfaces of pebbles with other isotopes (including silver-110 and gold-198) have been developed. In a field trial using 2,000 pebbles labelled on the surface in this way, six per cent. of the pebbles were recovered after 2 days and another three per cent. after three weeks (during which time some of the pebbles had moved a mile). At least ten times more pebbles were recovered by this method than is possible when painted pebbles are recovered by visual means, and the method opens new possibilities in studies of coastal erosion and build-up. This work has been done in conjunction with the Nature Conservancy.

175. A cheap method has been developed for continuously determining sulphur and lead contaminants in liquid hydrocarbons in oil processing. In this method, measurement of the absorption of bremsstrahlung* (from standard preparations of radioactive tritium on zirconium foils) by the contaminants gives an indication of the amount of contamination. This method is cheaper than, and at least as sensitive as, more orthodox methods using absorption of X-rays.

176. Radioisotopes have been used as tracers to measure the material throughput rates, hold-up, and recirculation in cement and fertiliser plants; analysis of charts from recording meters showed recirculation percentage

* Bremsstrahlung (braking radiation) are secondary X-rays given off when fast charged particles are slowed down by the electrostatic forces exerted on them by atoms. In the experiment referred to beta particles emitted by tritium are slowed down by zirconium atoms.

and period as well as the rate of movement and spread of the added material. Other industrial applications have included a self-adjusting gauge (using a thulium-170 source) to indicate continuously the liquid level in enclosed pipes, and a compact gauge to be used in a borehole for underground measurements of soil density over a wide range. Similar applications to these have also been made elsewhere.

Labelled Compounds and Natural Radioisotopes

177. The demand for labelled compounds was nearly 50 per cent greater than in the preceding year; this increase reflected the steadily growing appreciation of the value of these materials as tools in research, particularly in the biological sciences. Among the more important are compounds containing carbon-14, of which some 170 are now available. Research has been directed towards improving the specific activity and radiochemical purity of the materials and a point has been reached at which further improvement is limited by the decomposition of materials under the influence of their own radiation.

178. Notwithstanding the great variety and quantity of artificially produced radioisotopes, interest in natural isotopes, especially of derivatives of uranium and thorium, continues. These materials are however difficult to handle and the processes and equipment to deal with them at the Radiochemical Centre are being redesigned and rebuilt to bring the standard of protection into line with current practice. This reorganisation will take several years but during the current year a start was made by re-equipping a laboratory manufacturing radium appliances.

Electromagnetically-Enriched Isotopes

179. There is a small but important demand from research institutions for stable isotopes separated from the elements in which they occur naturally, in the electromagnetic separator at Harwell. With this machine the isotopes of about 50 of the polyisotopic elements below bismuth have been separated and additions are made to this number from time to time. During the six years since 1951 a total of about 1,300 isotopic samples has been despatched to laboratories in the Authority's establishments and in universities and other institutions in the United Kingdom and abroad.

180. Most of the isotopes are prepared as targets for nuclear physics experiments with particle accelerators. A specialist service for these targets is operated which, as well as providing standard targets, is able to meet unusual individual requirements. Other samples are prepared for research in such specialised fields as superconductivity, optical spectroscopy, and isotope dilution analysis. Quantities of separated isotopes are also supplied to the Isotope Division for the preparation by pile irradiation of certain radioisotopes with high specific activity.

181. During the year a new machine for separating the isotopes of plutonium and other heavy radioactive elements was brought into operation. Known as HERMES (for heavy-element radioactive material electromagnetic separator) this machine, which was designed and built at Harwell, has very high resolution and is capable of separating isotopes of the heaviest elements even though their masses differ by only 1 atomic mass unit. Because plutonium is such a toxic material the whole machine is completely enclosed in a dry-box and all servicing is done by men wearing protective pressurised suits. The separator is operated from an adjoining control room. The first run with plutonium was made in January, 1957.

CHAPTER X

THE WEAPONS PROGRAMME

182. The year has been one of great activity for the Weapons Group and it is satisfactory to report that all promised dates have been successfully met.

183. Fissile weapon cores have been produced for the Services, and the Research and Development programme has included the mounting of two major trials series and preparations for a third.

184. The first of the large-scale trials took place in May and June, 1956. Because the Atomic Weapons Range at Maralinga was not ready at that time, the Government of Australia gave permission for the trial to be held at the Monte Bello Islands. Two rounds were fired, both on towers. The responsibilities of the Authority were to provide and explode the nuclear devices and make the scientific measurements. Some members of the Australian Press witnessed the first shot from a ship.

185. The second trial took place in September and October, 1956, at the Maralinga Range in South Australia. There were four explosions, of which two were on towers, one was on the ground and one was an air burst. The first shot was seen by representatives of the British and Australian Press, and the second by a representative party of members of the Australian Federal Parliament.

186. The test series at Maralinga was by far the largest in scope yet carried out in the British atomic weapons programme. A large target array was prepared for the first explosion, which was on a tower. Tanks, guns, vehicles, ammunition, radar sets, aircraft and many items of Service equipment were exposed. The instrumentation for the target array was largely provided and manned by the Ministry of Supply. Shelters and other Civil Defence items were also tested. Several hundred Service Officers from the United Kingdom, Australia, Canada and New Zealand were present and received their first practical experience of a nuclear explosion. They gave valuable help in preparing the target array, and in evaluating the results.

187. The second explosion was a low yield ground burst. Some of the Service Officers saw this explosion.

188. The third explosion was largely a Royal Air Force operation. The weapon was dropped from a Valiant aircraft manned by a Service crew.

189. The final explosion was another tower burst.

190. The Australian Safety Committee made a careful check of conditions before and after the firing of every round, and were satisfied that no hazard to the people or stock of Australia was caused by any of the explosions at Monte Bello or at Maralinga.

191. Preparations have been completed for the tests of high yield weapons in the Pacific, using Christmas Island as the base. The responsibilities of the Weapons Group have been the design and making of the devices, and the provision and manning of instrumentation.

192. During the year two important research facilities have come into operation in the Weapons Group. A 6 MeV Van de Graaff accelerator, obtained from the High Voltage Engineering Corporation, has started work and will provide important nuclear data required by the Group, as well as being available for use on fundamental research problems. A large computer, the I.B.M. 704, has been installed, and has already proved a valuable asset to the Theoretical Division.

193. Design and development work on a 12 MeV Van de Graaff tandem accelerator is proceeding rapidly, in collaboration with Harwell.

194. The Second Annual Report (para. 141) stated that the Weapons Group would be responsible for the research and development of military reactors (other than the submarine reactor, where the Authority's responsibilities rest with the other two Groups). This decision still stands, but no work on military reactors is proceeding at present.

CHAPTER XI

RELATIONS WITH INDUSTRY

195. The placing of contracts for the building of the first nuclear power stations for the electricity authorities marked a significant stage in the translation of the United Kingdom's civil atomic energy effort from the status of a Government research and development project to that of full industrial realization. This stage was reached as the result of two years' close collaboration between the Atomic Energy Authority and the four industrial groups whose formation was referred to in the First Annual Report (para. 82). During this period of collaboration the design teams of these organisations, and staff seconded by the electricity authorities, were trained by the Authority in the design of gas-cooled, graphite-moderated reactors of the Calder Hall type.

196. The firms concerned will build their own versions of this type of reactor, designed primarily for power production and incorporating the firms' own technical developments, by arrangement with the Authority, who will grant them a non-exclusive manufacturing licence in return for a royalty on each reactor sold. As part of these licence arrangements the Authority will continue to keep the firms informed of the results of further research and development work undertaken by the Authority on this type of reactor. Collaboration will continue between the Authority, the electricity authorities and the manufacturers with the object of further improving the basic design.

197. A fifth group of companies was organised during the year, consisting of an association of two new companies: Atomic Power Constructors Limited, and Nuclear Civil Contractors. Atomic Power Constructors Limited was formed by Richardsons Westgarth & Co. Limited, International Combustion (Holdings) Limited, and Crompton Parkinson Limited. Nuclear Civil Contractors Limited was formed by Trollope and Colls Limited, and Holland Hannen and Cubitts. This new group of companies has entered into a collaboration agreement with the Authority, and arrangements have been made for their design team to receive training and facilities similar to those given to the design teams of the other four groups.

Conferences

198. To keep industry broadly informed of work in progress which might lead eventually to industrial application, the Authority hold conferences from time to time to which representatives of industry are invited. These conferences are concerned mainly with projects which are in the initial stages of examination. Their purpose is not therefore to transmit information from which industrial application may immediately follow; it is to acquaint industry with the possibilities that are being examined, so that firms may think about applications in their own fields, and to provide for discussion of the lines of development being followed.

199. Information about the conferences held in the period under review is given in the following paragraphs. (The principal conferences held at Harwell during the year are listed at Appendix V.)

Reactors

200. A conference was held at Harwell on 30th November, 1956, at which the salient features of six reactor systems, which have been chosen by the Authority for investigation as possible successors to the Calder Hall type, or which may find other applications, were described and discussed.

201. The conference was attended by more than two hundred representatives of British firms and electricity undertakings. They were given an outline of the Authority's reactor research and development programme, and were told about the particular problems presented by each of the systems under investigation. This was followed by a discussion—in which the representatives of industry took part—about the merits of the different systems.

Nuclear Propulsion of Ships

202. In collaboration with the British Shipbuilding Research Association and the British Chamber of Shipping, the Authority held a conference at Harwell on 19th October, 1956. Its purpose was to enable general discussion to take place between the staff of the Authority, and the shipbuilding and shipowning interests, on the prospects for the nuclear propulsion of ships. The conference was attended by representatives of the shipowning and shipbuilding industries, and of Government departments concerned. They were told about the investigation into the problems of marine nuclear propulsion which is being carried out at Harwell by the Authority and the British Shipbuilding Research Association. Papers were read on various aspects of the investigation, including the selection and development of suitable reactors, the economic factors, and the problem of safety. There was discussion on these subjects and on the best method of achieving the objective of commercial marine nuclear propulsion in the shortest time.

Use of Heat from Reactors

203. A conference on the possible uses of heat from nuclear reactors was held at Harwell on 18th January, 1957. It was attended by representatives of Government departments concerned, research establishments, research associations, and the chemical industry. The conference discussed potential industrial uses, other than the generation of electricity, of heat produced in nuclear reactors. Papers were read on various aspects of the subject.

Glove Box Design and Operation

204. Research workers from universities, and representatives of interested industrial firms, attended a symposium at Harwell from 19th to 21st February, 1957, on the techniques employed in the remote handling of highly toxic materials. Papers were read on the design, installation, maintenance and operation of glove boxes devised for this purpose. Delegates saw typical installations in the chemical and metallurgical laboratories.

Access Agreements

205. The basis on which access agreements may be granted to firms seeking information with a view to its commercial exploitation was described in the Second Annual Report (para. 168). Although there has been a steady

flow of enquiries from industry, only a few have as yet resulted in the negotiation of access agreements. One reason is that many of the enquiries have come from firms who were unaware of the large amount of published information already available. Such enquirers have been given bibliographies of the published information. From these they may select reading which will help them to define their interest or which may, without the need for special access, provide them with the information they are seeking.

Exports

206. Although the export of reactors is the responsibility of industry, the Authority are closely concerned for three reasons. First, the Calder Hall type of reactor is the only type of power reactor of British design at present available for export from the United Kingdom. As its designers and operators, the Authority are well qualified to describe its features and advantages to potential customers. Second, it will be the responsibility of the Authority to supply the fuel elements for reactors of British origin exported by industry. Third, the Authority have a part to play in the inter-governmental negotiations which are necessary before reactors or fuel elements may be supplied to other countries.

207. While up to the end of the year under review there had not been any overseas orders for British power reactors of British design, the A.E.I.-John Thompson Company has received an order for a "Merlin" research reactor from the German Land Government of North Rhine-Westphalia, who have also authorised the purchase of a DIDO type high-flux research reactor from the United Kingdom.

Patents

208. In pursuance of the Authority's policy of making their inventions available for use by British industry, the attention of individual firms has been drawn to inventions of interest in their own particular fields. Publicity has also been effected through manufacturers' associations and the technical press. Apart from inventions of major importance to the nuclear power programme, the Authority now have some 230 inventions which are protected by patents and patent applications and cover a wide range in the engineering, chemical, metallurgical, electronic, and instrument fields. Up to the present time 39 patent licences have been granted to British firms and six to firms in other countries.

209. In addition to the above patent holding, the rights in a considerable number of United Kingdom patents and patent applications covering atomic energy inventions that originated in the U.S.A. and Canada, have been acquired by the Authority under an interchange agreement entered into on 24th September, 1956, between the United Kingdom, U.S., and Canadian Governments. This agreement applies to atomic energy inventions on which patents were held or applied for by one Government, in one or both of the other countries, as at 15th November, 1955. The inventions concerned fall into two classes, (1) those arising from war-time co-operation among the three Governments in which the rights were held in trust pending a final settlement, (2) those independently developed and owned by one Government. As regards inventions within the scope of the agreement, a non-discrimination provision binds each Government to grant licences to nationals of the other Governments on the same terms and conditions as it accords licences to its own nationals.

CHAPTER XII

INFORMATION, TRAINING AND PUBLIC RELATIONS

210. In addition to the conclusion of access agreements in particular cases, there are three principal methods by which the progress of the Authority's work may be made public.

These are:—

- (a) Dissemination of technical information ;
- (b) Training of scientists and engineers drawn from British industry and from overseas countries ;
- (c) Public relations.

Dissemination of information

211. For well known historical reasons, a large proportion of the technical information on atomic energy has become concentrated in the hands of the Authority and continuing research places more there. The Authority have a duty to disseminate this information, especially within industry, as widely as is compatible with the national interest, and they devote a substantial effort to this end.

212. In 1946 nearly all atomic energy information was subject to security restrictions, i.e. it was classified. During the past ten years these restrictions have been progressively relaxed, and as a result very little information related to civil nuclear power is now classified. The United Kingdom, the U.S.A., and Canada observe agreed rules determining what information must be kept classified and what may be released, or declassified. These rules are reviewed at periodic Tripartite Declassification Conferences, which take into account, amongst other factors, the growth in knowledge and experience of atomic energy in other countries. Recent conferences have been concerned particularly with achieving a proper balance between national security on the one hand, and the rapid advance in the peaceful applications of atomic energy on the other. The eighth such conference was held in the U.S.A. early in the year under review, and its recommendations were ratified by the governments concerned late in 1956.

213. As a result of this conference, virtually all technological information needed for the development of a civilian nuclear power industry has been freed from security restrictions on publication. In fact the only information now classified is that relating directly to plants producing fissile materials for military purposes, to military propulsion and package reactors, and of course to nuclear weapons.

214. With the lifting of the security ban on publication it became necessary to consider how the information, much of which is of considerable industrial value, should be made available, in view of the large public funds expended in developing it. The policy adopted by the Authority and endorsed by H.M. Government was to aim at recovering some of this money by restricting the release of information of industrial value to holders of access agreements on a royalty basis.

215. Among the subjects now declassified is a very wide range of information on the design, construction, and operation of power reactors of all kinds, together with details of the metallurgy of fuel materials, the fabrication of fuel elements, and the effects upon them of radiation—all crucial

matters for power development. This range includes information about the metallurgy of certain alloys of plutonium, a material likely to become increasingly important in the future. The extraction and purification of all the principal atomic energy materials—uranium, thorium, heavy water, and graphite—are declassified and so too are data on uranium and thorium ore reserves and estimates of potential supplies of these ores, questions of great importance in planning nuclear power programmes. At the other end of the chain, information on chemical processes for treating spent fuel is no longer classified from a military point of view.

216. These changes will permit the greatest release of atomic energy information since the United Nations Conference on the Peaceful Uses of Atomic Energy at Geneva in August, 1955. To make them effective, the Authority have undertaken to review all the thousands of existing classified reports to see which of them can be made available to the public. Already some 5,000 documents have been reviewed. In reviewing documents, account has had to be taken not only of the agreed rules concerning declassification, but also of the commercial protection required.

217. The second stage of this review of documents is to make available copies of those which can be released. These documents have been divided into two classes, the first containing the more useful of them and the second those which are obsolescent or for some other reason not likely to be much in demand. Documents in the first class will be reprinted and distributed, in the same way as new reports, to "depository" libraries in the U.K. (see below) and to official atomic energy projects abroad; documents in the second class will not be reprinted, but periodical lists of them will be issued and it will be possible to borrow them from the Authority libraries.

218. Besides the declassified documents made available by this and earlier reviews, the Authority publish many unclassified reports. In addition, a large number of papers by Authority staff appear in the scientific and technical journals; the numbers during the past year were about 350 reports and 450 published papers. A monthly list of these reports and papers is issued and copies may be obtained free of charge from the Librarian, Atomic Energy Research Establishment, Harwell. Copies of unclassified reports are placed in public libraries designated as depositories for atomic energy documents; these libraries include, in addition to those listed in the Second Annual Report (para. 166), the Central Libraries at Acton, Bristol, Kingston-upon-Hull, and Leeds, and the Library of the Department of Industrial and Forensic Science, at Belfast. Some unclassified reports are also sold through Her Majesty's Stationery Office.

219. The libraries of both the Research and the Industrial Groups issue regularly lists of new publications which they have acquired, and information bulletins, i.e. lists of articles appearing in the world's technical press which are of interest to workers in atomic energy. These lists are available free of charge on request to the appropriate Group library.

220. Another way in which the Authority disseminate information is through bibliographies on selected subjects, prepared by the information offices of the Research and Industrial Groups. Lists of these bibliographies are issued from time to time. Within the limits of available effort, the information offices will compile other bibliographies in answer to requests from industrial, university and other research institutions.

Training of Scientists and Engineers

Reactor School

221. The Reactor School at Harwell moved into new premises in September, 1956, doubling its capacity and providing accommodation for 60 full-time students. The School has continued to give training to suitably qualified students from industry and from overseas countries on the science and engineering of nuclear power stations and their ancillary processes.

222. Up to and including the first course in 1957, a total of 471 students had passed through the School, of which number 84 came from overseas. In addition to the three-and-a-half month full courses taken by these students, two short courses have been given to industrial executives with a technical background. These classes, which are intended to give senior industrialists a general appreciation of the problems and possibilities of nuclear power, were attended by 62 students. They are the first of several new courses made possible by the expansion in capacity of the School; others will be held in the near future.

Calder Operations School

223. To meet the demand for the training of reactor operators for nuclear power stations, a school has been set up at Calder Hall, at which the course will be complementary to that of the Harwell Reactor School. The students will receive both theoretical and practical instruction in the operation of the Calder Hall type of reactors, working both with a simulator and, in approved cases, on the Calder Hall plant with the operational staff.

224. The first course started on 29th January, 1957, and lasted eight weeks; of the eight students who attended, four were from the Central Electricity Authority and four from the industrial groups engaged on the nuclear power station construction programme. Experience on the first course has led to a decision that future courses should last six weeks. Students will be expected to have attended the Reactor School at Harwell or to have reached a comparable standard of knowledge. Overseas students will be accepted on some of the courses.

Isotope School

225. Since the school was opened in 1951 over 900 students have passed through its different courses. There is a continuing demand for the ordinary four-week course and also for advanced and specialised courses. Among the latter held during the year under review have been courses in radiological protection, autoradiography, and the uses of radioisotopes in medicine. Plans have been made to increase the size and scope of the school.

Public Relations

226. Public interest in the Authority's work, and in atomic energy matters generally, continues to mount, both at home and abroad. This interest was reflected in the attendance of 300 journalists from twenty countries at the opening of Calder Hall and there have been comparable attendances at other events arranged for the press, such as the "Open Days, 1956" at Harwell in May; the press conference on the annual report in July; a visit to Harwell for the opening of the research reactor, DIDO, in November and a conference in connection with the start-up of the second Calder Hall reactor in February.

227. Among the new publications dealing with the work of the Authority have been "Calder Hall—The Story of Britain's First Atomic Power

Station",* written by Mr. Kenneth Jay (of Harwell) and published commercially last October, both in Britain and the United States of America. Foreign-language editions are to appear in Germany and Japan. A popular, illustrated version of the annual report was produced for the first time, under the title "Atom 1956"* and other publications have been "Harwell, a Brief Guide"* and "The Radiochemical Centre, Amersham".* In November the Authority began publication of their monthly bulletin, "Atom",* which provides a record of press releases and other announcements by the Authority, Governmental statements, including answers to Parliamentary Questions, and the text of important speeches by Members and staff of the Authority. The bulletin is circulated within the Authority and to interested firms and institutions at home and overseas.

228. Exhibitions in which the Authority participated during the year included the British Industries Fair (London); the Fuel Efficiency Exhibition; the International Congress of Radiology (Mexico); the Vienna Trade Fair; and those sponsored by the British Nuclear Energy Conference, the Physical Society, the Institute of Metals and the Institute of Physics. An exhibition called "Atoms and Health" was organised by the Authority for the Royal Society of Health. The Authority co-operated with the Australian Atomic Energy Commission in staging an isotopes exhibition at the Universities of Melbourne and Sydney and with the Board of Trade in the presentation of an atomic energy exhibit at the Canadian National Fair, Toronto.

229. A colour-film of the opening of Calder Hall, "Great Day", was produced by the Authority. Seven foreign-language versions were made and copies distributed to 25 countries. The Authority co-operated with the Central Office of Information in the production of the film "Atomic Achievement", which has also been distributed widely overseas.

CHAPTER XIII

INTERNATIONAL RELATIONS

230. The Second Annual Report (para. 181) called attention to the welcome growth in overseas interest in nuclear energy generally, and in developments and activities in the United Kingdom. The year under review has seen a further large increase in the number of overseas visitors to the Authority's establishments, either for courses of study, to discuss particular topics of special interest, or merely to see at close quarters what a nuclear research establishment or a nuclear power station looks like. Welcome as these visitors are, and stimulating as their visits often prove, it is necessary to apply certain limitations, especially on the latter class of visit, to avoid undue interference with the Authority's prime work. In the same way, not all of the requests from overseas countries for visits and lectures by British scientists and engineers can be met because the people concerned cannot always be spared from their normal work.

* "Calder Hall—The Story of Britain's first Atomic Power Station" is available through booksellers or from Methuen & Co. Ltd. (price 5s.). "Atom 1956" was published by H.M. Stationery Office (price 1s. 6d.). Copies of "The Radiochemical Centre, Amersham" (price 2s. 6d.) may be obtained on application to the Radiochemical Centre, Amersham, Bucks, and copies of "Harwell, a brief guide" may be obtained from the Scientific Administration Office, Atomic Energy Research Establishment, Harwell, Berkshire. Copies of the monthly bulletin "Atom" may be obtained through Public Relations Branch, United Kingdom Atomic Energy Authority, St. Giles Court, London, W.C.2.

Opening of Calder Hall

231. One of the outstanding events of the year from the point of view of international relations, as from many other viewpoints, was the formal inauguration of the Calder Hall nuclear power station by Her Majesty the Queen on 17th October, 1956. This was a truly international occasion, with distinguished representatives from thirty-nine overseas countries attending as guests of the Authority to see the first industrial scale power station in the world connected to the electricity grid.

232. A number of those who came to England for the Calder Hall ceremony took the opportunity of visiting the research establishment at Harwell and of having discussions with Authority representatives. The "Calder Hall Symposium" held in London by the British Nuclear Energy Conference in November, 1956, brought even larger numbers of scientists and engineers from overseas countries. At this Conference members of the Authority's staff and representatives of British industry gave a comprehensive description of the Calder Hall design, and dealt with some of the technical problems encountered and overcome. Some of the improvements to be expected in the development of commercial power stations from this prototype were also outlined.

233. The successful commissioning and operation of Calder Hall created great interest in the natural uranium, gas-cooled type of reactor in many countries. Especially was this so in countries where increasing energy demands and shortages of fossil fuels make the introduction of nuclear power a matter of some urgency. For such countries the type of nuclear power station now being constructed for the U.K. electricity authorities offers an attractive prospect of obtaining power in a relatively short time and at reasonable cost, from a reactor type which is inherently safe and of proved reliability. The Authority, in close co-operation with the U.K. firms principally concerned, have taken great pains to ensure that all overseas enquirers are given the information they need to evaluate the suitability of this reactor type for their own purposes and in their own particular circumstances. In addition, the Authority have declared their readiness to supply fuel elements, under long-term contracts, for nuclear reactors of British origin exported from the U.K.

General

234. Only one new agreement for co-operation in atomic research and development was concluded during the year—that with the German Federal Republic.* But active co-operation with many individual countries and international organisations continued to grow, and in a number of cases formal agreements are in course of negotiation.

Sales

235. Sales of nuclear materials (other than radioisotopes) and technological information to overseas countries brought the Authority a revenue of £545,954 during the year under review.

Commonwealth Countries

236. Relations between the Authority and the bodies responsible for atomic energy work in the Commonwealth countries remain close and cordial and cover an increasingly wide field.

* Cmd. 9842.

Canada

There was a steady flow of visitors and information between the Authority and Atomic Energy of Canada Limited throughout the year. The facilities offered by the Canadian NRX research reactor have continued to be most useful to the Authority in carrying out irradiation experiments. The possibility of still closer collaboration on certain reactor systems which are of potential importance as producers of power for particular applications is under consideration.

Australia

The Authority have continued to give assistance to the Australian Atomic Energy Commission in the installation of the DIDO research reactor at Lucas Heights, which is nearing completion. The Chairman of the Australian Commission visited London during the year for discussions with the Authority. The Commission's Chief Scientist and some of the members of the Commission's staff who have been working at Harwell returned to Australia during the course of the year to take up work at the Commission's own research establishment. Proposals for extending the scope of collaboration on a number of important topics are under consideration.

South Africa

In discussions with the Vice-Chairman of the South African Atomic Energy Board in the summer of 1956, arrangements were formulated for future collaboration on various aspects of the South African Atomic Energy Research Programme. In March, 1957, the Chairman of the Authority paid a visit to South Africa as a guest of the Government of the Union of South Africa, to establish closer contact with those in the Union concerned with uranium production and with the other aspects of atomic energy development.

India

The Authority's advice and help in providing fuel for the Indian swimming pool reactor were generously acknowledged by Mr. Nehru on the occasion of the formal inauguration of this reactor in January, 1957. During the year the Authority have given further help to India in obtaining the materials required for her research programme, and by seconding a member of the Harwell staff for an extended period to assist in the establishment of radiochemical laboratories in India. Dr. Bhabha, head of the Indian Department of Atomic Energy, visited the U.K. for discussions, and Dr. B. F. J. Schonland, Deputy Director of the Atomic Energy Research Establishment, Harwell, spent a week visiting Indian establishments.

Pakistan

During the year an Atomic Energy Commission was established in Pakistan. Discussions have taken place both in England and in Pakistan between Dr. Nazir Ahmad, Chairman of the Commission, and representatives of the Authority as to the ways in which the U.K. can help Pakistan to build up an atomic project. A number of scientists from Pakistan have already been trained in the Authority's establishments and arrangements are being made for the training of further specialists in various subjects. The Authority are also advising the Pakistan Commission on the organisation of their atomic work, and on the siting and equipping of their research laboratories.

Other Countries

237. Unclassified reports on fundamental research are exchanged with practically all countries which have established atomic energy commissions or

other bodies for the co-ordination of atomic work. During the year under review the Authority's activities in connection with the following countries call for special comment.

United States of America

Close contact with the U.S. Atomic Energy Commission was maintained in accordance with the co-operation agreement of June, 1955. In June, 1956, an amendment to this agreement was signed which extends the field of co-operation to cover in certain circumstances the exchange of classified information on the development, design, construction, operation and use of military package power reactors, and reactors for the propulsion of naval vessels, aircraft or land vehicles. Up to the end of the year under review, no exchanges under this specific heading had taken place, but arrangements were being discussed for exchanges to take place on the nuclear propulsion of submarines. The amendment to the agreement also made possible the exchange of materials (including fissile material) required for experimental purposes.

Visits by teams working on the fast breeder reactor projects in the two countries have been exchanged, and parties from the U.S.A.E.C. have visited the Authority to discuss the engineering and economic characteristics of the Calder Hall station. The Authority have offered to the A.E.C. detailed information on Calder Hall for A.E.C. use under Article II A 2 of the co-operation agreement in exchange for similar information on the A.E.C.'s pressurised water reactor installation at Shippingport. This offer was still under discussion at the end of the year under review.*

There have also been joint discussions on the controlled thermonuclear reaction. Valuable information on a number of other subjects has been exchanged and many useful visits have been paid by Authority staff to U.S. installations.

During the year ended 31st March, 1957, visits were paid to the U.S.A.E.C. by a total of 105 of the Authority's staff, of whom 79 took part in discussions involving classified topics. The U.S.A.E.C. sent 103 visitors to the U.K. during the same period, of whom 80 came for classified discussions.

Belgium

Following the extension of the U.S.-Belgian co-operation agreement to cover a wider field, there have been discussions with the Belgian Atomic Energy Commission about extending the scope of U.K.-Belgian co-operation. During the year, two Belgian scientists have been in residence at Calder Hall studying the methods used in constructing the reactors there. A number of Belgian experts, including a special party of engineers, inspected Calder Hall and had detailed discussions with representatives of the Authority and with industrial firms on the characteristics of the gas-cooled power reactor and its suitability for use under Belgian conditions.

German Federal Republic

An agreement between the Governments of the U.K. and the German Federal Republic for co-operation in research on the peaceful uses of atomic energy was signed on 31st July, 1956, and since then the growing activity in Western Germany in the field of nuclear research has prompted a large number of representatives of German Federal, Laender and Municipal Authorities and of German industry to visit Harwell and other establishments, and to seek advice on a variety of topics. The present Federal Minister for Atomic Affairs, Herr Balke, and his predecessor Herr Strauss

* An understanding has since been reached.

have visited the Authority on more than one occasion. As mentioned in Chapter XI (para. 207), German authorities are to buy two research reactors from British firms, and interest is also being shown in large nuclear power stations of the type being built for the U.K. electricity authorities.

Japan

A visit to Japan by Sir Christopher Hinton aroused great interest there in Calder Hall and in the commercial power stations being developed from it. The Japanese Government decided to send an expert mission to study atomic developments in the U.K. and to consider the suitability of the Calder Hall type of reactor for early use in Japan, where the problem of maintaining a sufficiently rapid expansion of power supplies is like that of the U.K. With the assistance of the Authority and of the industrial firms concerned with the manufacture of nuclear power stations, this mission, led by Mr. Ishikawa, a member of the Japanese Atomic Energy Commission, made a most careful examination of the Calder Hall type of reactor. On returning to Japan they reported favourably on its merits and suitability, and it is possible that another mission may come to the U.K. later in 1957. In addition to the official mission, a large party of businessmen representing the Japanese Atomic Industrial Forum also visited the Authority during the year.

Italy

Several Italian groups of electricity undertakings have also been evaluating the various types of nuclear power station which it is at present practicable to build. A number of Italian engineers have had technical and economic discussions with the Authority, and members of the Authority's staff have visited Italy to deal with questions about the technical characteristics and economics of British reactors.

Other countries

The Authority have continued collaboration in the research and development field with a number of other countries including France, Sweden, Norway, Denmark, the Netherlands, Portugal, Spain and Yugoslavia, and have had visits from and discussions with atomic scientists from many more. In some of these cases collaboration brings an immediate mutual benefit in the form of useful information. In other cases it paves the way for useful exchanges when the country concerned has built up an active atomic energy project. In all cases it tends towards the advancement of nuclear science and towards the growth of that general international co-operation which is fostered in a more formal way by the organisations referred to in the following paragraphs.

International Organisations

The International Atomic Energy Agency

238. In October, 1956, after a conference in New York lasting for nearly a month, the Statute of the International Atomic Energy Agency was agreed. This statute has since been signed by the representatives of eighty nations. A Preparatory Commission, of which the U.K. is a member, is now engaged in drafting detailed plans for the organisation of the Agency and for the work which it is to undertake in its first few years. It is likely that the Commission's recommendations will be considered at a general conference to be held in Vienna in the autumn of 1957. The Authority are called upon to give technical advice to the U.K. representatives taking part in these discussions and will be the principal medium through which

the U.K. will assist in the actual operations of the Agency when it has been set up.

The Authority have similarly contributed to the work of other United Nations agencies such as the U.N. Economic and Social Council, and the special U.N. Scientific Committee on Radiation Hazards.

The Organisation for European Economic Co-operation

The activities of O.E.E.C. in the nuclear energy field have increased during the year. The Steering Committee on Nuclear Energy, which was established by the Council of Ministers, in turn set up a series of Working Parties to investigate and report on particular aspects of European co-operation in atomic research and development. In three of these working parties, namely those concerned with training, joint experimental reactor projects, and a joint chemical processing plant project, representatives of the Authority have played an important part. The U.K. representatives on other working parties and committees have frequently called on the Authority for technical advice. Members of the Authority's staff also undertook to contribute a number of lectures to a Nuclear Energy Course for Management, to be held in Paris in the first week of April, 1957, under the auspices of the European Productivity Agency. It would be difficult, having regard to the size and comprehensive nature of the U.K.'s existing atomic energy programme, to justify direct participation by the Authority in many joint O.E.E.C. projects. Nevertheless, the U.K. has intimated its readiness to consider taking part in one joint project to develop a reactor system, and to consider siting such a project alongside one of the Authority's development establishments should the other co-operating countries so desire.

Euratom

With the signing in Rome on 25th March, 1957, of the Euratom Treaty, the first formal step has been taken towards establishing the European Atomic Energy Community composed of Belgium, France, Western Germany, Italy, Luxembourg and the Netherlands. The U.K. is not directly associated with Euratom as such; but the Euratom countries are fellow members with the U.K. of O.E.E.C., and the Euratom Treaty has been drawn up in a way which permits collaboration between the Euratom countries, either collectively or individually, and the other O.E.E.C. countries. An O.E.E.C./Euratom Joint Liaison Committee has been set up and the U.K. is represented on this body. In February, 1957, the Authority had discussions with the "Committee of Three Wise Men" set up by the six countries to advise on the need for, and the possible size and nature of, a Euratom nuclear power programme. The Committee's preliminary review had led it to the conclusion that a programme of 15 million kilowatts of nuclear power installed by 1967 would be desirable and practicable. The discussions in the U.K. were mainly concerned with the considerations which had determined the size and nature of the U.K. programme, the contribution which the Calder Hall type of reactor could make to the realisation of the Committee's target, and the assistance which the U.K. could give to the execution of such a programme. The Authority agreed to facilitate contacts between firms in the U.K. and in the Euratom countries interested in building nuclear power stations and to help with the training of scientists and engineers. Members of the Authority's staff have since had further technical discussions with Euratom scientists and engineers.

The Bagdad Pact

In accordance with the promise by Her Majesty's Government of help in establishing a nuclear training centre in Bagdad for the use of member countries, the Authority during 1956 trained at Harwell two instructors each from

Iraq, Iran, Pakistan and Turkey. A member of the Authority's staff, Mr. W. J. Whitehouse, has been appointed first Director of the Centre, and he, together with four other members of the Authority's staff, went to Bagdad early in 1957 to prepare the Centre, supervise the installation of equipment provided from the U.K., and organise and assist in running the first courses. The Centre, which will specialise for the time being in techniques for the use of radioisotopes, with special reference to Middle Eastern requirements and conditions, was formally opened by H.M. King Feisal II on 31st March, 1957. A Scientific Council has been set up to be the technical and scientific policy-making body of the Centre. Sir John Cockcroft has been elected first Chairman of the Council.

Others

The Authority have continued during the year to play an active part in the work of the World Health Organisation, the International Commission for Radiological Protection, the European Council for Nuclear Research (CERN), the European Atomic Energy Society, and a number of other bodies.

CHAPTER XIV

THE AUTHORITY'S STAFF

Senior Staff

239. The Authority's senior staff as at 31st March, 1957, are listed in Appendix II.

Strength

240. The total numbers employed by the Authority increased from 23,973 on 1st April, 1956, to 27,290 on 31st March, 1957. Of these, the non-industrial staff rose from 10,795 to 12,630 and industrial employees from 13,178 to 14,660.

241. The rate of expansion has thus continued at a high level. Vigorous recruitment has been needed to maintain this expansion. The actual intake has again been greater than the figures indicate, since it has been necessary to make good both normal wastage and, during the early part of the year, the losses due to the return of seconded non-industrial civil servants who did not wish to remain with the Authority.

Transition from the Civil Service

242. The arrangements described in the Authority's Second Annual Report (para. 145) for the return to appropriate Government Departments of the civil servants who decided not to join the Authority's staff were successfully completed by 31st July, 1956, the date of expiry of their period of secondment from the Civil Service.

Recruitment

243. As in past years, the hardest part of the recruitment problem has been to fill the more senior posts, particularly in engineering. Special efforts were also necessary to find an adequate number of suitable recruits for the more remote stations. Recruitment has remained reasonably successful for staff in the middle and lower ranges, and it is evident from the large response to staff advertisements and the many enquiries for information that the attraction of a career in atomic energy is as high as ever.

244. Recruitment of industrial labour has continued to be generally satisfactory, but vacancies for craftsmen still exist at some of the Authority's establishments.

Pay and Conditions of Service

245. In seeking to maintain a proper relationship between the salaries of their staff and what is regarded as fair remuneration in other comparable employment, the Authority have continued to have regard to pay and conditions in the Civil Service. In particular, the period covered by this Report has seen the application to the Authority's non-industrial staff of those recommendations of the Royal Commission on the Civil Service, 1953-55, which, by agreement, have been applied in the Civil Service. A comparable agreement was made between the two sides of the Authority Whitley Council leading to the introduction of detailed changes in the pay and conditions of service of the staff.

246. Discussions concerning the introduction of national minimum wage rates and uniform conditions for industrial employees in the Authority's establishments were concluded by agreement on the National Joint Industrial Council on 3rd May, 1956. The new arrangements replaced the various differing bases for industrial wages and conditions which had hitherto been in operation.

247. By agreement with the Trade Union side of the National Joint Industrial Council, the lead rates payable to craftsmen and non-craft grades above the agreed basic national minimum rates were revised on 14th February, 1957. The revision of the non-craft lead rates was an interim measure pending the application of a uniform scheme of job evaluation based on principles to be agreed with the Trade Unions. At the same time, a common grading and wages structure was introduced to cover all industrial domestic employees.

248. A claim for a substantial increase in industrial wages was submitted by the Trade Union side of the National Joint Industrial Council on 14th February, 1957. The claim was still under consideration at the end of the year covered by this Report.

Superannuation

249. The provisions mentioned in the Authority's First Annual Report (para. 165) whereby industrial employees who were formerly in the Civil Service and who joined the Authority on Vesting Day retain their previous pension rights, received the formal approval of the Lord President of the Council on 17th June, 1956.

250. Discussions have been opened on the National Joint Industrial Council of the details of a possible contributory pension scheme for those industrial employees who entered the Authority after Vesting Day and are not covered by the scheme mentioned in the preceding paragraph.

Training

251. The Authority's training facilities for their own scientific and technical staff were reviewed in the light of the White Paper on Technical Education*. As a result, a revised scheme of awards has been introduced to enable selected members of the staff to attend University and "sandwich" courses. Bursaries for full-time University education were awarded in May, 1956, and the first systematic selection of candidates for "sandwich" courses was made in time for the start of Technical College terms in January, 1957.

* Cmd. 9703.

252. The number of staff granted time off to help them to secure technical qualifications by part-time study has increased during the twelve months. Internal technical training schemes have also been extended and particular attention has been given to the training of junior scientific staff.

253. Similarly, the training arrangements for administrative staff have been reviewed with the object of giving them a better insight into the various aspects of the Authority's work and increasing the effectiveness of their contribution to it. Staff have been helped to attend a wider variety of external courses considered to be of advantage to the Authority and to the staff. Selected members of the staff have undertaken advanced courses in management and administration at external institutions.

254. During the year the Authority recruited one pre-graduate, 15 student and 99 craft apprentices. A number of places on full-time University courses and "sandwich" courses (including a course leading to the new Diploma in Technology) were awarded to student apprentices. 18 student apprentices have been selected for entry in September, 1957, and it is planned to recruit 96 craft apprentices at the same time.

Staff and Industrial Relations

255. The United Kingdom Atomic Energy Authority Whitley Council for non-industrial staff operated successfully during the year. An Authority Benevolent Fund was established under a Committee of Management representative of both sides of the Whitley Council. During the initial stages the Authority have undertaken to contribute to the Fund amounts equal to those subscribed by the staff.

256. The United Kingdom Atomic Energy Authority Joint Industrial Council has also worked satisfactorily throughout the year. Local Joint Industrial Committees have met regularly. Revised constitutions for them were ratified by the National Joint Industrial Council on 22nd August, 1956. Industrial relations in the Authority generally continued to be very satisfactory.

Housing

257. It was reported in the last Annual Report (para. 158) that by 31st March, 1956, the Authority owned 3,428 houses while the local authorities had helped by providing 1,100 houses for Authority staff coming into their areas from other localities. The Establishments have continued to expand during 1956 and the beginning of 1957 and the number of Authority owned houses at 31st March, 1957, was 4,164 with another 874 under construction or planned. The number of local authority houses occupied by Authority staff from other areas is now 1,412 and a further 307 houses are promised from this source together with help in housing locally recruited staff.

Hostels

258. The Authority hostels can now accommodate 1,476 members of the staff as compared with 1,272 at 31st March, 1956. The Authority propose to build a new hostel at Abingdon; to replace the existing hostel at Aldermaston and to extend the hostel at Dounreay. By these means it is hoped to provide a further 344 places. In addition to this the Authority inherited a number of hostels of temporary construction which had been hurriedly built during the war. They plan to replace them in due course by modern hostels.

Schools

259. Co-operation with the local education authorities proceeds smoothly and the provision of educational facilities for the children of Authority staff has presented no insuperable difficulties.

CHAPTER XV

HEALTH AND SAFETY

260. The Atomic Energy Authority Act, 1954, placed on the Authority the duty of securing that no ionising radiation from any of their premises or from any waste discharged from their premises should cause any hurt to any person or damage to any property whether on such premises or elsewhere.

261. The Authority have carried out their responsibilities under this Act through a number of committees dealing with the various aspects of safety policy. These committees have now been organised into a structure consisting of two main bodies, a Safety Executive Committee under the chairmanship of the Member for Engineering and Production and a Health Advisory Committee under the chairmanship of the Member for Scientific Research. The Safety Executive Committee considers safety in the design, siting and operation of reactors, process plants and laboratory installations, using the standards recommended by the Health Advisory Committee. The Safety Executive Committee is served by two subordinate bodies, the Reactor Safety Committee which is concerned with safety and location questions concerning reactors, and the Ancillary Establishments Safety Committee which covers all plants and experimental facilities other than reactors. The Health Advisory Committee is served by a Health Panel, composed of the Authority's chief medical officers and chief health physicists.

262. The Safety Branch, a permanent staff to serve the committee structure described above, has been set up at the Industrial Group Headquarters at Risley.

263. The record of the Authority in the field of health and safety has continued to be good. The responsible task of giving advice in this field falls to the Medical and Health Physics Sections. Apart from their immediate task of ensuring safety within the Authority, these Sections have co-operated with a number of national and international bodies which are concerned with setting standards for exposure to radiations and radioactive substances. The experience of the Authority is also available to other operators. In particular, a formal agreement has been reached with the electricity authorities under which the Authority accept a large measure of responsibility for the radiological protection of the new power stations.

Safety of Employees

264. The Authority continue to hold a good record in the field of normal industrial safety. The lost time frequency rates for the year were 1.19 per 100,000 man-hours for the Industrial Group, 0.68 for the Weapons Group and 0.70 for the Research Group. There has been no case of injury arising from radiation or the handling of radioactive substances; there has been one fatal accident from electrocution.

265. The report of the Medical Research Council "The Hazards to Man of Nuclear and Allied Radiations", was issued during the year, and was accepted by the Authority as their standard for future control of radiation exposure. The report confirms the recommendation of the International Commission on Radiological Protection of a permissible weekly dose of 0.3 rad*. This has been the basis for the control measures which were adopted on the design and operation of the plant now in use.

* A rad is a unit of *absorbed* dose arising from any form of radiation. It is defined as 100 ergs per gram in a specified medium.

266. The new recommendation contained in the report of the Medical Research Council aims at limiting total exposures received over periods of many years, to a level corresponding to about 50 rads per decade. Whilst this demands an exposure rate which is lower than that for which some of the Authority's plant was designed, nevertheless only 290 out of a total of over 8,000 employees exposed to radiation (i.e. less than 4 per cent) did in fact exceed 5 rads during the year. This reflects the high standard of control exercised by the Authority, as the M.R.C. report was issued too late to affect operations during the year. Moreover, the record does not conflict with the recommendations insofar as the average over a 10 year period can still be maintained to the new level. The Authority's aim to keep all radiation exposure to a minimum will be continued during the current year by adjusting operations in such a way that a smaller percentage of employees will receive doses exceeding 5 rads. The previous record of the Authority was noted in the M.R.C. report in the statement—"With regard to occupational exposure we consider that the record of the Atomic Energy Authority shows the standard that is attainable and the practicability of being satisfied with nothing less".

267. During the year several new reactors were brought into operation and a health physics survey of all radiation levels was carried out during the commissioning stages. In most places the levels were entirely satisfactory; in a few cases a small increase in local shielding was advised and installed. The operation of all existing plants continued to be observed, and a notable advance was made in effecting maintenance of chemical plants and reactors in regions of high radiation intensity. The experience of planned control of maintenance operations of this type proved to be extremely valuable.

268. The control of external radiation was exercised primarily through the issue of personal monitoring films, of which over 200,000 were issued and developed through the period. The average gamma-ray dose taken over all the employees of the Authority to whom films were issued is less than 0.25 rad per year. In addition to personal monitoring, control of the environment was exercised through the monitoring of working surfaces and buildings. Over 50,000 such surveys were made during the year. The maintenance of clean air in working space demands the highest standards in plant design and supervision of operation. Day-by-day control is exercised by air sampling, of which over 100,000 surveys were made during the year. The results of these monitoring procedures, together with urine tests, showed that no employee received whole-body radiation at levels exceeding the I.C.R.P. recommendations.

Sites for Nuclear Energy Establishments

269. The Authority have made a detailed study of the safety of the stations offered to the Central Electricity Authority by the tendering consortia and criteria have been established against which the safety of such stations can be judged. These include the coincidence of unrelated and unlikely failures of equipment and of the possibility of incorrect operation, whether from malice or ignorance, against which the plant must be so protected that these could not lead to a dangerous release of radioactive material.

270. Consideration has been given to sites in the north and south of Scotland and Northern Ireland. In considering siting proposals, the Reactor Safety Committee has taken into account the inherent safety in design of the British gas-cooled, graphite-moderated reactor and the policy defined in paragraphs 36, 37 and 38 of the White Paper "A Programme of Nuclear Power".*

* Cmd. 9389.

272. Experience during the last year in connection with the siting of both research establishments and nuclear power stations reveals a difficulty to which there can be no solution satisfactory to all sections of the public. Such establishments, for a variety of reasons of which safety is not always the most important, normally require to be sited away from heavily built-up areas. In this comparatively small island there are few stretches of country satisfying the requirements of nuclear energy establishments which do not have some historical or amenity value. The fact has to be faced that, no matter what care and respect for amenities is exercised by the Atomic Energy Authority and the electricity authorities, nuclear energy cannot be harnessed for the full benefit of the national economy without some disturbance to areas so far untouched by industrialisation.

273. All establishments have been visited by representatives of the authorising Ministries, who have expressed approval of the records relevant to the discharge of gaseous, liquid and solid wastes, and who have certified that the authorisations issued by the Ministries have been observed.

274. Continual surveys are made on all the Authority's sites, and information on the effect of discharge to sea is collected from the Cumberland coast. This information has been used in international discussions on the subject of waste disposal to sea.

APPENDIX I

MEMBERSHIP OF ATOMIC ENERGY AUTHORITY AS AT 31st MARCH, 1957

Chairman

Sir Edwin Plowden, K.C.B., K.B.E.

Members

Sir John Cockcroft, O.M., K.C.B., C.B.E., F.R.S.

(Member for Scientific Research)

Sir Christopher Hinton, K.B.E., F.R.S.

(Member for Engineering and Production)

Sir William Penney, K.B.E., F.R.S.

(Member for Weapons Research and Development)

Sir Donald Perrott, K.B.E.

(Member for Finance and Administration)

Mr. W. Strath, C.B.

(Member for External Relations and Commercial Policy)

Part-time Members

The Rt. Hon. Viscount Cherwell,* C.H., F.R.S.

Sir Luke Fawcett, O.B.E.

Sir Ivan Stedeford, O.B.E.

Sir W. Rowland Smith

Mr. C. F. Kearton, O.B.E.

Secretary

Mr. D. E. H. Peirson

APPENDIX II

ATOMIC ENERGY AUTHORITY ESTABLISHMENTS SENIOR STAFF AS AT 31st MARCH, 1957

LONDON

E. J. S. Clarke, T.D.	...	...	Principal Officer in Charge Metals
A. E. Drake, O.B.E.	...	...	Principal Finance Officer
C. J. Highton	...	...	Principal Legal and Lands Officer
J. A. Jukes	...	...	Economic Adviser to the Authority and Principal Economics and Programming Officer
R. A. Browning, O.B.E.	...	...	Director of Contracts
Dr. A. C. W. V. Clarke	...	...	Establishments Officer
A. W. Griffiths	...	...	Director of Patents
E. Harris	...	...	Director of Accounts
H. C. Hudspith	...	...	Chief Finance Officer
J. Lloyd, O.B.E.	...	...	Chief Labour Officer
J. Parkin, O.B.E., M.C.	...	...	Officer in Charge General Administration
E. H. Underwood, O.B.E.	...	...	Director of Public Relations
J. C. Walker	...	...	Officer in Charge Overseas Collaboration

INDUSTRIAL GROUP

Headquarters, Risley

Sir Leonard Owen, C.B.E.	...	...	Director of Engineering and Deputy to Managing Director
K. B. Ross, O.B.E.	...	...	Director of Operations
L. Rotherham	...	...	Director of Research and Development
J. C. C. Stewart	...	...	Director of Technical Policy
D. S. Mitchell	...	...	Director of Administration
D. R. Newman	...	...	Director of Accounts and Stores
D. D. W. Cole, C.B.E.	...	...	Deputy Director (Operations)
P. T. Fletcher	...	...	Deputy Director (Engineering)

* Lord Cherwell was a Member of the Authority from the time they were set up until his death on 2nd July, 1957.

INDUSTRIAL GROUP (continued)

J. B. W. Cunningham	...	...	Deputy Director (Industrial Power)
T. L. Viney	...	...	Deputy Director (Works and Buildings)
Dr. J. M. Hill	...	...	Deputy Director (Technical Policy)
H. Cartwright, M.B.E.	...	...	Assistant Director (Experimental Reactors)
W. Davies, O.B.E.	...	...	Assistant Director (Works)
H. V. Disney, C.B.E.	...	...	Assistant Director (Defence Plants)
R. V. Moore, G.C.	...	...	Assistant Director (Civil Reactors)
C. J. Turner, C.B.E.	...	...	Assistant Director (Chemical Plants)
H. F. Bannister, O.B.E.	...	...	Chief Engineer (Supply)
J. D. Glanville, O.B.E.	...	...	Chief Engineer (Inspection and Progress)
L. Grainger	...	...	Chief Metallurgist (Research and Development)
H. Kronberger, O.B.E.	...	...	Chief Physicist (Research and Development)
Dr. A. S. McLean	...	...	Group Medical Officer
F. R. Farmer	...	...	Chief Safety Officer
H. R. Johnson	...	...	Assistant Director, Overseas Relations
R. D. Gardiner	...	...	Principal Purchasing and Stores Officer

Works

Springfields	...	...	Works General Manager	Dr. H. Rogan
Northern Group Factories	...	...	Works General Manager	H. G. Davey, O.B.E.
Capenhurst	...	...	Works General Manager	S. F. Hines, O.B.E.

Experimental Stations

Dounreay	...	...	Works General Manager	S. W. Joslin, C.B., C.B.E.
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Research and Development Laboratories

Springfields	...	...	Head of Laboratory	J. Harper
Windscale	...	...	Head of Laboratory	D. R. Mackey
Capenhurst	...	...	Head of Laboratory	F. I. Hurley
Culcheth	...	...	Head of Laboratory	Dr. A. B. McIntosh
Dounreay	...	...	Head of Laboratory	C. R. Tottle

RESEARCH GROUP

Atomic Energy Research Establishment, Harwell

Dr. B. F. J. Schonland, C.B.E., F.R.S.	...	...	Deputy Director
G. W. Raby, C.B.E.	...	...	Deputy Director (Engineering)
Dr. J. V. Dunworth, C.B.E.	...	...	Head of Reactor Division
Dr. H. M. Finniston	...	...	Chief Metallurgist
Dr. W. Fry	...	...	Chief Physicist
Dr. R. Spence, C.B.	...	...	Chief Chemist
D. R. Willson, M.B.E.	...	...	Technical Secretary
T. B. Le Cren	...	...	General Secretary
Dr. K. Williams	...	...	Group Medical Officer

Radiochemical Centre, Amersham

Dr. W. P. Grove	...	...	General Manager
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WEAPONS GROUP

Atomic Weapons Research Establishment, Aldermaston

W. R. J. Cook, C.B.	...	...	Deputy Director
C. A. Adams	...	...	Chief of Research
J. E. Adamson	...	...	Group Secretary
Admiral P. W. B. Brooking, C.B., D.S.O. (Ret'd)	...	...	Assistant Deputy Director
J. R. V. Dolphin, C.B.E.	...	...	Chief Engineer
Dr. J. B. Lynch	...	...	Group Medical Officer

Woolwich Common (Electronics Engineering)

C. Smith	...	...	Superintendent
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<i>Proof Range, Foulness</i>			
E. H. Mott, O.B.E.	...	...	Senior Superintendent
<i>Advisers to the Authority</i>			
Mr. Anton Gray	...	...	Senior Mining Adviser
Mr. S. J. Pears, F.C.A.	...	...	Adviser on Accounting Matters
Mr. G. H. Nowell-Withers, C.B.E.	...	...	Chairman of the Advisory Committee of the Authority's Principal Non-Industrial Superannuation Scheme and Adviser on Pension and Taxation matters.

APPENDIX III

Balance Sheet of the United Kingdom Atomic Energy Authority as at 31st March, 1956

FOREWORD

1. The second Balance Sheet of the United Kingdom Atomic Energy Authority, as at 31 March 1956, is presented in the form prescribed by Treasury directive under the provisions of Section 4 (3) of the Atomic Energy Authority Act, 1954.

The Operating Account for the year ended 31 March 1956 is withheld from publication in the interests of national security.

2. Section 4 (2) of the Atomic Energy Authority Act, 1954, provides that any revenue of the Authority for any fiscal year shall be applied in such manner as the Lord President of the Council may, with the approval of the Treasury, direct. A directive from the Lord President of the Council dated 13 February 1956 requires the Authority to surrender all revenues, other than those not disclosed for security reasons, to the Office of the Lord President of the Council (Atomic Energy). Thus the substantial funds needed to finance large programmes of capital projects and research are provided by the Office of the Lord President of the Council (Atomic Energy) out of moneys voted by Parliament.

3. The Authority have not only to maintain adequate records to meet the requirements of Parliamentary accounting, but also a commercial system of accounting to facilitate management control and commercial operation. Good progress has been made in introducing commercial accounting throughout the Authority. At one research establishment transitional and staffing difficulties delayed the introduction of full commercial accounting to 1 April 1956.

4. The Authority's accounting has already reached a generally satisfactory standard and further improvements will be effected in commercial accounting procedures as the pattern of this new industry becomes clearer and more settled. In addition, there are problems in connection with the transition from Government Department to statutory authority, and arising from the introduction of commercial accounting, for example:—

- (a) When compiling the Statement of Assets and Liabilities taken over on 1 August 1954 some degree of estimating was necessary in dealing with the valuation of buildings, plant, equipment, &c., which had been acquired by H.M. Government over a period of many years; and the possibility of errors of duplication or omission, not insignificant in themselves but small in relation to the total figures, could not be precluded.

Such errors will be adjusted as they come to light, and although the process of investigation and analysis is proceeding final confirmation of the figures must be achieved over a period, during which adjustments of a marginal nature may be necessary.

- (b) Somewhat similar adjustments have been found necessary in respect of stocks and, in particular, of stocks in sub-stores. Most of these items have been dealt with and reflected in the accounts to 31 March 1956 and it is anticipated that the small residue will be cleared in the accounts for 1956-57.
- (c) The Authority have under review the problem, common to all research laboratories, of maintaining inventories of certain laboratory equipment which might lose its identity in experimental rigs.

5. The Balance Sheet at 31 March 1956 is in conventional form and sets out the assets and liabilities of the Authority at that date. The Capital Account reflects adjustments in respect of the prior period and shows the additions thereto during the year ended 31 March 1956 and the deduction of the net cost of operations on revenue account for that year.

6. The Authority have adopted normal commercial accounting principles, including the division between capital and revenue. The transactions on revenue account, and the conventions adopted in relation thereto, can be summarised as follows:—

- (a) The Industrial Group operates factories and the whole cost of their operation has been regarded as recoverable in the price of its products. Expenditure on research and design in aid of future projects is carried forward for later amortisation and recovery.
- (b) The whole of the cost of the operation of the Research Group less the proceeds of sales of radioactive substances, electronic equipment and other income, is regarded as the cost of fundamental research in the atomic energy field to be borne by the Exchequer.
- (c) The Weapons Group undertakes the production of components for weapons and research work in connection with weapons, both under contract from Ministry of Supply. It also undertakes other research and development. The cost of the operation of this Group, less the amounts chargeable to Ministry of Supply for production and research, and other income, is regarded as a charge to be borne by the Exchequer.

7. Provision is made in the accounts for depreciation and special depreciation of buildings, plant, &c., on a straight-line basis on original cost or estimated cost. No general provision is made for obsolescence as the Authority's policy is to undertake a frequent review of their main installations and adjust the period of write-off where it appears that the life of an installation will differ from that previously anticipated.

8. The accounts include a charge for interest on capital which has been calculated, at rates prescribed by the Treasury for Government trading accounts, on the average capital employed during the year. The rates varied during the year and resulted in weighted averages of 4.56 per cent. on fixed capital and 4.5 per cent. for working capital.

9. The Balance Sheet shows, for the first time as a separate item, the Principal Non-Industrial Superannuation Scheme. This is a contributory scheme with the employee contributing 6 per cent. and the Authority 8 per cent. of salaries. The Scheme is not funded and cash does not pass in respect of employees' and employers' contributions. The Scheme is, nevertheless, regarded as notionally funded, with the whole of its funds, apart from a small amount in respect of fully paid insurance policies, treated as deposited with H.M. Exchequer at interest. Provision has been made in the Authority's accounts for an amount of £250,000 towards the deficiency which may be disclosed by the first actuarial valuation of the Scheme at 31 March 1960.

10. Industrial workers employed by the Department of Atomic Energy at 31 July 1954 who remained in the Authority's employment retain their superannuation rights as Government servants under a special arrangement. Industrial and non-industrial staff who remain on secondment retain their rights under the Superannuation Acts. Pending clarification of the position of individual employees the Authority's liability at 31 March 1956 has been estimated and the provision made therefor in the accounts is included in the Balance Sheet under the heading "Superannuation Provisions".

11. The decision to create a Reserve for Losses (in lieu of insurance) was taken in February 1956 to cover major losses over £250. With effect from 1 April 1956 any such losses will be charged against this reserve.

28 November 1956.

UNITED KINGDOM ATOMIC

BALANCE SHEET AS

31 March

1955

£

I. CAPITAL ACCOUNT

Balance at 31 March 1955 before charging Net Cost of Operations

£

£

184,503,433

Add—

Adjustment in respect of stock valuation and allocation of receipts 1954–55

884,499

185,387,932

Deduct—

Net Cost of Operations for the period to

31 March 1955 10,385,129

Adjustment as above 884,499

11,269,628

154,659,335

Balance at 1 April 1955 per last Account

174,118,304

Add—

Prior Year adjustments (net)

249,328

Net advances from Lord President's Office (Atomic

Energy) during the year

52,832,700

25,789,462

Stocks not previously valued taken on charge during

the year

662,764

—

Assets taken over from Ministry of Works

16,182

54,648

Interest on Capital for the year

8,972,860

3,999,988

236,852,138

184,503,433

Deduct—

Net Cost of Operations for the year

18,908,573

10,385,129

Capital Account at 31 March 1956

217,943,565

174,118,304

II. RESERVE FOR LOSSES (in lieu of insurance)

Balance at 1 April 1955

700,000

—

Add—

Amount charged to operating costs in the year

1,200,000

700,000

1,900,000

III. CURRENT LIABILITIES AND PROVISIONS

Trade Creditors and Accrued Liabilities

7,424,703

2,770,109

Superannuation Provisions

771,876

521,114

8,196,579

178,109,527

228,040,144

IV. PRINCIPAL NON-INDUSTRIAL SUPERANNUATION SCHEME

Balance at 31 March 1956

4,201,108

—

NOTES: 1. Capital commitments at 31 March 1956 in respect of New Works and Housing amounted to £60 million.

2. The Authority do not insure and carry their own risks for fire, explosion, common law, third party and similar accidents. In the year to 31 March 1956 claims as settled were charged to operating costs. A reserve for losses in lieu of insurance has been created.

3. The amount shown as due from H.M. Exchequer to the Principal Non-Industrial Superannuation Scheme is made up as follows:—

Transfer Values in respect of Civil Servants transferred to the Authority

2,961,096

Excess of Contributions and other receipts over benefits and other outgoings for the period 1 August 1954 to 31 March 1956...

1,093,747

Interest on Funds remaining with H.M.

Exchequer

144,925

£4,199,768

£178,109,527

£232,241,252

ENERGY AUTHORITY
AT 31 MARCH 1956

31 March 1955 £		As valued at 1 August 1954 plus additions at cost less disposals £	Depre- ciation £	£
	I. FIXED ASSETS, at cost or estimated cost less depreciation:			
309,698	Freehold Land	349,455	—	349,455
41,339,336	Buildings, Housing and Hostels	51,618,866	3,885,763	47,733,103
	Plant and Machinery Ancillary Installations, Motor Vehicles, Loose Apparatus, Tools and Equipment	59,183,667	6,901,638	52,282,029
51,903,190	Furniture, Fittings and Office Machinery	1,653,139	87,791	1,565,348
1,300,869	Capital Assistance—assets with assisted contractors	622,538	145,306	477,232
577,089				
95,430,182		113,427,665	11,020,498	102,407,167
14,587,536	Assets in course of construction ...			30,458,412
110,017,718				132,865,579
	II. SPECIAL DEVELOPMENT AND DEFERRED REVENUE EXPENDITURE LESS AMOUNTS WRITTEN OFF			
1,326,207	Initial production expenses		783,002	
1,170,990	Research and Development expenditure in aid of design		2,691,341	
				3,474,343
	III. LOANS, ADVANCES AND INVESTMENTS			
22,405,761	Loans and advances for the production of uranium, including accrued interest		25,379,546	
	Geothermal Development Ltd. £			
10,000	Shares at cost	10,000		
—	Less Provision for loss	10,000	—	
	Investment at cost in £16,064 3% Electricity Stock 1968-73 deposited with the Supreme Court under Sec. 35 (4) of the Road Traffic Act, 1930 (Market value £12,259)		14,871	
14,871				25,394,417
	IV. CURRENT ASSETS			
11,408,614	Stocks of raw materials and stores		17,227,004	
29,729,516	Work in progress... ..		45,671,576	
1,239,727	Debtors, deposits and payments in advance		2,524,796	
	Balances with Paymaster General, with Bankers and in hand		882,429	
786,123				66,305,805
178,109,527				228,040,144
	V. PRINCIPAL NON-INDUSTRIAL SUPERANNUATION SCHEME FUND			
—	Amount due from H.M. Exchequer (see Note 3) ...		4,199,768	
—	Insurance Policies		1,340	
				4,201,108
<u>£178,109,527</u>				<u>£232,241,252</u>

E. N. Plowden, Chairman
D. Perrott, Member

APPENDIX IV

THE AUTHORITY'S REACTORS, 31st MARCH, 1957

Experimental Reactors at Harwell

NAME	DATE OF START-UP	PEAK NEUTRON FLUX	MAXIMUM HEAT OUTPUT	MODERATOR	COOLANT	FUEL	PURPOSE
1. GLEEP	1947	3.7×10^{10} thermal n/cm ² /sec	100 kW	Graphite	Air	Natural uranium metal and oxide	Initially isotope production and general neutron physics. Now routine graphite, uranium quality testing; research with oscillator; biological irradiations.
2. BEPO ...	1948	2×10^{12}	6 MW	Graphite	Air	Natural uranium	Isotope production and general radiation source.
3. ZEPHYR	1954	8×10^8 (fast)	A few watts	None	None	Plutonium	Fast reactor studies.
4. DIMPLE	1954	about 10^8	100 Watts	Heavy Water	None	Varies	Thermal reactor studies.
5. ZEUS ...	1955	5×10^9 (fast)	100 Watts	None	None	Uranium ²³⁵	To study a particular core design for Dounreay fast reactor.
6. ZETR ...	1955	4×10^8	Negligible	Heavy or Light water	None	Uranium ²³³ , ²³⁵ or plutonium	To study physics of homogeneous aqueous systems.
7. LIDO ...	1956	10^{12}	100kW	Natural water	Natural water	Uranium ²³⁵	Thermal reactor studies, including shielding.
8. DIDO ...	1956	10^{14}	10MW	Heavy water	Heavy water	Uranium ²³⁵	Isotope production, neutron physics, radia- tion chemistry, nuclear reactor material studies.
9. NERO ...	1957	about 10^8	Less than 100 watts	Graphite	None	Slightly enriched uranium	Investigations for advanced graphite-moder- ated reactors.

Experimental Reactors under Construction

NAME	LOCATION	DATE OF START-UP	PEAK NEUTRON FLUX	MAXIMUM HEAT OUTPUT	MODERATOR	COOLANT	FUEL	PURPOSE
10. Fast Reactor, Dounreay, Caithness.	Dounreay, Caithness.	1958	—	60 MW	None	Liquid metal	Enriched uranium or plutonium	Fast reactor breeding studies.
11. PLUTO... ..	Harwell	1957	10^{14}	10 MW	Heavy water	Heavy water	Highly enriched uranium	Studies on nuclear reactor materials.
12. DMTR (Pluto type).	Dounreay, Caithness.	1957	10^{14}	10 MW	Heavy water	Heavy water	Highly enriched uranium	Studies on nuclear reactor materials.
Plutonium Producing Reactors in Production								
13/14. Windscale (2 reactors).	Cumberland ...	1950	—	n.a.	Graphite	Air	Natural uranium	Plutonium production.
Power/Plutonium Producing Reactors in Production (1)								
15/16. Calder "A" (2 reactors).	Cumberland ...	1956	—	180 MW(2) per reactor	Graphite	Carbon Dioxide	Natural uranium	Power and plutonium production.
Power/Plutonium Producing Reactors under Construction (1)								
17/18. Calder "B" (2 reactors).	Cumberland ...	1958 (1st reactor)	—	180 MW(2) per reactor	Graphite	Carbon Dioxide	Natural uranium	Power and plutonium production.
19/22. Chapelcross (2 stations, "A" and "B" 4 reactors).	Annan, Dumfriesshire.	1959 (3 reactors)	—	180 MW per reactor	Graphite	Carbon Dioxide	Natural uranium	Power and plutonium production.

1. All power stations operated, or under construction for future operation by the Authority, are "two reactor" stations. These are Calder Hall "A", Calder Hall "B", Chapelcross "A" and Chapelcross "B".
2. Total output for Calder "A" (2 reactors) is 92 MW (electrical), of which 65 MW is supplied to the C.E.A. grid. When both Calder stations "A" and "B" (2 reactors each) are in operation, the total output will be 184 MW (electrical) and the feed-back percentage from each reactor will be slightly reduced, so that the combined output to the C.E.A. grid from both Calder stations (4 reactors) will be 150 MW. The electrical output from Chapelcross "A" and "B" stations will be identical in all respects with Calder "A" and "B".

APPENDIX V

CONFERENCES HELD AT THE ATOMIC ENERGY RESEARCH ESTABLISHMENT FROM 1st APRIL, 1956 to 31st MARCH, 1957

Subject	Date
Symposium on Extensive Air Showers (Oxford)	11th-13th April, 1956.
Symposium on the Production of Controlled Thermonuclear Energy	4th June, 1956.
Tripartite Conference on Cross Sections of Fissile Nuclei	9th-13th July, 1956.
Symposium on the Chemistry of Irradiated Fuels (European Atomic Energy Society) ...	27th-28th September, 1956.
Conference on the Nuclear Propulsion of Merchant Ships	19th-20th October, 1956.
5th U.K./Canada Technical Conference ...	22nd-24th October, 1956.
Conference on Advanced Type Reactor Systems	30th November, 1956.
Physical Society Conference on Nuclear Physics, including High Energy Physics ...	16th-17th January, 1957.
Conference on the Utilisation of Heat from Nuclear Reactors	18th January, 1957.
Symposium on Design, Construction and Use of Glove Boxes	19th-21st February, 1957.

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