

UNITED KINGDOM ATOMIC ENERGY AUTHORITY

FOURTH
ANNUAL REPORT
1957-58



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Annual Report

ERRATA

Page 60, Appendix IV, line 1, *Delete* " 1st March, 1957 " and
substitute " 31st March, 1957 "

Page 65, Appendix V. Experimental Reactors at Harwell.

1. GLEEP. Col. 3 " Peak Neutron Flux " should read

" 3.7×10^{10}
thermal n/cm⁻²/sec⁻¹ "

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UNITED KINGDOM
ATOMIC ENERGY AUTHORITY

FOURTH
ANNUAL REPORT

For the Period
1st April 1957—31st March 1958

*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 1958*

LONDON
HER MAJESTY'S STATIONERY OFFICE

PRICE 4s 6d NET

United Kingdom Atomic Energy Authority,
11, Charles II Street,
London, S.W.1.

13th June, 1958.

SIR,

I have the honour to submit, in accordance with Section 3 (5) of the Atomic Energy Authority Act, 1954, the Fourth Annual Report of the United Kingdom Atomic Energy Authority. This Report covers the period from 1st April, 1957, to 31st March, 1958.

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

FOURTH ANNUAL REPORT

1957—1958

CHAPTER I

INTRODUCTION

1. During the year ended 31st March, 1958, the Authority's principal tasks continued to be the fulfilment of defence commitments, research and development on the civil applications of nuclear energy, consultancy service to the electricity authorities and collaboration with industry in connection with the nuclear power programme. In all these fields, substantial progress was made during the year.

2. The first British nuclear weapons in the megaton range were exploded on Christmas Island in May, 1957.

3. At Harwell the zero energy thermonuclear assembly ZETA started to operate on 12th August, 1957. The results so far achieved are reported in Chapter VII of this Report. The materials-testing reactor PLUTO became critical on 25th October, 1957. The zero energy reactor NEPTUNE started working on 7th November, 1957. A successful Wigner energy release was carried out in BEPO in March, 1958, using a new method. A large installation for remotely handling irradiated fuel elements at very high activities has been brought into use in connection with the study of irradiation effects.

4. At the Radiochemical Centre, Amersham, the Marquess of Salisbury in November, 1957, opened the new radiochemical laboratory and a new office building.

5. The third reactor at Calder Hall became critical on 12th March, 1958.

6. The construction of the fast reactor and the materials-testing reactor at Dounreay, and of the facilities for housing a land based prototype submarine reactor, made good progress.

7. The Winfrith Heath Act, 1957, was passed into law on 31st July, 1957, and by the end of the period under review a building labour force of 600 was employed on the site. The new establishment will be known as the Atomic Energy Establishment, Winfrith. Plans have been made to take over an Admiralty Establishment at West Howe to serve as an engineering unit for the establishment. A programme has been formulated for the first phase of development at Winfrith: this includes a high temperature, graphite-moderated, zero energy reactor to be commissioned in 1959.

8. During the year, the Authority's staff increased from 27,290 to 30,341.

9. The several aspects of the accident at Windscale on 10th October, 1957, are discussed in the appropriate chapters of this report. The accident, and its consequences, had first call on the Authority's resources during the succeeding months. The measures of reorganisation, both technical and administrative, recommended by the Committees under Sir Alexander Fleck's chairmanship, will take some time to carry out. The Authority take this opportunity of expressing their indebtedness to Sir Alexander Fleck and to the members of his Committees for the time and effort which they have devoted to this work.

10. At the end of the period, the construction by industry of four nuclear power stations was under way, three for the Central Electricity Generating Board and one for the South of Scotland Electricity Board.

It is clear that nuclear power stations will be of substantially greater capacity than was assumed when the White Paper (Cmd. 9389) was issued in February, 1955: for example, the Hinkley Point station will have a capacity of 500 MW. An application by the Central Electricity Generating Board to site a further station at Trawsfynydd was under consideration by the Minister of Power at the end of the period. The Chancellor of the Exchequer informed the House of Commons on 29th October, 1957, that, as part of the Government's review of capital expenditure, the nuclear power programme would be rephased. The programme now provides for the installation of 5,000–6,000 MW of capacity by the end of 1966. A substantial part of the Authority's research and development effort is devoted to work directly in aid of this.

11. The National Institute for Research in Nuclear Science have decided to establish their first laboratory, to be called the Rutherford High Energy Laboratory, on a site made available by the Atomic Energy Authority adjacent to the Atomic Energy Research Establishment. The main research tool of the laboratory will be the 7 GeV proton synchrotron, which the Authority began to build for the Institute during 1957–58 and which is due to be completed at the end of 1961. Meanwhile, the Authority propose to transfer to the Institute in April, 1959, a 50 MeV proton linear accelerator, now in an advanced stage of construction. The Institute have appointed Dr. T. G. Pickavance as Director of the Rutherford High Energy Laboratory. The first Annual Report of the Institute for the year ended 31st March, 1958, is attached as Appendix I to this report.

12. In the international sphere the most notable event was the inaugural meeting of the International Atomic Energy Agency in Vienna, which opened on 1st October, 1957. Bilateral agreements were concluded during the year between the United Kingdom and the Governments of South Africa, Norway, Sweden and Italy. The European Nuclear Energy Agency (of which the United Kingdom is a member) was established by decision of the O.E.E.C. Ministerial Council taken on 20th December, 1957: the Agency came into being on 1st February, 1958. The treaty establishing the European Atomic Energy Community (Euratom) entered into force on 1st January, 1958.

13. The Authority were honoured to receive His Royal Highness The Prince Philip, Duke of Edinburgh, at their Dounreay Works on 25th October, 1957.

14. During the course of the year a total of 24,711 people visited the Authority's establishments, many of them from overseas. Foreign visitors came from the following countries:—

Arabia	Greece	Philippines
Argentina	Holland	Poland
Austria	Hungary	Portugal
Belgium	Iceland	Rumania
Brazil	Indonesia	Spain
Burma	Iran	Sweden
Chile	Iraq	Switzerland
China	Israel	Thailand
Cuba	Italy	Turkey
Czechoslovakia	Japan	U.S.A.
Denmark	Korea	U.S.S.R.
Egypt	Lebanon	Venezuela
Eire	Mexico	Viet-Nam
Finland	Nepal	Yugoslavia
France	Norway	
Germany	Peru	

15. The death occurred on 4th January, 1958, of Viscount Waverley, the report of whose Committee on "The Future Organisation of the United Kingdom Atomic Energy Project" (Cmd. 8986, November, 1953) paved the way for the setting up of the Atomic Energy Authority. Earlier, as Sir John Anderson, he was responsible for the direction of the atomic energy project during the latter part of the war. There are few who have contributed more to the development of atomic energy in the United Kingdom than Viscount Waverley.

CHAPTER II

MEMBERSHIP, FINANCE AND ACCOUNTS

Authority Membership

16. Viscount Cherwell, a part-time Member of the Authority from its creation, died on 2nd July, 1957. As Paymaster General, Lord Cherwell had been responsible for exercising general supervision over policy in the atomic energy field from November, 1951, to October, 1953, and it was during his period of office that the decision was taken to set up the Atomic Energy Authority. His wise counsel was of inestimable value to the Authority in its formative stages, and he is greatly missed by all his colleagues.

17. The Prime Minister appointed Sir James Chadwick to succeed Viscount Cherwell, with effect from 21st August, 1957, for a term of three years.

18. Sir Christopher Hinton resigned from the Authority on 31st August, 1957, on appointment as Chairman of the Central Electricity Generating Board. Sir William Cook was appointed by the Prime Minister, for a term of five years, as Member for Engineering and Production, with effect from 17th February, 1958.

19. The appointment of Sir Luke Fawcett as a part-time Member of the Authority, which had been extended, expired on 31st December, 1957. Sir Luke had been a Member of the Authority from its formation, and his wise counsel based on long experience, particularly in the field of industrial relations, was greatly valued by his colleagues.

20. Sir Luke Fawcett was succeeded by Lord Citrine, who was appointed as a part-time Member of the Authority on 1st January, 1958, for a period of three years.

21. The appointment of Sir Ivan Stedeford as a part-time Member of the Authority, which expired on 31st July, 1957, was renewed by the Prime Minister for a further two years ending on 31st July, 1959.

22. The Members of the Authority as at 31st March, 1958, are listed at Appendix II.

23. Early in 1958 alterations in the structure of the Authority were set in hand with the object of relieving the full-time technical Members from executive duties, and thus enabling them to devote more time to the formulation of policy on, and broad oversight of, the subjects constituting their own special fields. Sir Leonard Owen retained executive charge of the establishments of the Industrial Group, of which he had been appointed Managing Director in September, 1957. Dr. B. F. J. Schonland was appointed Director of the Atomic Energy Research Establishment with effect from 17th February, 1958, when he took over from Sir John Cockcroft executive

responsibility for the work of that Establishment. Sir William Penney, Member for Weapons Research and Development, continues as Director of the Atomic Weapons Research Establishment pending a new appointment to that post.

Finance

24. The Estimate of the Authority's expenditure in 1957-1958 was presented to Parliament on 19th February, 1957, and was approved for the net sum of £98,769,000.

25. A token Supplementary Estimate of £10 was approved by Parliament on 26th March, 1958, in order to sanction, inter alia, provisions for staff housing loans and guarantees. Other additional requirements, mainly concerned with pay increases and stores, materials and services, were met from savings on capital works, loans and general current expenditure.

26. The actual expenditure for the year 1957-1958 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.

27. On 17th February, 1958, an Estimate of the Authority's expenditure in 1958-1959 was presented to Parliament. This showed £105,744,010 as the net sum required, an increase of £6,975,010 over the 1957-1958 Estimate. Increases in the estimates for expenditure on Salaries, Wages, etc., on Stores, Materials and Services, on other current expenditure and on the National Institute for Research in Nuclear Science are partially offset by decreases in the estimates for expenditure on Capital Works and on Loans, and by increased receipts under Appropriations-in-Aid.

Accounts

28. In addition to the records necessary to meet the requirements of Parliamentary accounting the Authority maintain a commercial system of accounting to provide information for management and to enable accounts to be prepared in the form directed by H.M. Treasury under Section 4 (3) of the Atomic Energy Authority Act, 1954.

29. The Balance Sheet as at 31st March, 1957, was submitted to the Comptroller and Auditor-General on 28th November, 1957, and will in due course be presented to Parliament.* (The Operating Account is withheld from publication in the interests of national security.)

CHAPTER III

RAW MATERIALS

30. When the Annual Report for 1956-57 was written it appeared that for the foreseeable future the supply of and demand for uranium would be more or less in balance. Neither great shortages nor over-supply were expected. Since that time conditions have changed. It now appears that for some years at least more uranium may be available than will readily be bought. This is principally because uranium supplies, particularly in the United States, have been developed much faster than was foreseen.

* Ordered by the House of Commons to be printed on 1st May, 1958, 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 IV.

31. The Authority's own requirements have been somewhat reduced by the slowing down of the United Kingdom's nuclear power programme and the Authority are not proposing for the present to make any additional commitments for the purchase of uranium. There will, however, be increasing demands for uranium for nuclear power in many countries. The Authority have continued to encourage prospecting and the development of reserves for the future.

Combined Development Agency Contracts

32. South Africa continued to supply much the greater part of the Authority's imports of uranium concentrates during the year. The Buffelsfontein plant commenced production in July and was officially opened in October. This is the last of the plants built under the agreements concluded between the South African Atomic Energy Board and the Combined Development Agency, and completes the programme. There are now 29 approved uranium producers in South Africa, of which three are not at present contributing, one being flooded. The uranium treatment plants total 17. During the year the Agency declined proposals for the expansion of a number of South African plants and an application from a new mine to become an approved producer.

33. Uranium concentrates continued to arrive at Springfields also from the Belgian Congo, and from Rum Jungle and Radium Hill, Australia.

United Kingdom Contracts

South Africa

34. The Authority offered to take some additional uranium which had been declined by the Agency and negotiations were proceeding at the end of the period.

Canada

35. The Authority will purchase between 1st April, 1962, and 31st March, 1963, uranium concentrates to the value of about \$105 million from the Eldorado Mining and Refining Company Limited, the Canadian Government's selling agency. This uranium will come from nine mines. Negotiations are continuing for the purchase of a further quantity of uranium from the Eldorado Mining and Refining Company Limited during the period 1963-66.

Australia

36. The Mary Kathleen mine in N.W. Queensland is expected to come into production during 1958. The capital costs have proved to be greater than expected, and the Authority agreed to increase their loan to the Company from £5m. to £6m. (See Second Annual Report, 1955-56, Chapter III, paragraph 23 (a) (i).) During the year proposals for the erection of an ore treatment plant in the South Alligator River area of the Northern Territory were revived and the Authority were called upon under the terms of their 1956 undertaking (see Second Annual Report, 1955-56, Chapter III, paragraph 23 (a) (ii)) to offer a contract to companies there. Negotiations are continuing.

Central African Federation

37. The first uranium concentrates were received from the ore treatment plant at Nkana. No offers were received from small producers in the Rhodesias in response to the Authority's offer in 1957 to buy parcels of uranium ore there.

Prospecting

38. The Authority's office at Salisbury, Southern Rhodesia, continued to be mainly occupied in giving technical advice to prospectors throughout the Federation of Rhodesia and Nyasaland. An airborne radiometric survey was undertaken which covered approximately 7,000 square miles in the Urungwe area of Southern Rhodesia. In this survey the Authority were helped by a geophysicist lent by the Australian Bureau of Mineral Resources. Maps were published by the Authority showing areas of unusually high radioactivity.

39. An office was opened by the Authority at Dodoma in Tanganyika in April, 1957, to serve the East Africa territories. Plans were made for searches for minerals in Swaziland and British Guiana.

40. Discussions were held during the year with the New Zealand Mines Department and commercial interests about the assessment of reserves in the Buller Gorge and nearby areas in South Island.

41. The Geological Survey of Great Britain (Atomic Energy Division) undertook on the Authority's behalf reconnaissances in Sierra Leone, British Guiana, Jamaica, Bechuanaland, New Zealand and Southern Rhodesia. At home, the Atomic Energy Division, on behalf of the Authority, undertook jointly with the Geological Survey of Great Britain a 1,000 square mile airborne geophysical survey in south-west Cornwall, and towards the close of the year test drilling operations were begun.

42. Discussions were held with the Bureau des Recherches Minières of the French Commissariat à l'Energie Atomique in the course of which the Authority's and the Commissariat's prospecting programmes were reviewed.

Thorium, Beryllium and Helium

43. No further commitments were made during the year for the purchase of thorium concentrates. Beryl purchases were increased and the Mineral Dressing Laboratory at Harwell worked on the concentration of beryl from low-grade ores. A contract was placed with a French producer for a modest tonnage of beryllium metal for the fuel elements of the advanced gas-cooled reactor. Helium is of potential interest as a heat transfer medium in the high temperature gas-cooled reactor and drilling was commenced at a site in Tanganyika where the gas had been reported in unusually high concentrations.

Technical Services

44. During the year the Authority entered into an agreement with the Colonial Development Corporation under which the advice of the Corporation's Mining Division is made available to the Authority on mining engineering problems. A similar arrangement was entered into with the Directorate of Oversea Surveys for advice on geophysical surveys and general prospecting problems in overseas territories.

45. Technical services continued to be provided by the Radiochemical Laboratory of the Chemical Research Laboratory at Teddington, the Geological Survey of Great Britain, and the Electronics and Mineral Dressing Laboratories at Harwell. The Radiochemical Laboratory continued to work on a number of new metal extraction techniques, such as solvent extraction and resin in pulp, which might replace the now conventional ion exchange methods. The laboratory has devised a new method for detection of uranium in river waters which has been tried out successfully in certain streams in the United Kingdom. The laboratory has also patented an interesting process for recovering thoria from the liquid residues of the uranium plants in the Blind River field in Canada.

46. The Geological Survey has continued work on the identification of mineralogical specimens submitted by the Authority's overseas offices.

47. The Electronics Laboratory at Harwell has developed a new triple crystal scintillation counter of very high sensitivity for the detection of radio-active occurrences from the air; also a portable scintillation counter for ground use, having a much improved sensitivity compared with existing Geiger-Muller counters. These instruments are already in use in the field.

CHAPTER IV

PROCESSING PLANTS

Uranium Production and Fabrication

48. In addition to the supply of concentrates from South Africa, deliveries have been received, and processed at Springfields without difficulty, from the Australian mines at Radium Hill and Rum Jungle. Further quantities of concentrates have been delivered from the Belgian Congo, and the first small amount has arrived from Rhodesia.

49. The extraction process has operated so well that in addition to handling the required throughput of virgin material it has proved possible to carry out an extensive programme of uranium recovery from works residues.

50. Plant development work on the magnesium reduction process has resulted in increased efficiency of reduction and improved quality of the metal produced. The improvement in quality has simplified the casting operation, by making it possible to dispense with the special techniques previously found necessary in order to produce satisfactory bars.

51. Construction of the new extraction and metal reduction plant has continued and commissioning of the main plants will start within a few months. Careful attention has been given to the details of design, both by Engineering Branch and works staff, to ensure that as far as possible the operators are completely free from contact with any toxic or radioactive material, thus minimising the toxic hazard and the amount of protective clothing needed. The new hydrogen production plant has been commissioned to increase the supply for the existing Dryway plant and so meet the demand for additional supplies of uranium tetrafluoride. Electricity supplies to the Springfields Works have been reinforced.

52. The production of uranium hexafluoride has proceeded smoothly throughout the year, and the requirements of the diffusion plant have been met.

53. Fuel elements for Calder Hall have been produced throughout the period. In August the sequence of manufacture was modified in order to improve the heat characteristics of the cartridge.

54. In addition to the main production jobs for Windscale, Calder Hall and BEPO, a variety of special orders was completed at Springfields, including blanket elements for the Dounreay fast reactor and various rods and tubes for use in criticality experiments.

55. The fuel element production plants for the fast reactor and materials-testing reactors have been constructed at Dounreay. The fast reactor fuel element plant had started operation with training runs on dummy elements at the beginning of the period under review. The manufacture of actual reactor elements started in July, but a design modification in August

made it necessary to break down and reassemble those already produced. Part of the first charge, clad in stainless steel cans, was completed before the end of 1957. Some difficulty in achieving satisfactory inert atmospheres in certain parts of the plant has led to delay in completing the niobium-vanadium clad fuel elements which make up the rest of the charge.

56. Four charges were produced for DIDO and PLUTO in 1957. Early in 1958 the first charge of fuel elements for the Merlin research reactor of Associated Electrical Industries at Aldermaston was made, and since then the plant has easily kept pace with demands. During the year, the associated billet production and recovery plants have been commissioned.

Production of Fissile Material

57. The diffusion plants at Capenhurst have operated throughout the year. The extensions carried out and commissioned in accordance with the programme have resulted in a progressively increasing output of uranium hexafluoride highly enriched in the uranium-235 isotope. The latest extension has involved the assembly, installation and commissioning of stage units of new design and larger size, together with their associated ancillary plants and services. Most of the initial difficulties have been overcome but detailed tests are in hand with the object of improving still further the performance of these stages.

58. Certain components of the section of plant which has been in service for the longest period are being replaced by others of improved design, which have been developed during the past five years. It is expected thereby both to increase performance and reduce maintenance, thus leading to a higher output and a lower product cost.

59. Some progress has been made in the application of new techniques for enrichment determination, which will improve the technical control of the plants.

60. The first stage of the reconversion of uranium hexafluoride to metal, i.e., its conversion to uranium tetrafluoride, is now carried out at Capenhurst. The plants have worked well throughout the year. In addition, small processing plants for the treatment of residues have been successfully commissioned and operated.

61. The main plutonium line and associated plants at Windscale have operated satisfactorily without any major difficulties. Irradiated fuel elements from reactors in France and in Canada have also been processed. In the early part of the year the north unit of the primary separation plant, which had been modified to give a large increase in its capacity, was commissioned and achieved the scheduled throughput. At the same time work was started to prepare the south unit for a similar modification. Four months' work on decontamination of the medium active section reduced the level of activity sufficiently for engineering work to proceed and the modifications are well in hand. Similar operations in the plutonium purification plant have considerably increased the capacity of one unit and work has started on the decontamination of the second.

62. The plant for producing highly enriched uranium metal from uranium tetrafluoride has operated satisfactorily, and a large variety of residues containing enriched uranium has been processed.

Other Chemical Plants

63. A purification process for the uranium stream from the primary separation plant, using tributyl phosphate as solvent, has been tested in

one unit of the uranium purification plant. The object is to increase the decontamination factor from residual fission products.

64. The experimental caesium extraction plant has operated throughout the year and eight sources totalling about 9,500 curies of caesium have been despatched. The prototype is difficult to operate, but it is providing valuable experience for the design of a large scale plant.

CHAPTER V

AUTHORITY REACTORS IN BEING OR UNDER CONSTRUCTION

Part I

PRODUCTION REACTORS

Windscale

65. Until the accident of 10th October, 1957, the two piles at Windscale had operated normally and in accordance with the programme. Following the accident in No. 1 pile, No. 2 pile was shut down on 18th October, and will not be restarted until the Technical Evaluation Committee, under the chairmanship of Sir Alexander Fleck, has reported on the conditions to be complied with in operation.

Cause of the Accident to No. 1 Pile

66. On 10th October, 1957, a fire occurred in some channels of No. 1 pile, Windscale, releasing radioactivity to the surrounding countryside. The Authority set up a Committee of Inquiry under the Chairmanship of Sir William Penney to investigate the cause of the accident, the measures taken to deal with it and its consequences. The Authority accepted the report of Sir William Penney's Committee, a shortened version of which was issued in November, 1957, as a Government White Paper (Cmnd. 302), and the following account of the accident is a summary of this report.

67. When irradiated in reactors of this type in which, since they are not used for power generation, the coolant enters at a low temperature, the cooler parts of the graphite moderator become affected by irradiation. One manifestation of this is the accumulation of stored energy (Wigner energy) which may be released on raising the graphite temperature sufficiently above the normal operating temperature. The Windscale piles have been annealed at suitable intervals to control the release of the Wigner energy, and eight such releases had been carried out on No. 1 pile without incident prior to the release which led to the accident.

68. The pile was shut down on 7th October, 1957, and preparation for the release was completed. The general procedure for release of Wigner energy was to apply nuclear heating with no air flow, thus raising the graphite temperature until release of the stored energy commenced, the release then being self-sustaining. The first application of nuclear heating made on this occasion commenced at 19.25 on Monday, 7th October, and was stopped early the following morning. A second nuclear heating was applied at 11.05 on Tuesday, 8th October, to maintain the release of Wigner energy, and this second heating is believed to have caused unduly high temperatures in certain regions of the pile and to have led to the failure of one or more uranium cartridges. The rise in graphite temperature caused oxidation of the exposed uranium and gradually led to the failure of other cartridges and their combustion, together with combustion of magnesium lithium cartridges and the graphite. By the evening of Thursday, 10th October, some

150 channels were affected. The cause of the accident could have been the failure of a magnesium-lithium cartridge, but this was thought to be unlikely. Attempts to discharge the glowing channels were unsuccessful because of distortion of the cartridges, and the use of carbon dioxide to quench the fire was ineffective as the temperature of the affected region was too high. The fire was eventually put out by the use of water, which was turned on at 08.55 on Friday, 11th October. By Saturday afternoon, 12th October, when the water was turned off, the pile was cold.

Technical Evaluation Committee

69. After Sir William Penney's Committee had reported, the Prime Minister asked Sir Alexander Fleck to form a Technical Evaluation Committee to study the technical information relating to the design and operation of the Windscale piles deriving from the accident, to review the factors involved in the controlled release of Wigner energy and to make recommendations on future procedures for this operation and also regarding the re-starting of the Windscale No. 2 pile.

Calder Hall "A"

70. No. 1 reactor was completely discharged in April, 1957, and the "gags", which control the flow of coolant gas through each individual channel, were adjusted to bring temperatures into line with design. On restarting, a heat output of 180 megawatts was achieved with an electrical output of 42 megawatts. In August some experimental cartridges were discharged and the opportunity was taken to make adjustments, including the loading of some channels with absorber. As a result, the heat output was increased to 200 megawatts with an electrical output of 45 megawatts, and this has been maintained. During the period of the report only one cartridge was found to be defective. Experience with this cartridge led to a decision to modify the recording equipment of the detection gear.

71. No. 2 reactor operated at design power from April, 1957, to January, 1958, when a discharge of cartridges from the inner zone took place. The new cartridges were fitted with long braces. Four defective cartridges were identified during the year, and six channels were discharged on account of suspected defects.

72. Electricity exported from Calder Hall during the period amounted to 438,797,000 units.

Calder Hall "B"

73. Construction work progressed satisfactorily and No. 3 reactor, together with two turbo-alternators, was handed over to the Operations Branch in February. The reactor became critical on 12th March, 1958. Construction of No. 4 reactor was virtually complete at the end of the period. The pressure vessel had been stress-relieved and graphite laying was well advanced. The cooling towers were finished, and the building and civil work on the rest of the station were in their final stages.

Chapelcross

74. Some of the ancillary buildings, including the Administration Block, had been completed by 31st March, 1958. The first reactor, due to be handed over in September, 1958, had reached the final stages in equipping the pressure vessel circuits and other mechanical and electrical installations. Building and civil work on the second reactor were well advanced. The pressure vessel had been stress-relieved and pressure-tested, and the four heat exchangers had been lifted into position. On the third reactor, the stage of stress relieving the pressure vessel had been reached, and the

biological shield walls of the fourth reactor were complete. Staggering of construction enabled the same heavy lifting equipment to be used for each reactor in turn, and installation of the last pressure vessel, section by section, was going ahead at the end of the period.

75. The turbine hall and control building were weatherproof; the first turbo-alternator and dump condenser had been installed. Other civil engineering work, including the cooling towers and fuel element storage pond, was progressing in accordance with the programme.

Part II

EXPERIMENTAL REACTORS

Fast Breeder Reactor Experiment, Dounreay

76. The diversion of effort necessitated by the Windscale accident, together with certain modifications to equipment within the biological shield, have caused some delay in the completion of the reactor. All the civil engineering work and the major mechanical construction in the reactor building were completed within the period. The steel containing sphere, 135 feet in diameter, was successfully pressure-tested. The rotating shields on top of the pressure vessel, which allow the charge-discharge machine to be located over every individual fuel channel, and the main seals associated with the reactor vessel, passed their operational tests. The pipework and pressure vessels of both primary and secondary liquid metal coolant circuits had been erected and were undergoing pressure and leak tests.

77. The heat exchanger equipment was complete, apart from some electrical wiring, and had been tested. Several of the diesel-driven generator sets had been commissioned. Construction and erection work on the turbine house was in line with the programme, and the sea-water pump-house with its associated mains had been commissioned.

78. The Fleck Committee on the Organisation of the Industrial Group recommended in its report* that the staffing of existing production facilities should be strengthened, if necessary at the cost of concentrating the Authority's future development programme on fewer projects. As the fast reactor is a relatively long-term project its priority is lower than those projects more immediately concerned with the nuclear power programme; in particular, at Dounreay, the Materials Testing Reactor is a much more urgent requirement. In consequence, the diversion of operating staff will make the commissioning period longer than was planned, and the programme has been amended, with the result that the date when the fast reactor will become critical has been postponed from 1st April, 1958, for several months.

Advanced Gas-Cooled Reactor

79. The gas-cooled, graphite-moderated reactor for power production is being further developed by the industrial consortia, but the use of uranium metal rods and magnesium cans imposes definite limits on the operating temperature. Higher temperatures are needed to get a further large increase in efficiency. These can be achieved by replacing the uranium metal by a ceramic compound, and by replacing magnesium as the canning material by some other metal, such as beryllium. This represents such a major change in design that it is considered desirable to develop the new technologies involved by building a prototype reactor. The planning of this

* Cmnd. 338.

project started in September, 1957. The objective is the design, construction and operation of a carbon dioxide-cooled, graphite-moderated reactor experiment operating at a temperature intermediate between the improved Calder Hall type of reactor and the high temperature, gas-cooled reactor system.

80. The present intention is to use beryllium-clad uranium oxide as fuel, but the reactor will be designed in a way that permits alternative forms of high temperature fuel to be tested on a large scale. The uranium oxide will be enriched to about twice the normal concentration of uranium-235, which should permit higher burn-ups to offset the greater initial cost of beryllium cans and enriched fuel.

81. The lower capital cost of the advanced gas-cooled reactor will offset the falling load factor which will inevitably occur as nuclear power supplies an increasing proportion of the nation's electricity. It is also possible that this reactor system might, in a scaled-down version, be suitable for merchant ship propulsion.

82. The main factors to be investigated in design and operation of the advanced gas-cooled reactor are:—

- (a) The effects of operation at high temperature, high pressure, high neutron flux and high burn-up on beryllium clad, uranium oxide fuel elements. Statistical information is required.
- (b) The effects of high temperature, high pressure and high neutron flux on the life of the graphite moderator.
- (c) The compatibility of carbon dioxide at high pressure and temperature with reactor materials generally.
- (d) The control aspects of highly rated gas-cooled reactors.

83. This information will become available for use in the design of base load stations within a few years and those commissioned after 1965 should benefit by it.

84. The plant will have a mean core rating of 8 MW (heat) per tonne of uranium contained in the fuel, with parts reaching a peak rating of almost 18 MW (heat) per tonne, which will provide a substantial lead over the ratings expected in the civil stations up to 1965.

85. Test facilities will be incorporated for proving advanced types of fuel elements. Additional loop systems are being designed now (since these affect the design of the reactor) to test fuel elements to destruction and also to investigate operation with gases other than carbon dioxide. Four loops will be provided for the former and one for the latter.

86. It is proposed to site the reactor at an existing establishment, and work is expected to start in the third quarter of 1958. The reactor should be in operation by mid-1961.

Part III

RESEARCH REACTORS

87. A new, large materials-testing reactor, PLUTO, became critical at Harwell on 25th October, 1957. PLUTO is a heavy-water moderated reactor using enriched uranium fuel and running at 10 MW power; it is much like DIDO, which first operated in 1956. Since October, 1957, PLUTO has been used for a series of trials at low neutron flux. When fully operational it will have a high neutron flux and will be used for testing materials and components.

88. DIDO was brought up to the designed high thermal-neutron flux in stages and has been operating at this flux for 80 per cent of the time since March, 1957. The radiation levels available have been used to produce isotopes of high specific activity and to study radiation-affected chemical reactions of interest for the nuclear power programme. The reactor is also being used to study the behaviour of reactor fuels at high neutron fluxes and high burn-ups. The techniques for using high-flux reactors are highly specialised and require considerable practical experience among a large number of people. The experience gained with DIDO will be of great value to the designers of equipment for use in PLUTO and in the Dounreay Materials-Testing Reactor (D.M.T.R.).

89. A large programme of work on the effects of radiation on fuels and other materials is planned in connection with DIDO, PLUTO and other reactors. For this programme installations were completed at Harwell during the year in which irradiated specimens having very high activities, up to 100,000 curies, can be examined. These include concrete caves, equipped with master-slave manipulators, in which complete fuel elements, such as those from Calder Hall, can be handled; the cans can be removed, the uranium cut into sections, and physical and mechanical tests made. Small specimens cut in these caves from fuel elements are transferred for further examination to lead-shielded boxes in which activities up to 100 curies can be handled. Various physical and mechanical tests are made on these specimens, including measurements of hardness, elasticity, and brittleness. Specimens are examined metallographically, polishing, etching, and microscopic examination all being carried out by remote control. Several hundred specimens of irradiated fissile material have already been examined. Evidence is being gathered about the effect of irradiation on the micro-structure of the metals. The combination of high flux reactors and the new installations for post-irradiation examinations has speeded up this work.

90. A reactor (D.M.T.R.) practically identical with PLUTO is nearing completion at Dounreay. This reactor will have eighteen cavities in which specimens may be irradiated at various fluxes. In an initial programme of work in connection with the development of gas-cooled thermal reactors for civil power stations, the reactor will be used for irradiation of uranium fuels, casing materials, graphite and other materials. This will be followed by longer-term work on the measurement of the physical and mechanical properties of these materials during irradiation and upon the properties of steels suitable for constructing reactor pressure vessels. Experimental rigs to contain the specimens under controlled conditions during irradiation are being built. The heavily shielded cave, in which irradiated rigs will be dismantled for removal of the specimens, is nearing completion, as also is the building in which the irradiated specimens will be examined.

91. Another reactor at Harwell, NEPTUNE, became critical on 7th November, 1957. This is a zero energy reactor, moderated by ordinary water and fuelled with enriched uranium, and is designed to allow many different kinds of cores to be assembled rapidly. It is being used to study the physics of water-moderated reactors, and especially of pressurised-water reactors for ship propulsion.

92. HAZEL (formerly called ZETR II) is a zero energy reactor in which the fuel is a solution in heavy water of uranium-235 or uranium-233. The reactor is made critical by pumping the solution into a cylindrical tank surrounded by a graphite reflector. The first experiment with this reactor was completed in February, 1958.

93. LIDO, the 100 kW swimming-pool reactor, has operated at various flux levels throughout the year in order to supply a source of radiation for experiments on light weight shielding. The main aim of these experiments has been the development of a shield for the submarine nuclear reactor; the chief users of LIDO have thus been the Admiralty workers attached to the Atomic Energy Research Establishment.

94. NERO, the zero energy, graphite-moderated reactor, has been operated during the year with five different arrangements of fuel in the core. The detailed study of neutron behaviour in each of these cores has indicated improved theoretical methods that may be used in designing the advanced gas-cooled, graphite-moderated nuclear power stations.

95. BEPO, the air-cooled, graphite-moderated reactor, has continued to operate at 6 MW power during most of the year. In addition to radioisotope production and small scale experiments, a few large reactor loops have been operated in it. The loop, which is a replica of a Calder Hall channel, has been modified to provide further information on reactions between carbon dioxide and graphite. Work with a medium-pressure water loop has given valuable information for the pressurised-water reactor for the Admiralty. A loop in which organic liquid coolant is circulated has been operated in the reactor.

96. As BEPO was completing its tenth year of operation it became necessary to undertake long-term maintenance. The normal operating programme was therefore interrupted during January to March, 1958. In March a Wigner energy release was successfully carried out. The preparations and operating procedure (which was new) for the release were approved beforehand by the Fleck Technical Evaluation Committee and by the Authority's Safety Executive Committee. No unforeseen problems were encountered in the operation. This is the second time that a Wigner energy release has been carried out successfully on BEPO; the first was in April, 1954.

97. GLEEP, the oldest of Harwell's reactors, continues to be the main installation for checking nuclear purity of all materials used in the nuclear power programme. The experiments are done by moving samples of the materials in and out of the reactor by means of a pile oscillator. There are two oscillators in GLEEP, the larger one being used for routine tests and the smaller mainly for general research purposes. An oscillator similar to the small one has been installed in DIMPLE (the heavy-water-moderated, zero energy reactor). The research programme being carried out in these oscillators is directed to the measurement of neutron cross-sections on many separate materials and on fuel samples irradiated to different burn-ups. Other applications of GLEEP include its use as a source of neutrons for lattice studies and reactivity studies in connection with the development of Calder Hall type reactors, and for studies by the Medical Research Council of the biological effects of radiation.

98. ZEPHYR and ZEUS, the two zero energy fast reactors, have been used to obtain experimental data required for the development of fast reactors. In ZEPHYR, which is fuelled with plutonium, the possibilities have been explored of fast reactors in which there is some multiplication of thermal neutrons. The zero energy study in ZEUS (the uranium-fuelled system) of a simulated Dounreay fast reactor core was completed and the reactor has now been dismantled.

99. A light-water-moderated research reactor, HERALD, with forced water cooling, capable of operation at 5 MW heat output, is being constructed at the Atomic Weapons Research Establishment. Its purpose is

to provide intense beams of thermal and epithermal neutrons for general nuclear physics experiments, and an experimental region of high neutron flux for the irradiation of small samples to be used in radiochemical research. The high unmoderated flux available will also be applicable to studies of fast neutron damage in materials. An experimental facility, HORACE, has been constructed for the study of possible core arrangements in HERALD. Data obtained from these experiments will shorten the programme for bringing HERALD into operation.

CHAPTER VI

THE REACTOR RESEARCH PROGRAMME

100. During the year under review, the Authority's continuing appraisal of a wide variety of possible reactor systems has made it possible to discern with greater clarity the lines along which advances are most likely to be made during the next two decades. Technological and scientific knowledge is growing so rapidly, however, that no firm long-term programme could or should be formulated.

101. A primary objective of the Authority during the 1960s will be to realise the maximum development potentialities of the gas-cooled, graphite-moderated reactor system. Experience in the operation of the Calder Hall reactors, and the advances marked by the designs of successive commercial power stations, have demonstrated that this successful system is capable of still further development. In parallel with this work, the Authority are continuing to study the development of other systems which might be employed in succession to, or alongside, the latest reactors of the gas-cooled system.

102. By the 1970s, work on the fast breeder reactor system may have reached a stage at which commercial power stations can be built. Another system with a long-term development possibility, the high-temperature gas-cooled reactor, is receiving detailed consideration as a potential large-scale nuclear power station reactor.

103. Work is progressing upon submarine and merchant ship propulsion.

104. Research work aimed at producing energy from controlled thermonuclear reactions (see Chapter VII) has made good progress, but the prospects of commercial exploitation are necessarily long-term. It is impossible yet to suggest when a contribution to power supplies from this source can be expected.

105. Some of the work referred to above is described in other chapters. This chapter covers work done or in progress upon the remaining reactor systems or applications which have been mentioned.

106. Like any other reactor system, the advanced gas-cooled reactor will present many new design and development problems and attention has been drawn to these in Chapter V. It would be imprudent to base a future programme entirely upon the assumption that all the improvements which it is hoped to achieve with this system will in fact be realised at an economic cost. Accordingly, the Authority have continued to study other reactor systems which might be employed in commercial power stations by the mid-1960s should progress along the Calder Hall route be less rapid than expected.

Gas-Cooled, Heavy-Water-Moderated Reactor

107. The best possible alternative system for a commercial nuclear power station in the late 1960s may well be a heavy-water-moderated reactor. This conclusion has been reached in the course of feasibility studies of this class of system for small land-based power stations and for ship propulsion. The reactor does not necessarily require a containment vessel capable of withstanding a high pressure, and a design requiring only a low enrichment of the uranium fuel may be possible. It may also be suitable for a plutonium recycle fuel scheme in which the fuel feed is natural uranium. At present the main emphasis of the study is on the engineering aspects and is concerned with such matters as header design, cooling of the heavy water moderator and its thermal insulation from the hot coolant gas, and studies in heat transfer. If a satisfactory design can be evolved the first commercial station might be commissioned in the late 1960s.

Sodium-Cooled, Graphite-Moderated Reactor

108. A design study of the sodium-cooled, graphite-moderated reactor was completed in 1957. Such reactors would run at a fairly high temperature and could have a high thermal efficiency. They must be built in large units to achieve economy of operation and they could have low capital costs. Engineering studies have, however, shown that these prospective advantages could not be realised without long and costly development. The design of a reactor which could be properly maintained and safely operated would be complex. It would be necessary to employ a considerable amount of neutron-absorbing material to prevent the sodium coolant coming into contact with the moderator; in addition sodium itself absorbs neutrons to a considerable extent. For these reasons the reactor would require an appreciable enrichment and the cost of generating electricity from a sodium-cooled, graphite-moderated reactor does not seem likely to be significantly lower than the cost of generation from a gas-cooled, graphite-moderated reactor of advanced design. It has been decided that no further work should be undertaken on this graphite reactor system for the time being.

Reactor Systems for possible use in the 1970's

High Temperature Gas-Cooled Reactor

109. In addition to work on the fast breeder reactor system (see Chapter V, paragraph 76) study has continued of the high-temperature gas-cooled reactor system. This project has several variants since both graphite and beryllia could be used as moderating materials, and there is also a possible choice of gases. Furthermore the design could use a fuel element in which all fission products are completely retained or alternatively one in which they are removed to a storage system.

110. Consideration has been given in the first instance to a system using a non-metallic fuel element in which the outlet gas temperature would be about 700°C. This reactor system would be suitable for operation with the uranium-233/thorium fuel cycle and should be capable of giving a high conversion ratio and a high burn-up. Because the principles involved in the new system depart radically from those of previous designs, it will be necessary to test them in a flexible reactor experiment before building a prototype power-producing reactor.

111. The first core design would use a graphite moderator and the proposed fuel element would be sheathed in graphite. One of the major technological problems here is the development of a reasonably impermeable sheath, since commercially available graphites are highly porous and therefore

unsuitable. Valuable research has been done at the Royal Aircraft Establishment at Farnborough on this problem.

112. Other work has been done on the absorption of gaseous fission products from the fuel elements in a trapping system, and on studies of the manner in which fission products are released from the very hot fuel. The method of chemically processing the coolant to be used in the reactor experiment has also been studied. Because of the high surface temperature of the graphite in the core, the presence of oxidising impurities in the coolant can lead to serious corrosion and mass transfer (i.e., transfer of graphite from one part of the circuit to another). Present evidence suggests that the concentration of an impurity such as carbon dioxide must be kept down to a few parts per million if the rate of attack on the graphite is to be kept to a reasonable level.

113. The research programme on the high-temperature gas-cooled reactor, in addition to a variety of mathematical, physical, chemical and metallurgical investigations includes:—

- (a) fuel irradiation studies in BEPO and DIDO
- (b) the operation of a large "in-pile" loop to be inserted in PLUTO to study on a laboratory scale the behaviour of fuel, moderator and coolant gas at various temperatures under irradiation, and
- (c) the operation of an "out-of-pile" loop to investigate the degree to which a moderator, such as graphite, at high temperatures, is affected by impurities in the coolant gas which, by chemical action, may transfer some of it away and deposit it in cooler regions (mass transfer).

114. In order to study the neutron-physics aspects of such a high temperature, moderated reactor system, a high-temperature, zero-energy system is being constructed by industry, to Harwell's specification, for installation at Winfrith Heath; this assembly should be in operation by the summer of 1959. The core of the assembly may be raised to a temperature in the range 800–900°C and the reflector to 400°C by circulating electrically-heated nitrogen through it. This system will be used, initially, to study critical concentrations of fissile and fertile materials in the core, flux distributions, control and kinetic behaviour, temperature co-efficients of reactivity, and other important characteristics of the proposed reactor experiment.

Other Reactor Systems for Large Nuclear Power Stations

115. The Authority have considered other reactor systems which might be developed. The homogeneous aqueous system raises chemical engineering problems, especially of corrosion and maintenance, which would involve a long development programme. Study of the technology of fluid metal fuelled systems has shown similar problems of corrosion and maintenance.

116. Study of these systems has shown that there is little prospect of their being developed for commercial use in the U.K. unless substantial technical and financial resources are diverted from the other objectives of the Authority.

Marine Propulsion

Submarine Propulsion

117. During the year the zero energy reactor NEPTUNE was completed at Harwell on behalf of the Admiralty. This reactor was constructed by Rolls Royce Limited, a member of Vickers Nuclear Engineering Limited, with advice from the Authority. Work with NEPTUNE is being carried out by the Admiralty in association with Authority staff.

118. The pressurized water reactor system is particularly suitable for submarine propulsion. Natural water is an efficient moderator, so that fuel elements may be placed close together and the reactor core can be correspondingly compact inside a thick pressure vessel. On the other hand, highly enriched fuel must be used because natural water absorbs more neutrons than moderators like heavy water or graphite. This inevitably means that fuel costs will be high.

Merchant Ship Propulsion

119. During the year, the Admiralty Committee established to study the use of reactors for the propulsion of merchant ships continued its work. The main objective of the committee, on which the Authority have two representatives, has been to determine a reactor system which would show a prospect of being both efficient and economic in use for marine propulsion. The diversion of scarce resources, technological skill, and development effort to the project cannot be justified until the prospect is seen of getting to sea a ship which is economic or is well on the road to that goal.

120. One conclusion from these studies is that a scaled-down version of the present Calder Hall type of reactor would not be suitable for marine propulsion, except for very large vessels. Such a scaled-down reactor would have to be rated much more highly than its land-based antecedents, and would have to follow the technology now under development for the advanced gas-cooled, graphite-moderated reactor referred to in paragraph 106. Not enough is yet known of this type of reactor for it to be prudent to proceed direct to its installation in a ship, and experience of the prototype advanced gas-cooled reactor will be used to provide information for a propulsion reactor. The Authority are collaborating with the various shipping and shipbuilding interests in the study and are providing facilities for a study by the Admiralty of a design for a nuclear-propelled naval tanker.

121. The Authority are continuing to study other systems which might in due course be used for marine propulsion. A preliminary design is in hand of a gas-cooled, heavy-water-moderated reactor suitable for installation in a ship. It is too early yet to form a view on the practicability of this proposal. Reference has already been made (paragraph 118) to the pressurized water system. If cheap fissile material became available, this system might become a possibility for merchant vessels of average size which are too small to carry the advanced gas-cooled reactor.

122. A further possible system for marine propulsion is the organic-liquid-moderated reactor system which has been under preliminary study. It offers the possibility of a compact reactor system of which the containment vessel need not be capable of withstanding high pressure.

123. To determine the degree to which the coolant is converted by radiation into undesirable polymers, irradiation studies on various organic liquids are proceeding and a large experimental loop is under construction for use in PLUTO. It is too early to make economic forecasts of this reactor system but one attractive feature is that the amount of development work required does not appear to be large. The system may have applications to power stations of 10-30 MW (E) output.

Export Reactors

124. Because of the large electrical output of the reactors being built by industry for the electricity boards, the main overseas markets are likely to be in the larger industrialised countries. Ultimately, however, the main overseas demand for power reactors may come from countries which do not possess an integrated network for the distribution of electricity, and

where, in consequence, the base load demand is comparatively small. The present nuclear power stations are clearly unsuitable to meet these requirements; such overseas countries are likely to require much smaller nuclear power stations with outputs of the order of 30 MW (E).

125. Considerable development effort will be necessary before economic reactors having an output of the order of 30 MW (E) can be produced, but it is hoped that the Authority's study of systems potentially suitable for ship propulsion, and continuing long-term work on basic reactor systems, will promote the evolution of suitable reactors.

CHAPTER VII

WORK ON CONTROLLED THERMONUCLEAR REACTIONS

Introduction

126. As stated in the Third Annual Report (paragraph 153), the object of research into controlled thermonuclear reactions is to heat isotopes of hydrogen to such very high temperatures that the random thermal motion of their nuclei causes collisions with sufficient energy for them to join together and produce new and heavier nuclei. The process, which is usually called fusion, is accompanied by the release of energy as well as the emission of neutrons and other energetic particles which are lost by the fused nuclei. The energy released would be available in various ways to heat the gas still further and the possibility exists of employing this energy for power production.

127. Before this can be done five stages of development must be passed through:

- (a) A method must be developed by which the hydrogen isotopes, in gaseous form, can be raised to high temperatures and kept at these temperatures for an appreciable time inside a containing vessel.
- (b) The temperature of the gas, either hydrogen of atomic mass 2 (deuterium) or a mixture of deuterium and of hydrogen of atomic mass 3 (tritium), must be raised to such a degree that clear evidence of a thermonuclear reaction is obtained. The temperature required in this first stage can be calculated to be some millions of degrees centigrade. Since the reaction is accompanied by the release of neutrons which pass through the walls of the containing vessel the achievement of this stage can be determined from a study of these neutrons.

It is obviously essential that the hot gas be isolated from the walls of its containing vessel otherwise it would cool rapidly, the walls would be adversely affected and the gas itself contaminated with the wall material.

- (c) The temperature must be raised still further and for a long enough time for the nuclei to react at such a rate that they create by fusion as much energy as is lost by radiation from the hot system. For deuterium, the required temperature is calculated to be 300 million degrees centigrade and for a mixture of deuterium and tritium 50 million degrees. Theory indicates that with the gas densities practicable the process must continue for about one second.

(d) The third stage must be carried to the point where the system yields a net power gain. Thus the energy obtained from fusion must exceed not only radiation and other heat losses but also the energy required by all the ancillary equipment involved in the production of the reaction.

(e) An economic power producer based on fusion reactions must be constructed.

128. Investigations which have so far been made at the Atomic Energy Research Establishment, Harwell, and at Aldermaston (the Atomic Weapons Research Establishment and Associated Electrical Industries Limited) have been concerned with the first two stages of this work only.

129. One way of achieving high temperatures is to pass a large electric current through the deuterium gas. This current sets up a discharge in the gas (analogous to the discharge in a neon advertising sign) which heats it and also produces an intense magnetic field around the column of hot gas. The magnetic field causes the discharge to become constricted, or pinched, and so to move inwards from the walls of the containing vessel. The pinch concentrates and thus heats the gas still further as well as isolating it from the walls. In one form of the apparatus the gas is contained in a ring-shaped tube called a torus. The large current required to produce the discharge is obtained by passing a primary pulse of current from a bank of electrical condensers into a transformer for which the gas itself forms the single secondary turn.

Work at A.E.R.E. : ZETA

130. Experiments at Harwell with small toroidal tubes showed that though gas discharges of this type were constricted they wriggled about in the tube and touched the walls from time to time. Over a period of several years discharges in toroidal tubes have been studied both theoretically and experimentally with the object of reducing the loss of heat to the walls through the instability of the pinched discharge. New techniques were developed and used for the measurement of gas density and temperature, and of the magnetic fields which pervade the gas. The results obtained by 1954 showed that, whilst the gas was still unstable, very high temperatures could be achieved by using high currents and metal discharge tubes of larger bore (14in. diameter). The wide tubes yield a current path in the gas which has a low resistance and consequently carries a high current for small applied electric fields. The metal walls eliminate long wave-length instabilities by eddy-current repulsion as the pinched discharge approaches them.

131. Design began in 1954 of a large apparatus (see Third Annual Report, 1956-57, Chapter VIII, paragraph 156) called ZETA (Zero Energy Thermonuclear Assembly), which was based on these results and was intended to reach currents of 100,000 ampères. The predicted temperatures were believed to be just sufficient to give rise to detectable thermonuclear reactions. At the same time research continued on the investigation of instabilities and methods of suppression. By mid-1956 the use of a steady axial magnetic field produced by coils wrapped around the discharge tube appeared to be the most promising method of suppressing instabilities of short wavelength.

132. Accordingly ZETA, which was then completely designed and partly manufactured, was modified to incorporate the additional stabilising magnetic field. In ZETA the torus has a bore of 1 metre and mean diameter of 3 metres. This tube is linked by the iron core of a large pulse transformer; a current pulse is passed into the primary winding of the transformer from a bank of condensers capable of storing 500,000 joules of energy.

This pulse in turn induces a very large unidirectional pulse of current in the gas. Current pulses up to 230,000 ampères have been passed through the ionised gas for periods up to 5 milliseconds and repeated every 10 seconds. Commissioning tests of ZETA started early in August, 1957, and the machine was run up to full power on 30th August, when nuclear reactions in deuterium were detected by the neutrons emitted. The apparatus operated more successfully than was expected from the knowledge available for the design. Spectroscopic measurements indicated ion temperatures of from one to five million degrees, maintained for periods up to 3 milliseconds. Since its start-up, ZETA has been in regular operation except for planned maintenance and for the installation of experiments to diagnose the exact nature of the reactions taking place.

133. At these temperatures a gas is in a state different from any ordinarily experienced. The electrons that normally form the outer parts of the atoms are removed, so that they consist of charged ions and free electrons. In the case of hydrogen and its isotopes the nuclei are left without any attached electrons at all. This mixture is so different in its behaviour from a solid, a liquid, or a gas, that it can be regarded as a fourth state of matter, called a plasma. A hot plasma has a high conductivity for heat and electricity which increases still further with rise in temperature.

134. A wide range of existing experimental techniques has been used to investigate the properties of plasmas. The particle concentration can be measured by determining the absorption of millimetre radio waves transmitted through the gas; the hot gas also itself generates and emits centimetric radio waves and from the study of these approximate values may be deduced for the electron temperatures. This is not necessarily the same as the temperature of the ions or the deuterium nuclei.

135. The stability of the high-temperature current channel has been confirmed by measuring the internal magnetic fields by means of probes passed through the walls of the tubes to the region of the plasma, by other probe methods, and by photographic techniques.

136. The processes occurring in the plasma can be further elucidated by examining the radiation emitted. Short wavelength radiations in the ultraviolet, vacuum ultraviolet, and X-ray regions are being studied with a number of spectrographic and X-ray devices. The intensity of the light emitted in the ultraviolet region is comparatively weak. Methods of spectroscopy have to be adapted and developed for measurements in the soft X-ray region, where the radiation is strong. It is convenient to mix with the deuterium a small quantity of some heavier gas such as oxygen or nitrogen, the atoms of which are not stripped of all their electrons, and to study the spectral lines emitted by this impurity. Many of the spectral lines for such impurity atoms at these temperatures have never before been investigated and much work remains to be done to identify and tabulate them before precise measurements of temperature can be obtained.

137. The temperature of the deuterium nuclei cannot be measured directly by spectroscopic methods, since they emit no light. The temperature of the added impurity gas can however be estimated and values up to 5,000,000°C have been recorded. Under equilibrium conditions the deuterium nuclei would have the same temperature.

138. Since the period covered by this Annual Report, it has proved possible to obtain more information about the origin of the neutrons produced in ZETA. At a discharge current of 200,000 ampères the plasma emits about 4 million neutrons per pulse. By a variety of tests it has been definitely established that these come from collisions between deuterium nuclei in

the body of the gas and not from impacts with deuterium absorbed on the tube walls.

139. The yield of neutrons is however about ten times higher than would be expected at the temperatures indicated by the spectroscopic measurements. The explanation has been found from experiments with a diffusion cloud chamber. These show that the great majority of the neutrons are produced by deuterium nuclei which have been accelerated to energies of about 17,000 electron volts in the direction of the current. These "excess energy" deuterons would be kept in the plasma by the magnetic field and could readily produce neutrons by fusion with other nearby stationary deuterons. Owing to the large number of neutrons arising from this mechanism it has not yet been possible to identify the smaller number which are to be expected from a true thermonuclear fusion process in which the nuclei are moving in random directions in temperature equilibrium.

140. It is clear that knowledge of the processes occurring in ZETA and other high current devices is as yet incomplete. Work is now going on to clarify our knowledge in preparation for a more powerful machine. The necessary information will be obtained by increasing the current in ZETA, by devising new methods of measurement and developing the instruments required. Research is also proceeding on the properties of high temperature gases, particularly on the factors affecting stability and on methods of raising the gas temperature. Some research in this field will be carried out in universities and other research establishments.

Work at Atomic Weapons Research Establishment

141. Research on controlled thermonuclear reactions is also being done at the Atomic Weapons Research Establishment, where effort has been largely concentrated on the particular problem of achieving high temperature in the gas. The preferred approach at present is to heat the gas by the method of cylindrical shock heating compression. The simplest equipment is a straight discharge tube in which the current passes between plane electrodes and returns via a coaxial metallic sheath closely surrounding the tube. The appeal of such equipment to the experimenter is confirmed by the fact that it has been used by investigators in several countries.

142. In the Atomic Weapons Research Establishment work, the electrical circuits have been designed so as to achieve very high rates of rise of discharge current, and values exceeding a million million amperes per second are measured. At such rates of rise, cylindrical shock heating compression is the dominating feature of the discharge. This method of rapid heating of the gas has to be distinguished from the ohmic heating which is always present. It may well prove to be more efficient in the higher temperature ranges. A realistic picture of the forces involved can be drawn in various ways. Thus, the current can be considered as initially passing in a sheath of ionised gas near the wall and this sheath is equivalent to many conductors in parallel; these attract each other and lead to rapid acceleration of the sheath towards the axis. Alternatively, the current can be pictured as causing a rapidly increasing magnetic field to form around the sheath and the pressure from this field drives the sheath inwards, the charged particles acquiring a high velocity. The ions have much larger mass than the electrons; therefore most of the electrical energy is converted, in the first instance, to kinetic energy of the heavy particles. A rapid volume compression occurs as the gas is driven towards the axis, and the whole process takes place within a very short time, of the order of a few

millionths of a second. Further compression of the gas can occur as a result of reflections of the shock, created as pictured above.

143. To achieve the necessary high rate of rise of current it is vital that the total circuit inductance should be reduced to a minimum. For this reason, all the capacitors and their leads are connected in parallel and individually switched into the discharge vessel by means of separate triggered spark gaps, rather than a single one as is usual. This multiple switching presents formidable technical problems. In the smaller prototype equipment 144 condensers and associated gaps operate at 10 kV and are capable of switching up to 5,000 joules of energy to the gas in a time less than one hundredth of a microsecond. A larger bank designed to operate finally at 45,000 joules (30 kV) has operated at 25 kV, and given a rate of rise of current of 1.5 million ampères per second in deuterium. The initial rate of rise of current into a short circuit can be as high as five million ampères per second, a figure exceeding any so far published.

144. Both equipments have produced neutrons from discharges in deuterium. Studies of the neutrons made with the smaller equipment have continued since February, 1957, but up to the present have been made difficult by its limited yield of about 100,000 neutrons per pulse. It is not yet possible to come to a firm conclusion as to the origin of these neutrons. It has been shown that instability of the discharge can give rise to neutron emission and the possibility of emission arising in any such fashion must be considered. It has been demonstrated, however, by applying axial magnetic fields, that the reactions probably do not have their origin in instabilities of the well-known "sausage" type. An axial magnetic field has a stabilising effect on the discharge, and consequently a marked quenching effect on neutron emission arising from instabilities; in contrast, in the Atomic Weapons Research Establishment experiments a gradual reduction with increasing fields was observed, and this observation is not inconsistent with thermonuclear origin. The gradual reduction can be explained in terms of the increased resistance to compression arising from the magnetic field. At the same time, it has been found possible by deliberately introducing additional inductance into the circuit to change the mechanism of neutron production so that the emission is then sensitive to the applied magnetic field. These experiments are reassuring in their trend and indicate that the particular fast shock equipment in use introduces new features. It should be possible with the larger equipment, already able to yield approximately 10,000,000 neutrons per pulse, to achieve better understanding of the important phenomena in the discharge and, in particular, of the heating processes. In principle the methods of heating described above are applicable to many types of machine.

Work in Industry

145. Research on controlled thermonuclear problems is also being done at the laboratory of Associated Electrical Industries Limited at Aldermaston, in close collaboration with Harwell and under contract to the Authority. Following the initial success with ZETA at Harwell a smaller apparatus, about a third of the size, built by A.E.I. and used to study instabilities, was equipped with a stabilising magnetic field and in it conditions similar to ZETA were quickly reproduced. This apparatus is known as SCEPTRE III. Ion temperatures up to 4,000,000°C were obtained for times about a quarter the duration of those in ZETA. The number of neutrons per pulse was about 100,000 at currents of 200,000 ampères. Plans are being made for a modification of this apparatus with which it is hoped to attain much higher temperatures.

International Collaboration

146. During the last twelve months several visits have been exchanged by parties of scientists from the United Kingdom and the United States in accordance with the collaboration agreement, and the results of recent research discussed. In January, 1958, in collaboration with the United States, a substantial area of controlled thermonuclear research was declassified. More recently, scientists from several European countries have visited Harwell to discuss problems of mutual interest. This exchange of information has helped towards a better understanding of some of the phenomena taking place.

CHAPTER VIII

OTHER RESEARCH AND DEVELOPMENT

147. The Authority carry out their obligation to develop new ideas and processes, in the field of atomic energy for peaceful purposes, in the Research Group centred on Harwell and in the Research and Development laboratories of the Industrial Group. The scientific activities of these two large organisations are now controlled and co-ordinated by the Member for Scientific Research; reactor and plant development is the responsibility of the Member for Engineering and Production. Broadly speaking, the functions of Harwell are to obtain fruitful basic knowledge and to follow this up by determining the feasibility of using this knowledge in the economic development of nuclear power and in the increased application of radioactive isotopes. The main functions of the R. and D. Branch of the Industrial Group are, first, to support the design branches in the technological investigations required when feasibility studies have to be translated into prototype reactors and, secondly, to provide the plants and factories of the Authority with the scientific and technical services and improvements needed for efficient operation. Sometimes the responsibilities of the two organisations are reversed and, in order to make the best use of the men and facilities available, many projects are shared between them.

148. To enumerate all the research and development activities that have been taking place is not possible in a single chapter. Instead, in this brief account, selected items of the more noteworthy basic work in nuclear and reactor physics, chemistry and electronics, which has been done by the Research Group during the year, will be reviewed. This will be followed by a survey of some of the outstanding technological investigations undertaken by the R. and D. Branch of the Industrial Group during the same period. A third section reviews research and development work carried out in the Weapons Group.

Part I

ATOMIC ENERGY RESEARCH ESTABLISHMENT

Reactor and Nuclear Physics

The methods of reactor physics

149. Since the neutrons used to activate an atomic reactor are produced from fission with an energy much too great for the production of a chain reaction in natural or near-natural uranium, they must be slowed down by a moderator such as graphite. Absorption and other casualties to the neutron population have to be cut to the limit for there are not many neutrons to spare. The reactor designer must therefore pay particular attention to the

effects of the composition, shape, and temperature of the fuel elements as well as to the behaviour of the moderator. There are two methods of approach to this problem. The first is by digital computer calculation based on the measurement of the many physical constants involved; samples of the fuel and moderator and other materials to be used in the reactor are exposed to neutron beams of a wide range of energies and their effects on the neutrons are measured. The results of these measurements are then used in reactor calculations. The second method is to set up a model of the reactor system operating at very low, so-called zero, energy and to observe its behaviour with appropriate instruments. In the present state of the art, neither of these methods by itself is adequate to predict the performance of the reactor system and the two methods are used to complement each other.

Wigner Energy in Graphite

150. An important development in graphite moderator studies has been the setting up of a joint team, employing experts in all three Groups of the Authority, to study the stored Wigner energy caused by neutron bombardment. Fast neutrons lose their energy in graphite by colliding with carbon atoms. Although most of this energy is turned directly into heat, some is stored in carbon atoms that are knocked out of position by the collisions. This effect was first recognised by Professor E. P. Wigner in America, whose name it bears. Over a long period of service in a reactor, particularly at temperatures below 100°C, the graphite can store enough energy to raise its temperature by a few hundred degrees centigrade if this energy were turned into heat. When such graphite is warmed about 50°C above the temperature at which it was bombarded, the stored energy does in fact turn into heat because the displaced atoms move back into place again and release their energy. The practice with the BEPO and Windscale reactors has been to set off releases deliberately before the stored energy becomes large enough to produce such high temperatures. Another method, which is of greater interest for the Calder Hall and civil power reactors, is to raise the operating temperature of the graphite in the reactor to allow atoms to move back again as soon as they are displaced. In this way the amount of energy stored remains always small. The researches now in progress are aimed at increasing basic knowledge and understanding of stored energy and at establishing precise numerical data to aid designers in avoiding or diminishing the effects of stored energy. A theory of the rate at which the energy is released has been developed in these researches and was used in planning the recent Wigner energy release in BEPO.

Neutron Cross-sections of Materials

151. For the determination of the basic neutron physics of samples of various materials, Harwell has extended its techniques and facilities in the use of the time-of-flight method. In this method, which enables measurements to be made rapidly, short bursts or pulses of neutrons, with a wide range of speeds, are admitted to a long, evacuated tube. Each pulse travels a considerable distance down the tube and during the journey the faster (i.e. more energetic) neutrons overtake the slower. By means of electronic gates a neutron detector placed at the far end of the tube counts the number of neutrons arriving in separate but consecutive intervals of about a quarter of a microsecond. A sample of the material being studied is placed in the tube and its effect upon neutrons of different speeds, and hence of different energies, is deduced from the detector counts for each of the time intervals. As many as a thousand consecutive intervals can be examined from one pulse, constituting 1,000 separate measurements of the effect of change in

neutron energy on the scattering, absorption or other property of the test material. Neutrons from the DIDO reactor are arranged to pass down a flight tube 100 yards long. The necessary pulses from the reactor are provided by the rapid opening of shutters (choppers) rotated at high speed.

152. In another and more comprehensive form of this method, the neutron pulses are produced from a uranium target bombarded with electrons from a pulsed linear accelerator. This technique is being developed further to increase its neutron intensity (and hence improve its accuracy) tenfold, by employing a target of nearly pure uranium-235. The equipment—termed a neutron booster—has flight tubes 200 yards long extending in different directions so that measurements on several samples can be made at the same time. In another adaptation of the time-of-flight method the neutron spectrum of energies in a reactor is obtained by pulsing the centre of a model lattice, comprising fuel and moderator, with externally supplied neutrons and measuring the time of flight of the resulting fission neutrons in different directions.

Separation of Materials for Study of Neutron Cross-sections

153. The number and complexity of the measurements of neutron interactions are growing as the art develops. Detailed measurements are required for plutonium-239 and its isotopes 240 and 241, which are formed from uranium-238 in all reactors fuelled with natural or near-natural uranium. The separated isotopes of plutonium required in milligram quantities are being obtained from the Harwell electromagnetic separator HERMES. (See Third Annual Report, 1956-57, Chapter IX, paragraph 181.) Other new materials whose constants require measurement are those isotopes which are created as fission products in the reactor fuel elements themselves; the neutron absorption, and its variation with temperature, of these isotopes (like that of plutonium) affects the performance of the reactor as time goes on. Arrangements have been made to produce these materials in separated form.

High Energy Neutrons

154. For the measurement of physical constants at high neutron energies (in excess of 50 keV) the necessary neutrons must be produced from fast proton or deuteron reactions with suitable target elements. To add to the necessary equipment in this field two 10-12 MeV electrostatic generators have been the subject of a collaborative effort between A.W.R.E., Aldermaston, A.E.R.E., Harwell, and an industrial firm. The first machine will be installed at A.W.R.E. and the second at A.E.R.E. Fundamental research with the Harwell machine will also be carried out in association with universities.

Developments in Neutron Counting

155. Neutron counters using solid or liquid scintillators have the advantage over gas counters of a much greater density and hence of greater detecting efficiency. But since they also give scintillations from the electrons produced by gamma rays it is not usually possible to count neutrons with them in the presence of gamma rays. The proton-produced pulses of light from neutrons, however, decay more slowly than the pulses of light from gamma-rays and this difference has been exploited to develop a method of separating the effects of the two rays. It has been found possible in this way to measure accurately the yield of fission neutrons from uranium-235 as a function of incident neutron energy over a wide range of energy, in spite of the gamma rays emitted as a result of neutron capture in the material.

The Parity Principle

156. Beta ray spectrometers are used at Harwell to examine the characteristics of radioactive nuclei in order to obtain information about their structure. One of the spectrometers has recently been employed to provide evidence on the failure of the parity principle in the emission of beta rays from radioactive cobalt, a matter of importance in the understanding of the basic principles governing nuclear processes.

Chemistry

Radiochemical studies of the fission process

157. There are two problems in the theory of fission on which recent radiochemical studies at Harwell have given some information. The first is concerned with the fact that a fissioning nucleus divides into fragments, the masses of which may lie within a considerable range; the question is: why is it that, for fission by low energy neutrons, these masses are more likely to be unequal than equal, though the opposite might be expected? The second problem is: at what stage in the breakdown of a fissioning nucleus are neutrons emitted—before the compound nucleus breaks down, at the instant of breaking down, or after breakdown, from the separate fragments?

158. Three lines of work have been followed. In the first, uranium-238 contained in uranium was bombarded with neutrons of high energy (14 MeV) and a determination made of the mass distribution of the fragments formed, i.e., the percentages of the number of uranium atoms undergoing fission which yield particular masses. This mass distribution was compared with the distribution obtained using neutrons of thermal energy (about 0.025 eV). These measurements showed that symmetrical fission (equal masses) was eighty times more probable with 14 MeV neutrons than with thermal neutrons. Also it was possible to deduce from the total yield of all the masses that the number of neutrons emitted in the fission process increased from about 2.5 for thermal neutrons to about 5 for 14 MeV neutrons, supporting the view that fission symmetry and neutron yields are connected.

159. The second study concerned the mass distribution of the fragments formed in the bombardment of natural uranium with heavy carbon ions accelerated in the Birmingham University cyclotron. This was the first reported determination of mass yields from heavy-ion fission. It was found that in this case symmetrical fission had increased still further relative to asymmetrical fission and also that as many as 11 nucleons (protons and neutrons) were being emitted per fission.

160. In the third study it was decided to look more closely at the way in which the symmetry of fission changes with bombarding energy. The Harwell cyclotron is admirably suited for bombardments with protons of variable energy. This is done by moving a probe containing the sample to be irradiated, radially in the dee of the cyclotron. A determination was made, for the fission of thorium-232, of the ratio between the yield of a symmetrical fragment (silver-113) and an asymmetrical fragment (barium-139), as a function of proton energy at 1 MeV intervals from the fission threshold (about 6 MeV) to 100 MeV. Contrary to all previous assumptions, it was found that the symmetry did not increase smoothly with proton energy, but exhibited a series of peaks at certain proton energy values. These peaks have been attributed quantitatively to the successive emission of neutrons from the compound nucleus as excitation increases and provide, for the first time, information about the probability of neutron emission and the probability of fission for any one nucleus. The work is being repeated for

uranium and plutonium, and here it is found that the ratio of fission probability to neutron emission probability is much greater, so that the peaks in the curve of symmetry versus energy are less marked. This change follows the general trend with increasing atomic number, as exemplified by spontaneous fission.

Capture of fission neutrons by fission products

161. The cross sections for capture of neutrons by fission products are important in calculations of reactor "poisoning". They are difficult to determine directly because of the short half life of many of the fission product atoms. The final products of such capture processes are being examined by determining the mass yields of fission products formed from very highly irradiated plutonium. The irradiation was carried out in the American MTR reactor as part of a joint programme between Harwell and the Argonne National Laboratory, U.S.A., and was continued until over 99 per cent of the plutonium was converted to fission products. The rare earths (amongst which capture cross sections are very high) have been extracted and analysed by a mass spectrometer. The extraction has entailed the development of special techniques for separating microgram quantities of pure rare earth salts on very small ion exchange columns and transferring them to the filaments of the mass spectrometer. The results show the complete disappearance of those rare earth isotopes with high capture cross sections, and the formation of rare earth elements heavier than those normally found amongst fission fragments.

Chemical effects of recoiling fission fragments

162. When a nucleus undergoes fission the two fragments recoil one from another, just as a gun recoils from its shell. The momentum associated with recoiling fragments is as great as that of any other artificially-produced elementary particle, being comparable, for instance, with that of 2,000 MeV protons. This energy is absorbed in an exceedingly small volume of matter, and consequently the chemical effects are very marked. As comparatively little is known about them a number of examples have been investigated at Harwell. Striking visual evidence of the damage produced by individual fission fragments has been given by electron microscope photographs of the surface of a lithium fluoride crystal which had been bombarded by fission fragments; etching revealed clearly the points at which the fragments had entered the crystal and disturbed its lattice.

163. Little is known about the chemical state of the fission fragments when first formed. To throw some light on this, studies have been made of fission product iodine formed in potassium iodate and in uranyl iodate. It has been found that a certain percentage of the iodine arises in the reduced state (as in an iodide) and that this percentage is independent of the amount of fission and of the amount of decomposition, within wide limits. The percentage of reduced iodine varies between one iodine isotope and another, and appears to be connected with their differing origins in the fission process.

164. A substantial proportion of the fission fragments is formed as the rare gases krypton and xenon, and a study has been made of the rate of emission of these gases from fissile materials during neutron irradiation. It has been found that for uranium metal there is an emission process over and above that which can be attributed to direct recoil of fragments through the metal surface. This emission process is faster than that which could be attributed to normal lattice diffusion, whilst on the other hand the effect of increase of temperature is less than would be expected on the basis

of normal lattice diffusion. It is considered that the enhanced emission is associated with the thermal spikes (very small regions, of atomic dimensions, in which there is intense local heating) produced by recoiling fission fragments in the surface layers of the material.

165. This investigation has been extended to materials which are of more direct interest as reactor fuels. Here the behaviour of the rare gases is important from two points of view. The first relates to reactor poisoning; xenon-135 is the most important of the fission-product neutron-absorbing poisons and its effect upon the performance of a reactor varies according to whether the xenon is confined to the fuel or is allowed to escape before neutron capture occurs. The second relates to structural damage to fuel elements; continued accumulation of rare gases in the fuel as burn-up occurs, is a major cause of the changes in dimensions and other structural failures to which fuel elements are prone. Rare gas emission under irradiation at different temperatures from uranium dissolved in liquid bismuth, from graphite uranium compacts, from cermet and ceramic type fuels, and from zirconium-uranium alloy, has therefore been studied and it is at this point that the basic radiochemical work links up with reactor technology in which fission product behaviour is a problem of prime importance.

Electronics

Gamma Ray Spectrometry

166. Nearly all radioactive elements emit gamma rays of which the energies are characteristic of the element, so by analysing the gamma radiation emitted by a mixture of radioactive elements the relative quantities of the component elements could be estimated; gamma-radiation spectrometry can thus be a powerful analytical tool. A great deal of research and development on this method has been done at Harwell, mostly devoted to the use of scintillation counters. These counters employ a crystal which emits flashes of light when a gamma ray enters it, the intensity of the flashes being proportional to the energy of the absorbed gamma ray. These flashes are converted into electrical impulses by a photomultiplier tube and the impulses are then sorted and counted by suitable electronic devices. The work has covered the scintillators themselves and (in collaboration with industry) their accompanying photomultiplier tubes, and the electronic equipment that goes with them.

167. The development of pulse-amplitude analysers for gamma-ray spectrometry and allied problems has been a major research item for several years. The circuits become very complex when a large number of sorting channels are needed, and reliability is correspondingly reduced. Recent developments using new types of circuit components such as transistors and special magnetic-core elements show promise of resolving some of these difficulties.

168. In parallel with research and development on component parts of the system, investigations have also been made into the best way of exploiting and applying the method to a variety of problems. These investigations have included the analysis of mixed fission product samples, in processes for the extraction of plutonium from reactor fuel elements, analysis of long-range fall-out and high altitude samples of bomb debris, and estimation of trace impurities in a variety of materials using radioactivation techniques in conjunction with gamma-ray spectrometry. The method was also applied successfully to a variety of analytical measurements which were needed to assess radioactivity ingestion hazards in milk, vegetables, and other foods, following the accident to the Windscale No. 1 pile.

169. A new application now being investigated is the possibility of distinguishing rapidly between thorium and uranium in ground or aerial surveys of ore deposits. Small samples can be readily identified, but the distinguishing characteristics of the gamma-ray spectra are smoothed out by a variety of absorption processes when large quantities of the radioactive source at a great distance from the detectors are involved. The magnitude of these effects is being examined to determine the practical limitations. So far, identification has been possible with sources at a distance of three feet and the possibility of identification from a height of several hundred feet, which would be of interest for aerial survey work, is being investigated.

Part II

WORK MAINLY CARRIED OUT BY RESEARCH AND DEVELOPMENT BRANCH,
INDUSTRIAL GROUP

Calder Type Reactors

Fuel element metallurgy

170. Although the behaviour of the Calder fuel elements has been exceptionally favourable, one of the aims of the metallurgical development work is to increase reliability still further. Another object is to cheapen the manufacturing processes.

171. Examination of the few defective cartridges which have occurred in the Calder Hall reactors has shown that some cans may develop minute porosities which extend into tiny leak paths along grain boundaries and permit a slight leakage of gaseous fission products. Work had been proceeding for some time on the ductility and cavitation of magnesium alloys and a modification to the cartridge assembly process has been introduced to reduce the grain size of the can metal.

172. Detailed dimensional studies, which have been carried out on the uranium bars from irradiated Calder cartridges, have shown that a very high degree of stability has been achieved in regard to surface finish, overall dimensions and bowing. The surface and growth results fully confirm the heat-treatment processes, which can now be applied equally well to both calcium and magnesium reduced uranium. The bowing measurements, on braced and unbraced cartridges with both types of uranium, have proved the accuracy of the creep data, both for thermal and irradiated creep, and confirmed the bowing theories, including the predictions relating to possible modes of complex bow in braced cartridges.

173. The swelling of uranium due to the formation of bubbles of gaseous fission products, at high operating temperatures, has been investigated. Present indications are that the amount of swelling expected can be adequately controlled.

174. Statistical trials are being carried out in the Calder reactors to study the effects of the higher burn-up demanded by the power reactors. So far, these have been made with modified Calder fuel elements, but prototypes of the power reactor elements will be tested.

Fuel element physics

175. The maximum permissible fuel element temperature is at present the limiting factor in nuclear power station efficiency, but apart from increasing this by developing materials and designs which can withstand higher temperatures, some improvement can be made by reducing the

temperature drop between can and coolant, the temperature gradients within the elements, and the temperature differences between different fuel elements. Theoretical studies and the examination of the effect of changes in fin-tip profile have both led to advances during the past year.

176. Considerable progress has also been made in the calculation of the temperature increases which might be expected under various hypothetical fault conditions and experiments have been devised to study these transients. The strains induced in fuel elements by normal thermal cycling and by possible transients have also been studied.

Operation

177. At the start-up during the operation of reactors an opportunity is presented for confirming and extending the basic nuclear design for use in future calculations. Teams of physicists and engineers from the R. & D. Branch planned experiments as part of the start-up programme for the eight reactors at Calder Hall and Chapelcross. They have been carrying out this work as appropriate stages in commissioning reactors were reached during the past year.

Components

178. The work on graphite carried out in the past year has been mainly devoted to chemical reactions between graphite and coolants, and to the physical properties, especially stored energy; this work has covered normal and unusual conditions in Windscale, and in the Calder type reactors. In addition, in the civil designs, graphite may be used in the form of special supports for the fuel elements and this has required an extensive survey of its mechanical properties.

Steel

179. The R. & D. Branch has initiated a programme, in collaboration with Harwell and the industrial consortia of companies, for the study of the mechanical properties of steels proposed for construction of reactor pressure vessels. Under irradiation the properties of steels, particularly with regard to notch ductility, may suffer an adverse change; steels which should have an increased capacity to withstand this irradiation damage have been specified on theoretical grounds and a considerable number of samples have been placed in operating reactors for irradiation over a period of time. After irradiation these samples can be withdrawn and tested to provide a basis for specifications of future pressure vessel materials. The first of these samples irradiated in Calder Hall became available during the year.

180. In collaboration with the steel industry, the properties which would permit higher temperature pressure vessel operation have been defined and the development of new steels is proceeding satisfactorily; with the co-operation of pressure vessel manufacturers and inspecting agencies, advances have also been made in fabrication and non-destructive inspection methods.

Advanced Gas Cooled Reactor

181. The design of the fuel elements to permit the high ratings has posed a series of physical problems, both in relation to temperature distribution and to heat transfer.

182. New theoretical techniques had to be devised to study the nuclear characteristics, but the broad parameters have been fixed and are now being refined; possible transient conditions are being studied.

Developments in Processing

Springfields

183. During the year, further refinements to the solvent extraction purification process and the magnesium reduction process have been developed, and the main object now is to establish a fluidised bed process for the conversion of the pure uranyl nitrate solution from the former to uranium tetrafluoride suitable for the latter.

184. In a small scale plant, several tons of UF_4 have now been made and reduced to metal successfully. The reduction process has required some modifications to suit the flow characteristics of the UF_4 . This work has led to the design of a full-scale pilot plant, the construction of which is nearly complete.

185. A number of non-standard requirements, including foreign orders, for uranium or fuel elements has, in the past, been fulfilled at Springfields, generally requiring the development of new fabrication techniques. In the past year the most interesting task has been the manufacture of several tons of very long fuel elements, involving the first industrial rolling of uranium in this country; new canning materials and fabrication methods were also developed for this fuel element. Over the years quite a wide range of techniques and facilities has been developed in this way.

Windscale

186. Theoretical assessments have indicated that in the final stages of plutonium production continuous processing would provide economic advantages, largely because criticality considerations limit batch sizes. Continuous processes for two stages of the plant have been proven and are in the process of being applied.

187. The selected flowsheet for the extraction of caesium from fission products, based on precipitation followed by ion-exchange, has been fully developed.

188. A process has been evolved for the recovery of protactinium from residues arising from the processing of Congo uranium ores, and equipment for carrying out this process is now being assembled.

189. An integrated process is being examined which will combine the operations of the primary separation, plutonium purification and uranium purification plants, using a single solvent, and also the denitration of uranyl nitrate, with a view to its introduction when the throughput exceeds the capacity of the present plants. This system will reduce considerably the problems arising from the disposal of radioactive effluents, and enable notable economies to be made in nitric acid utilisation. Sufficient development work has been done to enable preliminary flowsheets to be drawn up for design studies to commence.

Capenhurst

190. An analogue computer has been devised and constructed to enable rapid surveys to be made of the effects of individual factors on the operation of the whole plant.

191. Development has continued of mass spectrometric methods of isotopic analysis. Mass spectrometers, which are normally laboratory instruments operated by qualified staff, have been adapted to routine use by semi-skilled operators. Extensive use is being made of electronic techniques to increase the speed of the measurement. Improvements in design have increased the accuracy of measurement and reduced the frequency of main-

tenance. These developments have resulted in a five-fold increase in efficiency of the instruments used for routine analyses. For research investigations, much higher accuracy of analyses is needed and a special instrument is being built for uranium analysis which will measure changes in the isotope concentration to one part in 100,000.

192. The B_{10} isotope of boron has very powerful neutron absorbing properties and therefore is attractive for many uses, such as shut-down rods. A plant for the separation of the boron isotopes has been built and operated successfully.

Dounreay

Fast Reactor

193. The theoretical studies of transients in the Dounreay fast reactor have been continued. Fundamental tests have been carried out on the effects of very high temperatures and heating rates on the fuel element materials, checked by tests to destruction of full-scale prototype elements. This has been followed by calculations of the rate of temperature rise in different parts of the core as a function of rate of coolant loss, power level and burn-up. Each stage of the safety sequence has been shown individually to possess a very high degree of integrity. Additionally, a reactor programme has now been devised for thoroughly testing the calculations and theory at various low power levels.

194. During the year, also, many prototype fuel elements have been subjected to long-term heating and thermal cycling tests. As a result of the latter a new method of increasing the geometrical stability of the core has been devised and introduced.

195. The basic phenomena of corrosion due to liquid sodium, and sodium-potassium used as a coolant, have been studied and the effects of the important factors determined quantitatively. The oxygen content of the sodium is particularly important; methods of reducing this to extremely low levels have been developed and installed in the Dounreay Fast Reactor circuit.

Dounreay Materials-Testing Reactor

196. During the final construction stages of this reactor, preparations have been made for the considerable number of experiments scheduled for the first year of operation, most of which are of immediate importance to the Authority's programme.

Criticality Laboratory

197. When fissile materials are being handled, the quantity of fissile material and the geometry of the system must always be so regulated that a critical mass can never be assembled. This requirement places considerable restriction on design and operation of the Authority's chemical plants.

198. To extend the study of these problems, theoretically and experimentally, a Criticality Laboratory has been set up at Dounreay. The first series of experiments on the criticality of uranium solutions has been completed and will assist in the economic operation of existing plant and in the design of future plants.

Part III

RESEARCH IN THE WEAPONS GROUP

199. No establishment concerned with applied research and with development, however advanced in its techniques, can flourish without a broadly-based research programme and appropriate facilities to this end. The Weapons Group, in making the fullest use of a range of the most modern scientific equipment, has continued to extend its contribution to scientific research in the Authority over a wide field. The following paragraphs are illustrative.

200. At A.W.R.E. the 3 MeV and 6 MeV electrostatic generators and the Cockcroft-Walton accelerator have proved invaluable research tools. They have enabled a vigorous and profitable attack to be made in conjunction with the Research Group on the acquisition of fundamental data on nuclear reactions. The studies during the year have covered such subjects as energy level structure and reaction mechanisms in the light elements, experiments in fast neutron physics, and precision measurement of the energies of charged disintegration products from reactions produced by 5.7 MeV ions of helium-3. When the 10-12 MeV electrostatic generator (see paragraph 154) is completed in 1959, A.W.R.E. will have a unique range of facilities for low energy nuclear physics research.

201. A 5 MW research reactor HERALD is under construction. Its characteristics are given at Appendix V. It will provide high intensity neutron beam facilities for a wide range of nuclear research, of importance not only to the Weapons Group programme, but to the Authority as a whole.

202. The Weapons Group is particularly well equipped at Aldermaston to speed up the laborious computations that are inevitable in theoretical studies of nuclear problems. Automatic data processing machines in use include a Ferranti Mk. 1* computer, an English Electric "Deuce", and an I.B.M. 704 computer, which came into operation during the year. Computation facilities on these machines have been provided to the Research and Industrial Groups and occasionally to universities. One example of the importance of these facilities is the speeding up of solutions of problems by the Monte Carlo method. These have been reduced to an efficient routine. An extension of this Monte Carlo experience to the solution of problems on the I.B.M. 704 is likely to prove of value in the rapid theoretical assessment of problems associated with the development of reactors. The method, for example, has been applied in studying resonance absorption problems in hypothetical reactors, to problems associated with the annealing of reactor graphite, and to a range of criticality and safety problems requiring analysis.

203. Other research and experience in the Weapons Group have been of direct importance in their application by the other Groups in civil reactor programmes. A.W.R.E. has considerable knowledge of the properties of plutonium, and research continues on the physical metallurgy of this novel toxic material. An example of recent work is the accurate determination of the specific heat of the metal up to its melting point and the measurement of heats of transformation.

204. Beryllium is a metal which has unusually favourable nuclear properties and its introduction to the reactor field appears to have distinct advantages. A pressureless sintering technique has been developed to produce a material with properties superior to those obtained by using more conventional techniques. This, and other work, has enabled the Weapons Group to contribute to the Industrial Group's studies of the introduction of beryllium as a cladding material for reactor fuel elements.

205. The Weapons Group has considerable experience in the criticality problems of solid assemblies of fissile material. This experience and the facilities available at A.W.R.E. have been of assistance in settling problems concerned with the design and operation of Authority plants.

206. In addition to the Weapons Group contribution to work on the controlled thermonuclear problem, described in Chapter VII, the fundamental physics of other approaches is being explored, derived from the Group's experience in this particular field. The experience of the Group on ultra high speed photography is drawn upon for the study of transient behaviour in high temperature gas discharges.

CHAPTER IX

ISOTOPES AND IRRADIATION PROGRAMMES

207. Sales of radioisotopes continued to increase during the year, reaching a total value of £650,000, of which £150,000 was from the Isotope Division at Harwell and £500,000 from the Radiochemical Centre at Amersham. This total represents an increase of more than 20 per cent over last year's total. The proportion exported was 60 per cent.

208. An international conference on the application of radioisotopes to scientific research, organised by U.N.E.S.C.O., was held in Paris during September, 1957. The Authority were represented at this Conference, at which Sir John Cockcroft presided, and several papers were presented by members of the staff. An exhibition of techniques and apparatus in industry was given. Exhibitions of the properties and applications of radioisotopes were given also in Hanover and in several British towns.

Production and Processing of Radioisotopes

209. During the year some holes in Harwell's new high-flux research reactor DIDO were made available for radioisotope production; during 1958 some space in the second high-flux reactor PLUTO will also become available. Separation of caesium-137 from fission product solutions continues in the experimental plant at Windscale. Several large sources have been made from this material (see paragraph 211 below).

210. As reported in Chapter V, the BEPO reactor at Harwell, which is the principal source of radioisotopes in this country, was operated on a restricted schedule during the last quarter of the period. Production of isotopes in the Windscale reactors was also lost as a result of the accident in October. Supplies of the more important radioisotopes were imported during this time and there was no serious interruption of the service to users accustomed to rely upon the Authority for these materials.

Large Sources of Radiation

211. During the year one unit of about 1,000 curies of caesium-137 was supplied to the Royal Marsden Hospital to be used, in a mounting designed by the hospital, for therapy; two other 1,000 curie units have been supplied to Southampton Royal Infirmary, for a rotatable mounting designed for the hospital by the Southampton University; another unit is in use at Addenbrooke's Hospital, Cambridge. Another 1,000 curie unit, mounted in a tele-therapy machine designed in the Isotope Division, has been supplied to Westminster Hospital. A unit of 1,300 curies of caesium-137 is being shipped to a Toronto hospital.

212. Among the sources of cobalt-60 supplied, ten sources of 100 curies have been sent to 5 overseas countries for tele-therapy or industrial purposes. About 10,000 curies of cobalt-60 have also been supplied to the Wantage Radiation Laboratory for installation in their irradiation cells.

Technological Irradiation Development

213. The Wantage Radiation Laboratory at Grove Airfield was operating by the end of the period. Of the 23 irradiation cells planned, 11 were in use, and cobalt-60 sources with strengths from 200 to 4,500 curies were available. Provision has been made for two 10,000 curie, twenty 2,000 curie, and two 100 curie sources, the last for plant genetics. It is hoped to augment these during 1958 by larger cobalt sources produced in a Calder Hall reactor. A 4 MeV linear accelerator is already in use. In addition, radiation equivalent to three million curies from spent fuel elements from DIDO and PLUTO will be used for irradiations at Harwell; the building to house this assembly has been completed. By January, 1958, scientists from ten industrial firms were using the installations at Grove for research into processes of industrial interest.

214. The main work of the laboratory is concerned with the application of gamma radiation to induce physico-chemical effects which are of industrial and biological importance. The advantages of radiation in these fields are its ability to produce effects under unusual physical conditions (for example at ordinary instead of elevated temperatures) and to sterilise materials without appreciably raising their temperature.

215. The initial work in the field of industrial chemistry has been on polymerisation. Because these reactions produce a high yield at a low dose rate, they offer the best possibility for early exploitation of radiation with the relatively small sources that will be available at first. By polymerisation is meant the building of long chain molecules, or branched molecules, from smaller molecules, e.g., making the plastic polyethylene from ethylene gas molecules. Graft polymerisation is the name given to processes in which a polymer, produced by any method, is made to combine with a new unit molecule (monomer) which will then grow to form another polymer grafted to the first, perhaps as a side chain. Radiation often enables polymerisation to take place at lower temperatures or pressures than otherwise, and it has been used at Wantage to produce graft polymers.

216. A particular process which is being studied is the application of graft polymers to improving the properties of synthetic fibres such as nylon, rayon, and terylene. One difficulty with these fibres is that, because they are good electrical insulators, they collect static charges and therefore attract dust which causes soiling of fabrics made from them. The fibres may be coated with a conducting film to prevent the formation of this static charge, but ordinary methods of doing this result in a coating that tends to wash off with laundering. At Wantage Radiation Laboratory a suitable polymer has been grafted experimentally to the material of the fibre, thus making a permanent conducting film which cannot be removed by any ordinary treatment. The same principle may be applied to motor tyres; preliminary experiments indicate that, by using a synthetic fibre to make the tyre cord and growing a suitable graft polymer on it, it may be possible greatly to improve the adhesion of the cord to a synthetic rubber tread.

217. Another important group of applications is concerned with preventing the deterioration of food in store. The damage done by insects to stored products is enormous; estimates of the annual loss of harvested cereals vary from 5 per cent to 50 per cent in various parts of the world. Clearly, a valuable contribution would be made by any economic system that prevented

or reduced these infestations. Grain weevils are among the principal pests and work at Wantage has established a dose level for treating grain which will reduce to a few days the life span of these insects and will also prevent them from having any progeny. It would appear that other cereal pests are affected similarly; present evidence suggests that this dose does not impair the quality of the grain. Strains of grain weevil from all over the world are being tested to determine their sensitivity to radiation.

218. In another application, radiation is used to control an infestation by the release of radiation-sterilised mature insects. An attempt is made to swamp with cultured insects a pest population which is inherently low, or one reduced to small numbers by insecticidal treatment. The method is suitable for use only with certain kinds of insect and over fairly small areas; in current work it is being applied to the flour-mill moth, in collaboration with a local flour mill.

219. To aid plant-breeders by providing them with a wide range of plant mutations, the laboratory is investigating the best conditions to produce radiation-induced mutations, and, in particular the possibilities of crossing otherwise incompatible strains under the influence of radiation.

220. The application of irradiation to sterilisation of bones and arteries for surgical grafting has been under investigation for some time. In this work, as in many other fields involving techniques unfamiliar to the Authority, expert advisers have given valuable guidance to ensure the best lines of investigation.

New Applications of Specific Isotopes

221. New applications of radioisotopes continue to be evolved. The following are among the more interesting.

222. It is possible to make long-lived light sources of low intensity by mixing a radioactive gas, such as tritium or krypton-85, with a suitable phosphor; the radiation from the isotope excites luminescence in the phosphor crystals. Such sources have many possible applications, for example, as markers on airfields, obstruction markers in mines, signal lamps on railways, etc. A difficulty in this application is that krypton is an inert gas and does not enter into chemical compounds. However, attempts to fix the krypton atom quasi-mechanically in a molecule of basket-like construction, such as the so-called clathrate compounds, have been partly successful; a patent application has been filed for a film incorporating a suitable phosphor and sealed between sheets of a transparent plastic.

223. Radioisotopes are being used in some experiments on X-ray fluorescent spectrometry. This is a method for detecting an element by illuminating a sample containing it with X-rays; the latter excite the characteristic X-rays of the element (i.e., cause it to fluoresce with X-rays) and these can be measured by suitable detectors. In the development under investigation the expensive X-ray machine of the usual equipment is replaced by a cheap radioisotope. The method thus works with cheap and compact equipment, though the dose rate is lower from an isotope than from an X-ray tube; on the other hand it appears that elements of lower atomic number can be detected than is possible with normal fluorescent X-ray techniques. Industrial applications are being developed. In one application the thickness of deposits of chromium plating can be measured down to as little as a few millionths of an inch; the detection is selective, and chromium (or the material of interest) can be measured irrespective of base coatings of other materials.

224. Radioactivation analysis is proving a useful tool in many fields for determining minute amounts of materials. The technique has been applied in industry in the manufacture of ferrite blocks used in centimetric-wavelength radio equipment; by its use impurities were determined in the ferrite, which provided a probable explanation of hitherto unaccountable differences in performance between nominally identical blocks.

225. Many industrial applications of the tracer technique have been developed. Thus the magnitude and position of leaks in a system of pipes in an underground coal-gasification plant have been determined by injecting a pulse of krypton-85 and measuring its transit times and concentrations at two points in the system. The flow rate of the Big Spring in the Severn Tunnel was measured by dilution and by pulse-injection techniques using sodium-24. There is a need for simple methods of measuring the efficiency of industrial filters and several radioactive tracers have been tested for this purpose. The most promising one at present is to use particles of sodium-free glass containing 0.01 per cent of gold, the latter being activated by irradiation in the pile.

226. Autoradiography has been used to study surface porosity in magnesium alloys. Paraffin containing palladium-109 was forced into the metal under pressure and the position and size of the pores determined by autoradiographs. In another application of autoradiography it has been possible to show that the distribution in depth of antimony in lead alloys used for bearings is not uniform; it is difficult to think of another technique that would have given the same useful information.

227. A new thickness gauge has been developed for research on paper, in which alpha particles from polonium-210 pass through the paper and fall on a strip of photographic film. Microphotometric measurements of the resultant blackening provide, for thin paper, accurate determinations on a microscopic scale of changes in the density of the paper. A camera has been designed which enables the measurement to be made simply.

Standardisation of Sources

228. An important service is the testing and checking of the standards against which radioactive sources are measured in various laboratories. During the year 242 absolute standard, 237 sub-standard, and 82 reference sources were measured. For this work, 51 requests were from overseas, and 465 were from within the United Kingdom. The Authority were represented at two International Conferences on Absolute Measurements and Standardisation.

Labelled Compounds and Natural Radioisotopes

229. Additional facilities are being provided at Amersham to meet the rapidly increasing demand for the products and services of the Radiochemical Centre. On 1st November, 1957, the Marquess of Salisbury opened a new office building and a radiochemical laboratory. The former houses the Commercial Department which now handles some 20,000 consignments per annum and has transactions with more than fifty countries. The laboratory provides accommodation for processing beta- and gamma-emitting isotopes at much higher levels of activity than was previously possible and with the highest standards of safety. In this building a suite of "hot caves" has been installed for chemical work with fission product isotopes up to the kilocurie level. Construction of new laboratories for organic chemistry and for handling alpha-emitting isotopes has begun and is expected to be complete by the spring of 1959.

230. The use of isotopically labelled compounds is still predominantly in biological research, and additional compounds of carbon-14 which have become available from Amersham during the year reflect this interest. They include labelled sugars, amino acids, purines, fatty acids and a number of intermediary metabolites. Several carcinogenic compounds have been made for cancer research. In general there is an appreciable improvement in the quality of all these materials and they can often be made at five times the specific activity previously available. The limit of radiochemical purity now tends to be set by the susceptibility of the compound to decomposition under its own radiation.

231. The value of labelled compounds in the technology of specific chemicals such as weedkillers, pesticides, fertilisers, rubber additives and detergents is becoming more widely appreciated. The use of labelled drugs for determining the mode of action and metabolic fate is also increasing steadily. For such purposes the Centre synthesised during the year some five hundred compounds containing twenty different isotopes, and this work has recently been extended to include tritium. For clinical use, a regular supply of vitamin B₁₂ labelled with cobalt-58 has been available since January, 1958.

Isotope School

232. The Isotope School has increased considerably the scope of its activities during the past year. In addition to seven basic isotope courses and two on radiological protection, two special courses on the uses of isotopes in medicine have been held in conjunction with leading London and provincial hospitals. A fortnight's course, sponsored by the World Health Organisation, was given for health inspectors from 20 European nations. A three day course for 120 non-technical directors and executives was held with the aim of giving them ideas for the introduction of isotope techniques into their own businesses. The initial training of staff for the Bagdad Nuclear Centre (see Chapter XIV, paragraph 291) is organised by the school.

CHAPTER X

THE WEAPONS PROGRAMME

233. Research and Development work on nuclear and thermonuclear weapons for Her Majesty's Government has proceeded according to plan.

234. An important stage was reached on 15th May, 1957, when Britain's first nuclear device in the megaton range was successfully exploded in the Central Pacific. Four rounds were tested, two in May, one in June and one in November, 1957. All were burst high in the air. The operations, which were based on Christmas Island, were under the command of a Service Operational Commander. The responsibilities of the Atomic Energy Authority lay in the provision and preparation of the devices to be tested, the provision and manning of the ground instrumentation to measure the scientific results, and co-operation with the Royal Air Force in firing control. A Scientific Director was appointed by the Authority to assist the Operational Commander in technical aspects and to advise on radiological safety.

235. A test series of kiloton range nuclear weapons was successfully carried out in September/October, 1957, at the Maralinga range in South Australia. There were three rounds, of which one was suspended on a balloon and the other two were on towers.

CHAPTER XI

HEALTH AND SAFETY

Protection of the Staff against Exposure to Radiation

236. It is the policy of the Authority that all operations should be carried out with a minimum of exposure to radiation. To ensure that there shall be no harmful effects, maximum permissible levels of exposure, which have been approved by the Medical Research Council or the International Commission on Radiological Protection, are applied rigorously. The maximum permissible level for workers in radiation areas is 0.3* rads per week, and every effort is made to keep the exposure received by every individual to below 3 rads over a period of thirteen weeks. The level for those employed elsewhere is 0.03 rads per week. In addition, the Authority, on the advice of the Medical Research Council, have adopted further standards for long-term control. For whole body exposure, the accumulated dose is kept below 50 rads by the age of thirty and 200 rads by the age of sixty. Records are kept to ensure that the level of exposure does not exceed 50 rads per decade. The number of occasions during the period under review when the figure of 3 rads in thirteen weeks was exceeded was 54 and in every case steps were taken to ensure that these longer-term dose levels were not exceeded.

237. Employees working in controlled areas wear film badges to record the doses received. On special operations they may also wear films on their wrists to measure the dose received on the hand, and carry direct reading quartz-fibre electrometers which measure the dose to the body over a short period of time.

238. Apart from these individual measurements, routine monitoring is carried out wherever appreciable radiation levels are likely to exist. Special attention is paid to areas where the levels are high or are subject to considerable fluctuation. For example, routine surveys are undertaken at the faces of experimental reactors and in laboratories working on irradiated fuel or on the preparation of isotopes for commercial sale. These regular surveys are an effective check on the normal radiation control measures.

239. Nearly 100,000 surveys of the level of surface contamination in active areas have been made by the Authority over the past year.

240. The breathing of contaminated air is largely prevented by confining the contaminated air to plant areas to which there is no normal access. It is thus only under abnormal conditions, and for special maintenance work, that entry is necessary and then breathing apparatus is worn. Routine air sampling ensures that the levels of air contamination in normal working areas are satisfactorily controlled but, in addition, special air sampling is carried out for particular operations or unusual circumstances. During the past year the Authority have taken over 140,000 routine air samples and over 30,000 special air samples. By comparison with previous years these figures show a significant increase in the proportion of special samples taken. This reflects a clearer distinction between the two categories rather than any fundamental change in survey practice.

Waste Disposal

241. In addition to occupational health problems, the Authority give much attention to the problems of waste disposal. In this they are subject to the provisions of the Atomic Energy Authority Act, 1954, by which

* 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.

they are bound to obtain authorisations from the Minister of Housing and Local Government and the Minister of Agriculture, Fisheries and Food (or from the Secretary of State for Scotland), for any disposal of radioactive waste. Part of the waste material has to be stored permanently. Some is in the form of very dilute solutions and these can safely be discharged into rivers or the sea, sometimes after preliminary purification. Detailed studies are made of possible biological effects. At Windscale these studies included measurements of the radioactivity in fish, seaweed and sea bed, shore sand, and detailed studies of tidal movements and currents and their effects in diluting the activity. Similar measurements are being made at Dounreay. The results of this work are studied by the appropriate Government Departments. All establishments are regularly visited by representatives of the authorising Ministries, who inspect the records of the discharge of gaseous, liquid and solid wastes.

Normal Industrial Safety

242. The previous paragraphs have dealt mainly with hazards arising from the Authority's work with radioactive or toxic substances. In addition there are the ordinary industrial hazards which may occur in any big industrial undertaking, and the Authority regret to report that two fatal accidents of this type occurred during the year. The lost time frequency rates for the year were 0.86 per 100,000 man hours for the industrial Group, 0.43 for the Research Group and 0.67 for the Weapons Group. These figures compare with the average frequency rate of 1.73 in 1956 for all the industries which supply this information to the Factories Inspectorate.

Health and Safety Aspects of the Windscale Accident

243. During the thirteen-week period including the accident, doses recorded by film badges worn by workers exceeded the value of 3 rads in only 14 cases, the highest dose recorded being 4.66 rads. During the accident period direct reading quartz fibre electrometers were also worn. These showed that two workers received wrist doses of 4.5 rads, one received 3.3 rads and there were four others in excess of 2 rads. In all cases of workers who received doses in excess of the maximum permissible level, steps were taken to reduce subsequent exposure to radiation. There was also some hair and hand contamination, but this was successfully removed.

244. Measurements were also taken in the countryside surrounding the site. These showed that the escaping activity, consisting largely of iodine-131 together with smaller quantities of other fission products, had been carried by the wind in a direction south-south-east of Windscale. The measurements also demonstrated that, while there was no danger to health from breathing the air or from eating anything growing in the affected area, there was a possible hazard to infants from drinking milk which had become contaminated. Steps were taken to restrict the sale of milk over an area of 200 square miles, including a coastal strip running south of Windscale to a distance of 30 miles. Radioactive iodine, which was the only isotope causing concern, has a short half life (i.e., the time taken for the radioactivity to decay to half its initial value) and it was therefore confidently expected that the iodine levels in milk would fall steadily to a safe value. This, indeed, proved to be the case and the milk restrictions were lifted progressively and finally removed on 23rd November, 1957.

245. The Medical Research Council, after examining the various possibilities, reported that it was in the highest degree unlikely that any harm was done to the health of anybody, whether a worker in the Windscale plant or a member of the general public, as a result of the accident.

246. Careful measurements have made possible an improved understanding of the relationship between an increase above the normal background radioactivity, following an accident involving the release of radioactive iodine, and the effect on the radioactive content of milk drawn from cows grazing in affected pastures.

Organisation

247. At the suggestion of the Authority the Prime Minister set up a committee under the Chairmanship of Sir Alexander Fleck to review the organisation within the Authority as a whole for the control of health and safety and to make recommendations. In their report, which was published as a White Paper (Cmnd. 342) on 8th January, 1958, the Committee said that they were satisfied that there were no fundamental weaknesses, but a number of recommendations were made on points of detail. They emphasised particularly the effect on the organisation of the shortage of qualified operational staff. The Paymaster General announced in the House of Commons on 27th January, 1958, that the Government and the Authority were considering how best to implement the committee's recommendations.

248. Important recommendations in the Fleck Report concerned the training of the specialist health and safety staff who will be required in increasing numbers as the applications of atomic energy become more widespread. The importance of education in radiological problems over a wide field of industry and the public service was also emphasised. Detailed schemes to give effect to these recommendations are being prepared in consultation with the Government Departments concerned. In the meantime, the staff of the Authority's Health and Safety organisation is being built up. The Authority have also set up a Committee to advise them on the training and provision of specialist health and safety staff, not only for their own purposes, but also to meet the needs of the nation as a whole. Sir Douglas Veale, C.B.E., until recently Registrar of the University of Oxford, has accepted the chairmanship of this committee, which will include in its membership independent experts in the field under review.

249. The Authority wish to acknowledge the help they have received during the year from the Medical Research Council and the Agricultural Research Council. Not only is the advice given by the Councils invaluable in assisting the Authority in the determination and application of their standards of health control, but, following the Windscale accident, the help given by both Councils in evaluating and advising on the results obtained by the Authority's monitoring teams contributed greatly to the speed with which the situation was cleared up and restrictions removed. The Authority take this opportunity of expressing their thanks to the two Councils.

CHAPTER XII

PUBLIC RELATIONS

250. Public interest in atomic energy mounts steadily as the areas of public activity affected by its application extend. Requests for information about atomic energy in general and about the work of the Authority in particular come from all over the world. Those who wish to be informed range from the layman to the expert, with many gradations between the two extremes.

251. The Authority have a public relations staff specifically concerned with these problems, but the need to inform the public also makes heavy calls on the Authority's technical staff. Scientists and engineers are constantly

called upon to address learned societies and lay organisations, and in 1957-58 have addressed audiences in this country, and in the United States, France, Germany, Italy, Sweden, Switzerland, Portugal, Iraq, Yugoslavia and Poland. They are in demand as authors of articles for technical and other journals and for contributions to wireless and television programmes. During the year under review, Members and officers of the Authority have prepared over 1,400 papers for the purposes described.

252. Continuing press interest in atomic energy matters is indicated by the fact that the Authority's press office in London received approximately 15,000 telephone enquiries during the year, in addition to personal visits by journalists of many countries. To help cater for this interest a two-day course for United Kingdom journalists was held at the Harwell Reactor School in May, 1957. In the same month more than 150 journalists and photographers took part in a press visit to the Dounreay Works. About the same number attended the Authority's press conference on the Third Annual Report in July, 1957. The opening of new buildings at the Radiochemical Centre, Amersham, in October was the occasion of another large-scale press visit. The press conference on the White Paper "Accident at Windscale No. 1 Pile on 10th October, 1957", (Cmnd. 302) was also well attended. A further press conference was held at Harwell in January, 1958, on the occasion of the release of information about ZETA. A total of 370 journalists and photographers attended.

Exhibitions

253. The "Atoms and Health" exhibition on radiation hazards and protection, which was opened by the Marquess of Salisbury at the Royal Society of Health headquarters in London in March, 1957, continued until 31st May, 1957, and during that time had 6,000 visitors with specialised interest in the subject, such as medical officers of health and other local Government officials, doctors and nurses. This exhibit, supplemented, to a total area of 5,000 square feet, by others dealing with reactor development, the industrial and medical uses of isotopes and the careers opportunities in atomic energy, was also shown at the Birmingham Safety and Factory Efficiency Exhibition in June, and at Newcastle (in co-operation with the Rutherford College of Technology; King's College, University of Durham; and local industry) in January, 1958. The 10,000 visitors to the Newcastle exhibition included 2,500 senior pupils from technical and grammar schools and 1,700 students from technical colleges. At both Birmingham and Newcastle lectures were given by Authority staff. It is found that the association of a lecture programme with an exhibition is a valuable method of imparting information on atomic energy.

254. An exhibition prepared for the Dounreay "open day" in May was shown subsequently in Inverness and Aberdeen. Her Majesty Queen Elizabeth the Queen Mother visited an Authority exhibit at the Liverpool "Industry Advances" exhibition in July. The Authority also exhibited in Manchester (Industrial Efficiency and Productivity Exhibition) and Glasgow (Royal College of Science and Technology).

255. A portable exhibition on atomic energy has been exhibited at a number of universities and technical colleges.

256. Research and development work in the Industrial Group, with special reference to the fast-breeder reactor experiment at Dounreay, was the subject of an exhibition at Carlton House Terrace, London, in November. The Authority exhibited at the Royal Society Conversazione in May, 1957, and at the Physical Society Exhibition in March, 1958, both in London.

257. The Authority co-operated with the Board of Trade in the preparation of a British atomic energy exhibit for the Amsterdam exhibition "Het Atoom" (June-September, 1957) and of a travelling exhibition which toured six Australian cities from July, 1957, to January, 1958. The Authority, the Board of Trade and the Nuclear Energy Trade Associations' Conference combined to present an exhibit at the Hanover Trade Fair (April-May, 1957). This exhibit, which included an animated-diagram film, "How a Thermal Reactor Works", had over 200,000 visitors in ten days. An exhibit on isotope applications was staged at a U.N.E.S.C.O. conference in Paris in September.

Films

258. Early in the year the Authority completed a colour film called "Criticality",* to assist in the safety training of the Authority's industrial workers. The film explains what is meant by criticality, when the conditions of criticality can be permitted, how it can be kept under control and when it must be avoided.

259. As an example of the use of film for safety training in the atomic energy industry, "Criticality" has attracted considerable international notice. It was one of ten British films chosen from an entry of 300 for showing at the International Film Festival in Venice and won first prize in the scientific film category at Padua. It has been shown subsequently to scientific congresses and other specialist audiences in Argentina, Austria, Belgium, Ceylon, Chile, France, Holland, India, Iraq, Israel, Japan, Yugoslavia, Portugal, Siam, Spain, Turkey, United States and Venezuela.

260. Animated sequences from "Criticality" were made available to the Educational Foundation for Visual Aids for the production of a classroom film, "The Principles of Nuclear Fission".

261. Four films on constructional work in the Industrial Group were completed during the year to assist in the training of British industry in the techniques of building nuclear reactors for power production. They are: "The Construction of Calder Hall"; "Heat Exchangers at Calder Hall"; "Engineering at Calder Hall"; and "The Dounreay Sphere".

Publications

262. During its second year of publication the circulation of the Authority's monthly bulletin "Atom", was increased, in response to greater demand, from 5,400 to 8,500. Of this total 5,000 go to the Authority's own staff; 1,500 to universities, industrial firms and other interested bodies in the United Kingdom; and 2,000 overseas.

263. An illustrated summary of the Authority's Third Annual Report was published under the title "Atom 1957". Other publications included an illustrated "Careers Handbook", for careers masters and prospective recruits; "A Guide to Calder Hall", for the use of the many visitors to the plant; "Facts about ZETA", a description of Harwell's experiments towards controlled thermonuclear reactions; "A Guide to U.K.A.E.A. Documents"; the first three of a series of technical information sheets ("The current output of heat energy from nuclear fuel and what it might be", "Some of the nuclear reactions that take place in reactors", and "Thermonuclear reactions"); "Calder Hall: Technical Survey"; and three pamphlets: "The U.K.A.E.A.", "The Power Programme" and "Isotopes". Some of the above are available in foreign languages.

* Criticality denotes the conditions under which a chain reaction can be sustained in fissile material.

Photographs

264. A thousand new negatives were added to the Photographic Library (Public Relations) during the year, bringing the total of subjects to 6,000. Over 12,000 prints were issued to newspapers, magazines, television producers, exhibition designers, authors, lecturers, universities and schools.

CHAPTER XIII

RELATIONS WITH INDUSTRY

265. Each of the four industrial consortia, which were formed in 1954 to design and construct nuclear power stations, is now engaged on one of the stations mentioned in Chapter I, paragraph 10. The Authority collaborate with the industrial consortia and act as consultants to the electricity boards in connection with the nuclear power programme. In addition, collaborative programmes of development work relating to the gas-cooled, graphite-moderated reactor system are formulated by a committee on which the four consortia and the Authority are represented; and facilities have been provided at Harwell for collaboration between the consortia in the carrying out of exponential experiments.

266. Staff from Atomic Power Constructors Limited have received training in the Authority's Industrial Group during the year under review.

267. A new industrial partnership, Hawker Siddeley/John Brown Nuclear Constructors Limited, was formed in the summer of 1957. The new company declared that they intended to study the nuclear propulsion of merchant ships.

268. Industry has participated in the work on controlled thermonuclear reactions reported in Chapter VII. The principal contractors for construction of ZETA were Metropolitan-Vickers Electrical Company Limited (who also collaborated in the design), British Insulated Callenders Cables Limited and Telcon Limited. Research work in this field is also being carried out by Associated Electrical Industries Limited's Research Laboratory under contract with the Authority.

269. The Authority normally have a number of scientists and engineers from industry working on attachment to various of the Authority's research, development and design projects. This promotes a valuable interchange of ideas between the Authority and industry; access to the Authority's facilities enables staff from industry to acquire experience not obtainable elsewhere; and such staff provide a useful reinforcement of the Authority's own technical resources. The number of attached staff which the Authority can accommodate is limited: but at 31st March, 1958, more than one hundred scientists and engineers from British industry were attached to the Authority's establishments.

270. During the year under review discussions were held with the British Chemical Plant Manufacturers' Association with a view to enabling member firms to have scientists and engineers from their staff trained by the Authority's Industrial Group in the design of chemical plant for the treatment of radioactive materials. This will enable the firms concerned to compete in overseas markets for this type of plant.

271. The Authority are necessarily concerned in the export of power-producing and research reactors, as the Authority are at present the sole producers of fuel elements in the United Kingdom. However, the primary responsibility for export promotion rests with the industrial consortia.

272. It was announced in November, 1957, that the Italian firm Agip Nucleare had issued a letter of intent to the Nuclear Power Plant Company Limited envisaging the negotiation of a contract for the construction in Italy of a gas-cooled nuclear power plant of 200 MW to British design. It was contemplated that the Nuclear Power Plant Company Limited and Agip Nucleare would work together in designing and constructing the plant, and that a substantial portion of the nuclear part of the station would be supplied from the United Kingdom. Also during the year under review, Head Wrightson Processes Limited secured two orders for DIDO type reactors, one from the Danish Atomic Energy Commission and another, to be erected at Jülich, near Cologne, for the German Land Government of North Rhine-Westphalia. (See Third Annual Report, 1956-57, paragraph 207.)

Patents

273. Twenty-seven patent licences were granted during the period under review, making a total of 72 from the commencement of commercial exploitation by the Authority. To assist the licensees in the manufacture of the patented inventions the Authority have placed at their disposal the relevant know-how developed in the Authority's establishments. During the year extensive patent filing on inventions in the nuclear power field was undertaken both in the United Kingdom and abroad, with a view to safeguarding British industry in the manufacture and export of nuclear power plant.

274. In March, 1956, an action was brought in the High Court by Philips Electrical Limited against the Authority for alleged infringement of Patent No. 465,045. This patent covered an invention based on the discovery made by Professor Fermi and his collaborators, working in Rome in 1934, that neutrons which had been slowed down by light atoms were more effective than fast neutrons in the process of producing radioactive elements. The action was settled in July, 1957, on mutually satisfactory terms.

Insurance of Nuclear Establishments and Fuel Elements, etc.

275. The British Insurance (Atomic Energy) Committee was set up in 1956 to study insurance problems associated with the development of atomic energy. The report of the Committee was published in April, 1957. The capacity of almost the entire British insurance market is now available to provide comprehensive cover for risks associated with the construction, ownership and operation of reactors in the United Kingdom and in many other countries. It was announced in Parliament on 10th February, 1958, that the Government intended to introduce legislation to ensure that nuclear reactors on land in the U.K. are made effectively subject to control in the interest of public safety. All owners of such reactors are to be subject to the same duty as the Atomic Energy Authority of preventing damage to property or personal injury from radioactive contamination. They will, therefore, be liable to pay compensation for such damage and, in order to make this provision effective, a reactor owner will be required to insure his liability or to show that he is holding adequate liquid assets. The Government propose to include in the legislation a provision fixing a limit of £5 million in respect of each installation and the insurance market has informed the Government that it is ready to provide the necessary cover. Fuel elements (new and irradiated) in transit may also be insured.

Harwell Reactor School

276. The Reactor School extended its scope considerably during the period. In addition to the standard fourteen weeks course and the Senior Technical Executives course, other courses were run. These included: a

course consisting essentially of the first six weeks of the standard course ; a two weeks course organised in conjunction with the Ministry of Education for technical college lecturers, similar in content to the Senior Technical Executives course ; a course organised in conjunction with the O.E.E.C. for European university professors and lecturers ; and two two-week courses for Authority staff on criticality problems. The number of places on the Senior Technical Executives course was almost doubled and this course was opened to overseas students.

277. Starting with the first course in 1958, the standard Reactor School course has been increased from fourteen to sixteen weeks, and the first six weeks of the course are now held at one of three colleges of advanced technology. These are Birmingham College of Technology, Bradford Institute of Technology, and Salford Royal Technical College.

278. During the year 378 British and 120 overseas students attended courses ; the total numbers from the formation of the school to 31st March, 1958, have been 765 British and 204 overseas students.

Calder Operations School

279. During the period under review, six-week courses have been held : three for British students and three mainly for overseas students. Thirty-two British students and 41 overseas students attended. A special one-week course was held for overseas industrialists in October, 1957.

280. More information is gradually becoming available as the result of the operation of the Calder reactors. This is making the course more interesting and instructive, and more able to fulfil its rôle as a basic course of instruction to those who will ultimately operate similar types of reactor.

281. Between courses special instruction has been given to various operating staffs of the Authority.

Conferences

282. Conferences held at Harwell during the period are listed at Appendix VI.

CHAPTER XIV

INTERNATIONAL RELATIONS

283. The Third Annual Report, 1956-57, paragraph 230, referred to the heavy load imposed on the Authority's staff by the need to participate in the work of international organisations, to pay visits to countries overseas, to receive overseas visitors at the Authority's establishments, and by similar work arising from the growth of nuclear energy activities throughout the world. This load has inevitably become even more heavy during the year under review. The great intensification of interest in the technical and economic aspects of nuclear power, and an increasing realisation of the magnitude of the problems, such as those of health and safety, associated with the successful exploitation of it, have led to an unceasing demand upon the Authority for information and assistance.

International Organisations

United Nations

284. The Authority have been entrusted with the task of making the arrangements for the United Kingdom's participation in the Second United

Nations Conference on the Peaceful Uses of Atomic Energy which will open in Geneva on 1st September, 1958. The United Kingdom will be represented by five delegates, headed by Sir John Cockcroft (who will be a Vice-President of the Conference) and supported by a team of advisers drawn from the Authority, the universities, other scientific bodies and industry. The United Kingdom team will be responsible for presenting about 200 papers.

285. The Authority are inviting a limited number of representatives of delegations, other than those of Commonwealth countries, to visit Atomic Energy Authority Establishments after the Conference. Special arrangements are being made for Commonwealth delegates, as mentioned below (see this Chapter, paragraph 296).

286. The Authority are represented by Sir John Cockcroft on the United Nations Scientific Advisory Committee on the Peaceful Uses of Atomic Energy. Authority staff have acted as advisers on the work of the U.N. Scientific Committee on the Effects of Atomic Radiation. They also have provided data on specific topics and have assisted in the preparation of the report which is to be presented during the summer of this year.

International Atomic Energy Agency

287. The International Atomic Energy Agency came into being on 29th July, 1957, after ratification of its Statute by the requisite number of Member States, including the United Kingdom. The Agency's first General Conference was held in Vienna (the seat of the Agency) in October, 1957, when the Chairman of the Authority addressed the opening Session and delivered a message of good wishes from the Prime Minister. The message reaffirmed the United Kingdom's willingness to place its experience in the application of atomic energy to peaceful purposes at the disposal of the Agency and, in particular, to provide opportunities for training in U.K. schools, colleges and atomic energy establishments. The United Kingdom has since offered to make a contribution to the Agency's Fellowship Fund equivalent in value to \$25,000. The Authority have indicated that they will accept six students nominated by the Agency for research with powerful radiation sources at their Wantage Laboratory. Dr. Seligman of the Authority's Research Establishment staff has been seconded to the Agency as Deputy Director-General for Research and Isotopes, and the Authority have undertaken to assist the Agency in finding other scientific and technical staff. The Authority maintain close touch with the development of the Agency's policy and activities through the U.K. member of the Board of Governors.

Organisation for European Economic Co-operation

288. The O.E.E.C.'s nuclear energy activities received further impetus during the year through the establishment of the European Nuclear Energy Agency. The Agency's Statute was approved by the O.E.E.C. Council of Ministers on 20th December, 1957, and the Agency came into being on 1st February, 1958. The work of the Agency will be directed by the Steering Committee for Nuclear Energy though major decisions will require the approval of the O.E.E.C. Council. A joint company for the processing of nuclear fuels—EUROCHEMIC—was set up during the year and a small processing plant is to be built at Mol in Belgium. The United Kingdom will not be taking up shares in this undertaking since facilities for fuel processing are already available in this country, but the Authority have undertaken to continue to give technical advice and assistance. Plans for a Joint Experimental Reactor project received detailed study; types of

reactor which might be suitable for further development in this way were considered by a high level scientific committee on which the United Kingdom was represented by two Members of the Authority. It is expected that a final decision will have been taken by the early summer of this year. The Authority have continued to make experts available for consultation on such matters as training, health and safety questions, liberalisation of trade in nuclear energy materials and equipment and a tentative project for manufacturing heavy water in Iceland.

289. The Authority provided speakers for two Nuclear Energy Courses for Management organised during the year by the European Productivity Agency (another organ of the O.E.E.C.).

Euratom

290. The Euratom Treaty between France, Western Germany, Italy, Belgium, Holland and Luxemburg came into force on 1st January, 1958. As from that date the six member countries are under an obligation to pool their national nuclear energy research activities and information, to give the Euratom Supply Agency an option to purchase all raw materials produced in their territories, to accept allocation by the Commission of scarce supplies, and to regulate prices according to a common policy. The Treaty includes provision for a common nuclear market and customs tariff. Security control will be exercised by the Commission throughout Euratom territory. Since all six members of Euratom are also members of O.E.E.C., the best methods of dealing with a number of mutual problems such as health and safety and security are currently under discussion between the two organisations. The United Kingdom as a member of O.E.E.C. is closely associated with these discussions.*

Bagdad Pact

291. The Nuclear Training Centre in Bagdad, under the direction of Mr. W. J. Whitehouse, a member of the Authority's staff, has now been in operation for a year. Two courses in the practical applications of radioactive isotopes have been held for students from member countries. Five more teachers from the member countries (other than the U.K.) were trained at Harwell during the year. The Centre has started a research programme, including work on insect control, plant nutrition and applications to oil technology and soil salinity research. Help will be given to the Bagdad Museum on the carbon-14 dating of antiquities. The Authority have undertaken to provide information and assistance on methods of survey and prospecting for radioactive materials. The Director of the Centre has given advice on the establishment of Radioisotope Departments at the Royal Hospital in Bagdad and at the University of Shiraz in Iran. Mr. H. A. C. McKay, another member of the Authority's staff, is shortly to succeed Mr. Whitehouse as Director of the Centre.

International Standards Organisation

292. Members of the Authority's staff took an active part in the proceedings of the first meeting, in August, 1957, of the Technical Committee on Nuclear Energy of the International Standards Organisation. Sub-committees have been set up to consider (1) Terminology, Definitions and Symbols; (2) Radiation Protection; and (3) Reactor Safety. One of the Authority's representatives is chairman of the last-named committee. The Authority's staff continue to be associated with this work through service on committees set up by the British Standards Institution in preparation for the next meeting of the International Standards Organisation, which is to be held in the United Kingdom in June, 1958.

* Since the end of the period under review discussions have begun with a view to the conclusion of an agreement between Euratom and the United Kingdom.

General Co-operation with Other International Organisations

293. The World Health Organisation held a course on the Public Health Aspects of Radiological Protection, at Oxford, in January, 1958, with the co-operation of the Research Group of the Authority. The International Labour Office is to hold a training course on Protection of Workers against Radiations, at Oxford, in conjunction with the Research Group, in July, 1958. A meeting of the European Atomic Energy Society was held at Harwell in March, 1958, and, in particular, discussed information relating to the accident at Windscale. Members of the Authority's staff have attended other meetings of the Society during the year. The Authority's staff have continued to take an active part in the work of the International Commission for Radiological Protection and the European Organisation for Nuclear Research (CERN), and the Authority have been consulted by various Government Departments on the nuclear energy aspects of the work of other international organisations, such as Western European Union.

Commonwealth Countries

294. Good working relations, informal but close and business-like, were maintained between the Authority and equivalent organisations in Australia, Canada, India, Pakistan and South Africa, and with interested bodies in other Commonwealth countries. Scientists from all the countries named above are at present working in the Authority's establishments on subjects which are of special interest to the organisations to which they belong. For example, two engineers from the South African Atomic Energy Board are doing research at Harwell on methods of heavy water production, with a view to establishing heavy water as a valuable by-product of the Union's oil-from-coal project.

295. Events deserving to be singled out for special mention are the conclusion in July, 1957, of an agreement for co-operation between the Authority and the South African Atomic Energy Board, and the attainment on 26th January, 1958, of criticality by the Australian Atomic Energy Commission's HIFAR materials-testing reactor. This reactor is a replica of DIDO at Harwell and uses enriched uranium fuel elements supplied by the Authority.

296. Arrangements are being made, and a provisional programme has been drawn up, for a conference and a tour of U.K. atomic energy establishments for Commonwealth nuclear scientists and others interested in atomic energy. Since many of those concerned will be their countries' representatives at the Geneva Conference on the Peaceful Uses of Atomic Energy, and subsequently will be attending the Second General Conference of the International Atomic Energy Agency in Vienna, the conference and tour in the U.K. for the Commonwealth visitors will take place during the week immediately following the Geneva Conference and preceding the Vienna Conference, i.e., the week beginning 15th September, 1958. The programme is being drawn up by the Authority in conjunction with the Commonwealth Relations Office and other interested Departments and bodies. It is expected to include a two-day conference at Harwell, visits to establishments of the Industrial Group, and meetings with the Electricity Authorities and the industrial consortia associated with the U.K. nuclear power programme.

United States of America

297. The Authority's relationship with the United States Atomic Energy Commission is close, cordial and continuous, as evidenced by the fact that the U.S.A.E.C. has permanent representatives in London and the Authority in Washington. The interests of both organisations lie in the pooling of effort,

experience and inspiration in exploring and mapping the unknown territories of science.

298. A valuable, steady, two-way traffic of ideas goes on all the time. The following are some particular instances of co-operation during the past year.

299. Discussions were held with a number of parties of American visitors concerning the technology of the gas-cooled, graphite-moderated reactor system. Exchange of information concerning submarine propulsion reactors began in the summer of 1957. There were further useful exchanges on fast reactor technology, especially during an Authority team's visit to the United States. Joint conferences on health and safety, on the effects of irradiation on graphite and on controlled thermonuclear fusion took place and proved valuable. There were many other visits both ways, and a few temporary exchanges of staff.

Other Countries

300. In a year in which the Authority had dealings of one kind or another with some 40 overseas countries, it is difficult to select particular events for comment. The most notable general trend was the further intensification by the governments and power undertakings in many countries of their study of the technical and economic aspects of nuclear power. The Authority have done their best to facilitate these investigations, mainly by inviting experts from the countries and organisations concerned to inspect Calder Hall and to discuss the technical features and potentialities of the nuclear power stations now being built by industry for the U.K. electricity boards. Some details of Italian and Japanese plans for the introduction of nuclear power are given below. Serious interest in the U.K. type reactor was also shown by electricity undertakings in Germany and in a number of other European countries, and by official bodies in other countries as distant and diverse as India and Brazil.

Italian Projects

301. A notable event during the year was the exchange of letters of intent between a British and an Italian firm for the erection of the first nuclear power station overseas to British design. (See Chapter XIII, paragraph 272.) The Authority were retained by the Italian firm as consultants on those aspects of the project on which the Authority are at present uniquely qualified to advise. The Authority will also be directly concerned at a later stage as suppliers of fuel for the station.

302. Another Italian project with which the Authority have been concerned is that known as "Project ENSI". This is sponsored by the Italian Government and has as its object the construction, also in South Italy, of a 150,000 kW nuclear power station to be financed in part by the International Bank for Reconstruction and Development. The reactor type and the constructing firm are being selected by international tender under arrangements supervised by the International Bank and the Italian National Committee for Nuclear Research. The Authority have, at the request of the Italian organisation SENN, which is to purchase and operate the station, given advice on the suitability of the sites which were under consideration. They have also agreed to examine those tenders which are based on natural uranium-fuelled reactors, with a view to assuring the promoters of the project that the designs are technically sound and satisfactory from the point of view of safety. A member of the Authority's staff has been appointed to serve on the international panel of experts which has been set up to review all the tenders.

Japan

303. During the year there also have been numerous consultations with the Japanese authorities on matters connected with the possible purchase of a U.K. type nuclear power station by Japan. Intensive investigations were carried out in the U.K. in June, 1957, by a team led by Mr. Uda, then Minister of Atomic Affairs in the Japanese Government and, in January/February, 1958, by an Earthquake Study Group and Negotiating Mission led by Mr. Yasukawa, Chairman of the recently established Japan Atomic Power Company. The latter mission announced at the end of their visit that they had reached the conclusion that the Calder Hall type reactor, which was satisfactory in other respects, could with minor modifications be made safe in earthquake conditions. The first nuclear power station to be imported into Japan would therefore be of this type. They invited the three interested consortia to tender by 31st July, 1958, for a 150,000 kW station, with a view to starting construction at the beginning of 1959.

Bilateral agreements

304. Close contact under existing agreements for co-operation in atomic matters continued with the U.S.A. (see paragraph 297), France, Belgium, Denmark, the Netherlands, Western Germany and Israel. Collaboration has continued through visits, discussions on topics of mutual concern, and exchange of reports and information. The Authority have in particular been glad to offer their help and advice to the Atomic Energy Commission in Denmark and to the German Land Government of North Rhine-Westphalia, both of which are installing in their research centres reactors of U.K. design.

305. A landmark during the period was the conclusion of the first U.K. bilateral agreement providing for the supply of nuclear power stations and the necessary fuel to an overseas country. This was the Anglo-Italian Atomic Energy Agreement (Cmnd. 349) signed on 28th December, 1957, and brought into effect on 12th May, 1958. Two other agreements were concluded during the year (in addition to the South African agreement mentioned in paragraph 295). These were an inter-governmental agreement with Sweden (Cmnd. 290) for co-operation in nuclear research and an agreement between the Authority and the Norwegian Institutt for Atomenergi. The latter is the Authority's counterpart in Norway and the agreement is largely a formal recognition of previously existing co-operation. Negotiations for an agreement with Japan with the same scope as the Anglo-Italian agreement were far advanced by the end of the period under review and its signature was expected to follow shortly. Other agreements of both "power" and "research" types were under negotiation. The Authority have been closely concerned with all these negotiations and will bear the main responsibility for their implementation on the U.K. side.

CHAPTER XV

THE AUTHORITY'S STAFF

306. The Authority wish to take this opportunity of recording their appreciation of the devotion to duty of those who were concerned in dealing with the Windscale accident, and of the extra burdens which have been shouldered since then by a large number of the staff in dealing with all the consequential action to which reference has been made throughout the report. As was stated in Annex 4 to the White Paper (Cmnd. 302) the Authority accept full responsibility for the accident.

Senior Staff

307. At Appendix III are listed the Authority's Senior Staff in the London Office; the Boards of Management of the three Groups; officers having independent charges; and the Advisers to the Authority.

Strength

308. The total number of staff employed by the Authority increased from 27,290 on 1st April, 1957, to 30,341 on 31st March, 1958. The total non-industrial staff rose from 12,630 to 14,481 and industrial employees from 14,660 to 15,860.

309. A sustained effort has been necessary to deal with the problem of organisation and accommodation arising from this continued rate of growth.

Recruitment

310. A corresponding effort has been necessary in recruitment, particularly in obtaining staff of the high calibre and breadth of experience required for the most senior posts. Following the reports of the Fleck Committees* on the organisation of certain parts of the Authority and on the control of health and safety, the Industrial Group have embarked on an intensive recruitment campaign to bring their existing complements up to strength and to fill several new posts resulting from the Committees' recommendations. A number of these posts have already been filled by the promotion of suitably qualified members of the Authority's staff, but there remains a substantial margin of vacancies to be filled from external sources. It is still too early to assess the results of this campaign.

311. In the middle and lower ranges and in the industrial grades the level of recruitment has for the most part been satisfactory, although there has been difficulty in recruiting in certain specialised fields.

312. The size of the response to staff advertisements and to the university recruitment drive is evidence of a continuing interest in the work and future of the Authority.

313. Wastage has continued at approximately the same rate as in previous years.

Pay and Conditions of Service

314. Pay increases negotiated for certain classes and grades in the Civil Service were followed by corresponding increases in Authority rates of pay. In view, however, of the different structure of Drawing Office grades in the Authority from that of the Civil Service, separate negotiations were entered into with the Society of Technical Civil Servants when that body was negotiating with the Treasury. The increases of pay agreed for Authority staff as a result of these negotiations were of the same order—but of a different pattern—as those agreed for Civil Service staff.

315. During the year the Authority have been engaged on a review of staff grading arrangements inherited from the Civil Service in order to consider what modifications might be needed to meet the Authority's special needs. The main recommendations of this review will shortly be considered by the Authority.

316. The claim for a substantial increase in wages by the Trade Union Side of the Authority National Joint Industrial Council, which was under consideration during the period of the Third Annual Report, 1956–57, was subsequently settled by agreement between the two sides of the Council on 31st May, 1957.

* Cmnd. 338 and Cmnd. 342.

317. A claim by the Institution of Professional Civil Servants for substantial salary increases for scientists and engineers employed by the Authority was still under discussion at the end of the period.

318. During the year the Authority formulated a scheme of job evaluation for determining lead rates above the national minimum rate payable to non-craft industrial grades. The principles of the scheme have been agreed by the Joint Industrial Council and it is expected that the evaluation of non-craft work in Authority Establishments will have been completed by April, 1958.

Superannuation

319. Discussions continued in the Joint Industrial Council of the details of a possible contributory pension scheme for the benefit of those industrial employees of the Authority who are not at present eligible for superannuation benefits.

Training

320. The Authority continued to develop the arrangements for training their staff in the light of the White Paper on Technical Education* and of the Report by a Sub-Committee of the National Joint Advisory Council of the Ministry of Labour and National Service under Mr. Robert Carr, M.P.†, then Parliamentary Secretary to the Ministry of Labour and National Service.

321. During the year, 18 student apprentices and 150 craft apprentices were recruited. In the light of the Carr Committee Report the Authority are reviewing their arrangements in order to take advantage of the larger numbers of school leavers who will be coming on the labour market during the next few years. Plans are being made to recruit larger numbers of young persons and to ensure that they are properly trained. Consideration is being given to extending the present apprenticeship scheme to include the concept of "technician apprentices" envisaged in the Carr Report.

322. The Authority have continued to award, both to selected student apprentices and to selected members of the junior staff, full-time degree courses in universities and sandwich courses at technical colleges leading generally to the Diploma in Technology or to a professional qualification. In addition, a considerable proportion of the younger employees receive help in the form of day release and payment of fees to improve their qualifications through part-time study at technical and other colleges of further education.

323. Training schemes within the Authority including full-time courses in laboratory techniques for junior staff, have been further expanded. Courses and management conferences for more senior staff continue to be a developing feature of the Authority's training arrangements.

Staff and Industrial Relations

324. The machinery of the Authority Whitley Council for non-industrial staff continued to operate satisfactorily during the year. The full Council met once, but much of the day-to-day business on pay and conditions of service was discussed at informal meetings between representatives of both sides.

325. In the Third Annual Report, 1956-57, paragraph 255, the establishment of a Benevolent Fund under the auspices of the Whitley Council was reported. Since then it has made steady progress and the growth of its funds

* Cmd. 9703.

† "Training for Skill—Recruitment and Training of Young Workers in Industry", Report by a Sub-Committee of the National Joint Advisory Council (H.M.S.O. 1958).

during the year has been satisfactory. A number of grants and continuing allowances have been made to members of the non-industrial staff and in some cases to their dependants.

326. The Authority National Joint Industrial Council and the local Joint Industrial Committees have again worked satisfactorily throughout the year. Good industrial relations have been maintained. The Council met on three occasions and the negotiating sub-committee of the Council had five meetings. Apart from the Trade Union Side's claim for increased wages, the job evaluation scheme and the contributory pension scheme referred to in paragraph 14, the main matters dealt with were:

- (a) Agreement on special allowances for working in abnormal conditions and for wearing irksome protective clothing.
- (b) Agreement on the setting up of a special sub-committee of the Council to consider apprenticeship matters.
- (c) Agreement on the format and contents of a Handbook of Rules and National Joint Industrial Council Agreements. The handbook was issued to all industrial employees in January, 1958.
- (d) Agreement on the constitutions for Local Joint Industrial Committees at the Authority's Establishments at Dounreay, Foulness and Woolwich Common.
- (e) Discussions on financial assistance to local industrial benevolent funds.
- (f) Agreements on sick and annual leave schemes and public holidays.
- (g) Consideration of a claim by the Trade Union Side for increased pay for Charge and Leading Hands.

Housing

327. To meet the continued expansion of staff the Authority provided 788 houses during the period. By 31st March, 1958, the Authority owned 4,952 houses with another 500 either under construction or planned. The local authorities have helped by providing 1,592 houses, with a further 678 either under construction or planned, for Authority staff coming into their areas from other localities. In addition local authorities have provided some houses for locally recruited staff.

Hostels

328. The Authority's hostels can at present accommodate 1,442 members of the staff, a small decrease from last year's figure. A hotel has been acquired in Bournemouth for use as a staff hostel and existing hostels at Thurso and Aldermaston are being extended. All these will be brought into use during 1958-59. In addition, a new hostel is being built at Abingdon. By these means 664 additional places will be provided. The Authority plan to replace, in due course, the hostels of temporary construction built during the war. As part of this programme a new hostel is being built at Risley.

APPENDIX I

NATIONAL INSTITUTE FOR RESEARCH IN NUCLEAR SCIENCE

REPORT FOR THE YEAR ENDING 31ST MARCH, 1958

1. The Government's decision to set up the National Institute for Research in Nuclear Science was announced in the House of Commons on 14 February, 1957, in a statement by the Financial Secretary to the Treasury, from which the following is an extract:—

"The main object of the Institute will be to provide, for common use by universities and others, facilities and equipment which are beyond the scope of individual universities and institutions carrying out research in the nuclear field."

2. On 12 March, 1957, the Chancellor of the Exchequer announced that the Institute had been constituted with the following membership:—

Chairman:—The Rt. Hon. Lord Bridges, G.C.B., G.C.V.O., F.R.S.

Representing the Universities

Professor J. Diamond.
Professor H. S. W. Massey, F.R.S.
Sir Philip Morris, C.B.E.
Professor N. F. Mott, F.R.S.
Sir James Mountford.
Professor R. E. Peierls, C.B.E.
Dr. D. H. Wilkinson, F.R.S.*

Representing the University Grants Committee

Mr. J. C. Gridley, C.B.E.
Sir George Thomson, F.R.S.

Representing the Royal Society

Sir David Brunt, F.R.S.

Representing the Atomic Energy Authority

Sir John Cockcroft, O.M., K.C.B., C.B.E., F.R.S.
Sir Donald Perrott, K.B.E.
Dr. B. F. J. Schonland, C.B.E., F.R.S.

Representing the Department of Scientific and Industrial Research

Professor P. M. S. Blackett, F.R.S.
Dr. H. W. Melville, F.R.S.†

Sir David Brunt retired from Membership on 20 January, 1958, and was succeeded as the member representing the Royal Society by Professor W. V. D. Hodge, F.R.S., who had succeeded him as Physical Secretary of the Royal Society.

3. The Institute held their first meeting on 12 March, 1957, and have met at approximately two-monthly intervals since then. They have set up a Physics Committee, a Research Reactor Committee and a Visiting Committee, each including some members of the Institute and additional senior scientists. They have also set up a General Purposes Committee including only members of the Institute.

* Now Professor D. H. Wilkinson, F.R.S.

† Now Sir Harry Melville, K.C.B., F.R.S.

4. The Institute have decided to establish their first laboratory, to be called the Rutherford High Energy Laboratory, on a site made available by the Atomic Energy Authority adjacent to the Atomic Energy Research Establishment. The principal feature of the laboratory will be a 7 GeV proton synchrotron. The general design for this machine was approved by the Institute. The Atomic Energy Authority were then invited to assume responsibility for detailed design and supervision of construction on behalf of the Institute, subject to general oversight by the Institute's General Purposes Committee, to whom has been given the responsibility for the approval of all major contracts. The laboratory will also contain a 50 MeV proton linear accelerator, now at an advanced stage of construction, which the Atomic Energy Authority have offered to transfer to the Institute in April, 1959.

The Institute have appointed Dr. T. G. Pickavance as Director of the Rutherford High Energy Laboratory.

5. The 7 GeV proton synchrotron will consist of a ring-shaped magnet 150 feet in diameter and 7,000 tons in weight, into which protons will be injected from a subsidiary accelerator of 15 million volts. The protons will be accelerated in a vacuum chamber by radio-frequency equipment on each circulation around the magnet ring. During the acceleration the magnetic field will be steadily increased by increasing the current from the magnet power supply, in order to confine the proton orbits to the magnet ring. The whole machine will be housed in a heavily shielded building.

A major contract was placed in October, 1957, for the magnet yoke and another in November, 1957, for the buildings. Detailed design work is proceeding on the components of the accelerator. Further contracts have been placed and others are being negotiated.

6. The arrangements for operating the proton linear accelerator have been decided in broad outline. The Institute have appointed a Group Leader who will have full responsibility, under the Director of the Rutherford Laboratory, for the operation and maintenance of the proton linear accelerator including the determination of the programme of experiments to be done. The Institute's Visiting Committee will advise both on the general policy and on the details of the programme. The Group Leader will have a small research team of his own. Apart from their own work, their presence and experience should be very helpful to the visiting teams. The Group Leader will have a certain amount of experimental equipment available for general use but visiting teams will be expected to provide their own special equipment. Universities will also be responsible for the salaries of their teams. No charge will be made to universities for the use of the machine or Institute laboratories. The actual operation and maintenance of the proton linear accelerator, to the requirements of the Group Leader, will be carried out by the Atomic Energy Research Establishment as a service to the Institute.

7. The Institute have only a very small staff at present. Besides the Director of the Rutherford Laboratory and the Group Leader for the linear accelerator, already mentioned, they have appointed a Secretary who is also accommodated at the Rutherford Laboratory.

8. The Institute is financed from the Treasury through the Atomic Energy Authority, under a separate sub-head of the Atomic Energy Vote. The full cost of services provided for the Institute by the Atomic Energy Authority, and expenditure incurred by the Authority on behalf of the Institute, are charged to this sub-head, so that it shall represent the true cost of the Institute.

9. Since they are not merely an advisory body but will own property and must make decisions for which legal liability must be accepted, the Institute are seeking incorporation.*

* The method of incorporation considered most appropriate was by Royal Charter, and by Order in Council dated 7th May, 1958, Her Majesty was graciously pleased to approve the grant of a Charter.

APPENDIX II

MEMBERSHIP OF ATOMIC ENERGY AUTHORITY AS AT 31st MARCH, 1958

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 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)

Sir William Cook, C.B.

(Member for Engineering and Production)

Part-time Members

Sir Ivan Stedeford, K.B.E.

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

Sir W. Rowland Smith

Sir James Chadwick, F.R.S.

Rt. Hon. Lord Citrine, P.C., G.B.E.

Secretary

Mr. D. E. H. Peirson

APPENDIX III

ATOMIC ENERGY AUTHORITY SENIOR STAFF*

LONDON

E. J. S. Clarke, T.D.	...	...	Principal Metals Officer
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
A. W. Griffiths	...	...	Director of Patents
E. Harris	...	...	Director of Accounts
H. C. Hudspith	...	...	Chief Finance Officer
A. I. Scott	...	...	Head of Overseas Relations
J. G. P. Spicer	...	...	Establishments Officer
J. H. Stephens	...	...	Chief Labour Officer
F. A. Tatford	...	...	Director of Contracts
E. H. Underwood, O.B.E.	...	...	Director of Public Relations
J. C. Walker	...	...	Head of Overseas Relations (International Agencies)
I. G. K. Williams	...	...	Head of Health and Safety and Secretariat Branches

* As at 1st July, 1958.

INDUSTRIAL GROUP

Headquarters, Risley

Sir Leonard Owen, C.B.E.	...	Managing Director
P. T. Fletcher	...	Deputy Managing Director
J. C. C. Stewart	...	Deputy Managing Director
J. B. W. Cunningham	...	Director of Industrial Power
H. V. Disney	...	Director of Engineering
Dr. H. Kronberger, O.B.E.	...	Director of Research and Development
Dr. A. S. McLean	...	Director of Health and Safety
D. S. Mitchell	...	Director of Personnel and Administration
R. V. Moore, G.C.	...	Director of Reactor Design
D. R. Newman	...	Director of Finance
K. B. Ross, O.B.E.	...	Director of Operations

Dounreay Experimental Reactor Establishment

Dr. R. Hurst, G.M.	...	Director
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Works

H. G. Davey, O.B.E.	Works General Manager ...	Windscale and Calder Hall
S. F. Hines, O.B.E.	Works General Manager ...	Capenhurst
G. R. Howells	Works General Manager ...	Chapelcross
Dr. H. Rogan	Works General Manager ...	Springfields

Research and Development Laboratory, Culcheth

Dr. A. B. McIntosh	...	Head of Laboratory
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RESEARCH GROUP

Atomic Energy Research Establishment, Harwell

Dr. B. F. J. Schonland, C.B.E., F.R.S.	...	Director
D. W. Fry	...	Deputy Director
J. R. V. Dolphin, C.B.E.	...	Chief Engineer
Dr. J. V. Dunworth, C.B.E.	...	Head of Reactor Division
Dr. H. M. Finniston	...	Chief Metallurgist
T. B. LeCren	...	General Secretary
Dr. R. Spence, C.B.	...	Chief Chemist
D. R. Willson, M.B.E.	...	Technical Secretary

Radiochemical Centre, Amersham

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

Atomic Weapons Research Establishment, Aldermaston

C. A. Adams	...	Chief of Trials and Safety
J. E. Adamson	...	Group Secretary
Admiral P. W. B. Brooking, C.B., D.S.O. (Retd.)	...	Assistant Deputy Director
Dr. S. C. Curran, F.R.S.	...	Chief of Nuclear Research
J. M. High	...	Head of Engineering Services
G. L. Hopkin, O.B.E.	...	Chief of Materials
E. F. Newley	...	Chief of Warhead Development

Woolwich Common (Electronics Engineering)

C. Smith	...	Superintendent
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Proof Range, Foulness

E. H. Mott, O.B.E.	...	Senior Superintendent
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ADVISERS TO THE AUTHORITY

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 IV

BALANCE SHEET of the United Kingdom Atomic Energy Authority as at 1st March, 1957.

FOREWORD

1. The third Balance Sheet of the United Kingdom Atomic Energy Authority, as at 31 March 1957, 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 1957 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 financial year shall be applied in such manner as may, with the approval of the Treasury, be directed. The directive requires the Authority to surrender all revenues, other than those not disclosed for security reasons, to the Atomic Energy Office. Thus the substantial funds needed to finance large programmes of capital projects and research are provided by the Atomic Energy Office out of moneys voted by Parliament.

3. In addition to the records to meet the requirements of Parliamentary accounting the Authority maintain a commercial system of accounting, including the division between capital and revenue, to facilitate management control and commercial operation. The conventions adopted in relation to transactions on revenue account remain unchanged and 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 and other income, is regarded as the cost of fundamental research in the atomic energy field to be borne by H.M. Exchequer.
- (c) The Weapons Group undertakes the production of components for weapons and research work in connection with weapons, both under contract from the Ministry of Supply. It also undertakes other research and development. The cost of the operation of this Group, less the amounts chargeable to the Ministry of Supply for production and research, and other income, is regarded as a charge to be borne by H.M. Exchequer.

4. The Authority have introduced a revised procedure for dealing with the problem, common to all research laboratories, of maintaining inventories of certain laboratory equipment which might lose its identity in experimental rigs; the application of the revised procedure will be kept under review to ensure that it proves satisfactory in practice. The problems that arose in connection with the transition from Government Department to Statutory Authority have for all practical purposes been overcome.

5. The Balance Sheet at 31 March 1957 is in conventional form and sets out the assets and liabilities of the Authority at that date. The Capital Account reflects minor adjustments in respect of previous years and shows the additions thereto during the year ended 31 March 1957 and the deduction of the net cost of operations on revenue account for that year.

TA The figures of assets reflect changes in the grouping of accounts under Fixed Assets and Current Assets which resulted from some redefinition of the standard account headings previously adopted; there are consequential adjustments in the detail of the comparative figures at 31 March 1956.

6. 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.

7. 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 5.13 per cent on fixed capital and 5.44 per cent for working capital. The Treasury have agreed to a revised method of computing the charge for interest in the accounts with effect from 1 April 1958.

8. Work in progress has been valued for Balance Sheet purposes at factory cost including an appropriate share of depreciation and overheads, but excluding interest.

9. A reserve for losses in lieu of insurance to cover major losses has been created, against which, as recorded in Note 2 to the Balance Sheet, the practice is to charge losses in excess of £250. In the year to 31 March 1957 claims totalling £17,699 were charged against the reserve.

10. The Principal Non-Industrial Superannuation Scheme 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 employer's contributions. It is, nevertheless, regarded as notionally funded with the whole of its funds, apart from the amount in respect of fully paid insurance policies, treated as deposited with H.M. Exchequer at interest. (Details of these notional funds are given in Note 3 to the Balance Sheet.) The first actuarial valuation of the Scheme will be undertaken at 31 March 1960.

11. 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. The position was formalised in the Protected Persons Superannuation Scheme, which was approved by the Lord President of the Council on 17 June 1956. This Scheme is non-contributory and the Government Actuary has assessed the contribution required by the Authority to meet their liabilities under the Scheme. The balance is regarded as notionally funded with the whole of its funds treated as deposited with H.M. Exchequer at interest (see Note 4 to the Balance Sheet). The first actuarial valuation of the Scheme will be undertaken at 31 March 1961.

12. No provision has been made in the Authority's accounts for a pension scheme for industrial workers entering the service of the Authority after 1 August 1954.

28 November 1957.

UNITED KINGDOM ATOMIC

BALANCE SHEET AS AT

31 March 1956		£	£
£	I. CAPITAL ACCOUNT		
174,118,304	Balance at 1 April 1956	217,943,565	
	Add—		
249,328	Adjustments for previous periods	70,833	
174,367,632		218,014,398	
	Add—		
52,832,700	Net advances from Atomic Energy Office	70,990,795	
662,764	Stocks not previously valued taken on charge	—	
16,182	Assets taken over from Government Departments	10,667	
8,972,860	Interest on Capital	13,029,444	
236,852,138		302,045,304	
	Deduct—		
18,908,573	Net Cost of Operations for the year	25,361,407	
217,943,565	Capital Account at 31 March 1957	276,683,897	
	II. RESERVE FOR LOSSES (in lieu of insurance) (see Note 2)		
	Balance at 1 April 1956	1,900,000	
	Add—		
	Amount charged to operating costs in the year	1,275,000	
		3,175,000	
	Deduct—		
	Claims charged in the year	17,699	
1,900,000		3,157,301	
	III. CURRENT LIABILITIES AND PROVISIONS		
7,424,703	Trade Creditors and Accrued Liabilities	10,829,094	
771,876	Superannuation Provisions	250,000	
		11,079,094	
228,040,144		290,920,292	
	IV. PRINCIPAL NON-INDUSTRIAL SUPERANNUATION SCHEME		
4,201,108	Balance at 31 March 1957	5,799,568	
	V. PROTECTED PERSONS SUPERANNUATION SCHEME		
	Balance at 31 March 1957	1,662,059	

Notes forming part of this Balance Sheet are appended.

£232,241,252

£298,381,919

ENERGY AUTHORITY

31 MARCH 1957

31 March 1956		As valued at 1 August 1954 plus additions at cost	Depre- ciation	
£		£	£	£
	I. FIXED ASSETS, at cost or estimated cost less depreciation			
349,455	Freehold Land	476,826	—	476,826
53,296,656	Buildings, Ancillary Installations, Housing and Hostels	68,163,900	6,957,349	61,206,551
46,718,476	Plant and Machinery, Motor Vehicles, Loose Apparatus, Tools and Equip- ment	76,072,929	12,053,032	64,019,897
1,565,348	Furniture, Fittings and Office Machi- nery	2,375,896	191,000	2,184,896
477,232	Capital Assistance — assets with assisted contractors	660,638	229,342	431,296
102,407,167		£147,750,189	19,430,723	128,319,466
30,458,412	Assets in course of construction			42,075,561
132,865,579				170,395,027
	II. SPECIAL DEVELOPMENT AND DEFERRED REVENUE EXPENDITURE LESS AMOUNTS WRITTEN OFF			
783,002	Initial production expenses		642,720	
2,691,341	Research and Development expenditure in aid of design		2,398,971	3,041,691
	III. LOANS, ADVANCES AND INVESTMENTS			
25,379,546	Loans and advances for the production of uranium, including accrued interest		28,096,747	
14,871	Investment at cost in £16,064 3% Electricity Stock, 1968-73, deposited with the Supreme Court under S. 35 (4) of the Road Traffic Act, 1930 (Market Value £12,410)		14,871	28,111,618
	IV. CURRENT ASSETS			
13,636,590	Stocks of raw materials and stores		19,869,250	
49,261,990	Work in progress		61,754,031	
2,524,796	Debtors, deposits and payments in advance		7,041,573	
882,429	Balances with Paymaster General, with Bankers and cash in hand		707,102	89,371,956
228,040,144				290,920,292
	V. PRINCIPAL NON-INDUSTRIAL SUPERANNUATION SCHEME FUND			
4,199,768	Amount due from H.M. Exchequer (see Note 3)		5,765,446	
1,340	Insurance Policies		34,122	5,799,568
	VI. PROTECTED PERSONS SUPERANNUATION SCHEME FUND			
—	Amount due from H.M. Exchequer (see Note 4)			1,662,059
£232,241,252				£298,381,919

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

NOTES

These notes form part of the Balance Sheet as at 31 March 1957.

1. Capital expenditure authorised but not incurred on New Works and Housing amounted to £59m. at 31 March 1957.

2. The Authority do not insure and carry their own risks for fire, explosion, common law, third party and similar accidents. A reserve for losses in lieu of insurance has been created, against which claims of over £250 are charged. The costs of smaller claims are charged to operating costs.

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	2,948,904
Excess of contributions and other receipts over benefits and other outgoings for the period 1 August 1954 to 31 March 1957	2,524,348
Interest on funds remaining with H.M. Exchequer	292,194
	<u>£5,765,446</u>

No provision is included for transfer values still to be determined at 31 March 1957.

4. The amount shown as due from H.M. Exchequer to the Protected Persons Superannuation Scheme is made up as follows:—

	£
Transfer values in respect of established industrial Civil Servants transferred to the Authority	738,711
Excess of contributions and other receipts over benefits and other outgoings for the period 1 August 1954 to 31 March 1957	831,997
Interest on funds remaining with H.M. Exchequer	91,351
	<u>£1,662,059</u>

No separate provision has been made in these accounts for liabilities arising from pre-Authority service of non-established industrial Civil Servants transferred to the Authority.

APPENDIX V
THE AUTHORITY'S REACTORS AS AT 31st MARCH, 1958

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 $n/cm^2/sec^{-1}$	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. LIDO ...	1956	10^{12}	100 kW	Natural Water	Natural Water	Uranium ²³⁵	Thermal reactor studies, including shielding.
6. DIDO ...	1956	10^{14}	10 MW	Heavy Water	Heavy Water	Uranium ²³⁵	Isotope production, neutron physics, radia- tion chemistry, nuclear reactor material studies.
7. NERO ...	1957	about 10^8	Less than 100 Watts	Graphite	None	Slightly enriched uranium	Investigations for advanced graphite-moder- ated reactors.
8. PLUTO ...	1957	10^{14}	10 MW	Heavy Water	Heavy Water	Uranium ²³⁵	Studies on nuclear reactor materials, isotope production.

NAME	DATE OF START-UP	PEAK NEUTRON FLUX	MAXIMUM HEAT OUTPUT	MODERATOR	COOLANT	FUEL	PURPOSE
9. NEPTUNE*	1957	about 10^8	Less than 100 Watts	Light Water	None	Enriched uranium	Studies by an Admiralty team at Harwell, in association with Authority staff, on water-moderated core designs, with specific reference to a pressurised water reactor for submarine propulsion. Rolls-Royce Limited are responsible for design and construction.
10. HAZEL ...	1958	about 10^6	Less than One Watt	Heavy Water	None	Uranyl fluoride (U^{235})	To obtain basic nuclear information on heavy-water-moderated, homogeneous systems.

Experimental Reactors under Construction

NAME	LOCATION	DATE OF START-UP	PEAK NEUTRON FLUX	MAXIMUM HEAT OUTPUT	MODERATOR	COOLANT	FUEL	PURPOSE
11. Fast Reactor, Dounreay.	Dounreay, Caithness.	1958	—	60 MW	None	Sodium potassium alloy	Enriched uranium or plutonium	Fast reactor breeding studies.
12. DMTR (Pluto type).	Dounreay, Caithness.	1958	10^{14}	10 MW	Heavy Water	Heavy Water	Uranium 235	Studies on nuclear reactor materials.
13. HERALD ...	Aldermaston ...	1958	10^{14}	5 MW	Light Water	Light Water	Uranium 235	Neutron physics, radiochemical studies.
Plutonium Producing Reactors								
14/15. Windscale† (2 reactors).	Cumberland ...	1950	—	—	Graphite	Air	Natural uranium	Plutonium production.

Plutonium/Power Producing Reactors in Production.†

16/17. Calder "A" (2 reactors).	Cumberland ...	1956	—	180 MW§ per reactor	Graphite	Carbon Dioxide	Natural uranium	Plutonium and power produc- tion.
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Plutonium/Power Producing Reactors under Construction.‡

18/19. Calder "B" (2 reactors).	Cumberland ...	1958 (1st reactor)	—	180 MW§ per reactor	Graphite	Carbon Dioxide	Natural uranium	Plutonium and power produc- tion.
20/23. Chapelcross (2 stations, "A" and "B" 4 reactors).	Annan, Dumfries- shire.	1959 (3 reactors)	—	180 MW per reactor	Graphite	Carbon Dioxide	Natural uranium	Plutonium and power produc- tion.

* Admiralty experimental reactor.

† One reactor damaged in the accident; the other reactor at present shut-down.

‡ 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".

§ The total installed generating capacity of Calder Hall "A" (two reactors) is 92 MW (electrical). The gross design output is 84 MW (electrical) and the net output of the station is about 70 MW. However, as stated in Chapter V, paragraph 70, Calder Hall "A", No. 1 reactor, has been running at a maximum heat output of 200 MW providing a gross electrical output of 45 MW. The greater part of the output of the station is fed into the Central Electricity Generating Board grid. When both Calder Hall "A" and "B" (two reactors each) are in operation the installed capacity will be 184 MW and the total output to the C.E.G.B. grid will be about 150 MW. The electrical output from Chapelcross "A" and "B" stations will be identical in all respects with Calder Hall "A" and "B".

APPENDIX VI

CONFERENCES HELD AT THE ATOMIC ENERGY RESEARCH ESTABLISHMENT FROM 1st APRIL, 1957 to 31st MARCH, 1958

Parity (in Nuclear Physics) Conference	13th May, 1957.
Conference on Controlled Thermonuclear Reactions	20th-22nd June, 1957.
Physical Society Conference on Plasma and Atomic Physics... ..	3rd-4th October, 1957.
The Institute of Metals Symposium on Vacancies and other Point Defects in Metals and Alloys	9th-10th December, 1957.
Conference on Reactor Instrumentation	14th-15th January, 1958.

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