

UNITED KINGDOM
ATOMIC ENERGY
AUTHORITY

SIXTH
ANNUAL REPORT
1959-60



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UNITED KINGDOM
ATOMIC ENERGY AUTHORITY

SIXTH
ANNUAL REPORT

For the Period
1st April, 1959—31st March, 1960

*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
13th July 1960*

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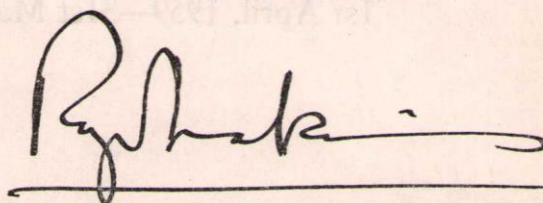
UNITED KINGDOM ATOMIC ENERGY AUTHORITY,
11, CHARLES II STREET,
LONDON, S.W.1.

10th June, 1960

SIR,

I have the honour to submit, in accordance with Section 3 (5) of the Atomic Energy Authority Act, 1954, the Sixth Annual Report of the United Kingdom Atomic Energy Authority. This Report covers the period from 1st April, 1959, to 31st March, 1960.

I have the honour to be, Sir,
Your obedient Servant,

A handwritten signature in dark ink, appearing to read 'R. Hailsham', is written over a horizontal line.

Chairman.

The Rt. Hon. Viscount Hailsham, Q.C.,
Minister for Science,
Richmond Terrace,
London, S.W.1.

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UNITED KINGDOM ATOMIC ENERGY AUTHORITY

SIXTH ANNUAL REPORT

1959—1960

CHAPTER I

GENERAL SURVEY

Introduction

1. During the year 1959-60 those major projects undertaken by the Authority primarily to support the defence programme were completed and all the main plants constructed for that purpose had been commissioned and were operating successfully. New capital projects approved during the year were individually on a relatively small scale.

2. The Authority continued to devote a major effort in support of the civil power programme of the Central Electricity Generating Board and the South of Scotland Electricity Board.

3. In other fields of activity, the Authority's programme went steadily forward. The division of the Industrial Group into two separate groups, the Development and Engineering Group and the Production Group, took place during the year, and was effected without serious disturbance to the Authority's work.

Ministerial Responsibility

4. On 14th October, 1959, the Prime Minister announced the transfer of Ministerial responsibility for atomic energy matters from himself to the Lord Privy Seal and Minister for Science.

Board Membership and Organisation

5. Lord Plowden relinquished his appointment as Chairman of the Authority on 31st December, 1959. He was succeeded by Sir Roger Makins. Sir Ivan Stedeford relinquished his appointment as a part-time Member on 31st July, 1959.

6. The Atomic Energy Authority Act, 1959, increased the permitted Membership of the Authority from 11 to 16.

7. Sir Leonard Owen was appointed Member for Production and Sir Claude Pelly Member for Weapons Research and Development. Both appointments were effective from 1st January, 1960.

8. The Membership of the Authority, as at 31st March, 1960, is set out at Appendix I.

Summary of the Report

9. The Select Committee on Estimates, after examining the Authority's Industrial Group, reported that the group had carried out its tasks with efficiency and success. The Committee's specific recommendations, with

the Minister's observations, are at Appendix III. The Authority's Estimates for 1960-61 provide for a net expenditure of £93,293,000, compared with £92,433,010 for 1959-60. (Chapter II.)

10. New uranium processing and fuel element fabrication facilities were completed during the year and at the end of the year the Authority were about to commence manufacture of the first fuel element charges for Bradwell and Berkeley. The last three Chapelcross reactors were brought up to full power, and the planned extension of capacity of the Capenhurst diffusion plant was completed. Production during the year, of both plutonium and uranium-235, was up to programme. (Chapter III.)

11. A large amount of development work was carried out in aid of the nuclear power stations at present under construction for the electricity generating boards. The construction of the advanced gas-cooled reactor prototype at Windscale proceeded according to programme. The Dounreay experimental fast reactor commenced operation on low power on 14th November, 1959, and the zero energy reactor ZENITH at Winfrith on 19th December. A good start was made on the organisation, planning and initial construction of the high temperature gas-cooled reactor experiment at Winfrith in which the Authority are co-operating with eleven other European countries under the auspices of the Organisation for European Economic Co-operation. In addition the Authority continued to study the potentialities of other reactor systems, including those employing both light and heavy water and organic liquids. Technical assistance was provided to the Admiralty in connection with submarine reactor development, and to the Admiralty also, and later to the Ministry of Transport, in connection with studies of possible reactor systems for merchant ship propulsion. (Chapter IV.)

12. Examples of the general research and development work being carried out in the Authority's laboratories are given in Chapter V.

13. The design of the new experimental facility I.C.S.E. (Intermediate Current Stability Experiment), together with other work on controlled thermonuclear reactions proceeding at Harwell, at the Atomic Weapons Research Establishment, Aldermaston, and at the laboratories of Associated Electrical Industries Limited at Aldermaston Court, are described in Chapter VI. In January, 1960, the Authority received planning permission for a new establishment to be built on the site of the former Royal Naval Air Station at Culham in Oxfordshire. Work on thermonuclear reactions is to be transferred from both Harwell and Aldermaston to this new establishment. (Chapter VI.)

14. While development of weapons for various military applications continued, the Authority also provided technical assistance in connection with the Geneva discussions on nuclear test suspension, and, in this connection, undertook an experimental programme of underground firings of non-nuclear explosives in the United Kingdom. (Chapter VII.)

15. There has been a change in the relationship between the supply of and the demand for uranium, and the Authority's commitments under long-term contracts are greater than their immediate requirements.

Proposals were formulated to stretch out some deliveries of uranium over longer periods than were provided for in current contracts. (Chapter VIII.)

16. The reorganisation of the Authority's health and safety staff led to the establishment of a new Authority Health and Safety Branch. The Committee on Training in Health and Safety (the Veale Committee) completed its report in February, 1960, and this is now under consideration. The Authority assisted in the establishment of the Inspectorate of Nuclear Installations required under the Nuclear Installations (Licensing and Insurance) Act, 1959. (Chapter IX.)

17. There was a marked increase in the number of requests from overseas organisations for advice and help in disseminating information on atomic energy. Three technical films produced for the Authority won awards at international film festivals. (Chapter X.)

18. Receipts from the Authority's commercial operations amounted to almost £20 million. Heads of Contract for the supply of fuel elements for the first Japanese nuclear power station were signed in London on 7th March, 1960. Sales of radioisotopes increased by 25 per cent. over the previous year. (Chapter XI.)

19. The Authority continued to collaborate with overseas atomic energy organisations under both bilateral and multilateral arrangements. Co-operation between the U.K. and Euratom was set in hand in pursuance of the agreement of February, 1959. New inter-Governmental agreements were concluded during the year with the United States and with Spain. (Chapter XII.)

20. The Authority's employees increased in number during the year from 35,260 to 38,500. This represented a slightly decreased rate of growth, due in part to a decision by the Authority to restrict the rate of growth of staff on civil research and development to not more than 8 per cent. per annum for the three years 1959/60-1961/62. (Chapter XIII.)

CHAPTER II

SELECT COMMITTEE REPORT, FINANCE AND ACCOUNTS

Fifth Report from the Select Committee on Estimates

21. During the year the Select Committee on Estimates carried out an examination of the Industrial Group (since divided into the Development and Engineering Group and the Production Group). This was the first time any part of the work of the Authority had been examined by the Select Committee. The main purpose of the committee was to assess whether the principal ways in which policies were being executed by the group and the way the group was organised were giving the best return for the money invested. The majority of the Industrial Group establishments were visited in the course of the inquiry; in addition the committee took evidence from representatives of the consortia of British firms engaged in the construction of nuclear power stations, from the Chairman of the Central Electricity Generating Board, from a representative of the Treasury,

from the Secretary to the Atomic Energy Office (now part of the Office of the Minister for Science), and from Mr. S. J. Pears, F.C.A. (senior partner in the firm of Cooper Brothers and Company, Chartered Accountants, and the Authority's honorary adviser on accounting matters).

22. The committee's report (5th Report from the Select Committee on Estimates) was published on 29th July, 1959. The committee recorded as their main impression that the Industrial Group had carried out its tasks with efficiency and success. They were satisfied both with the way in which the group had tackled new problems of technology and with the cost consciousness it had shown in the development of a modern system for controlling expenditure. At the same time they warned against the danger of uncontrolled diversification of the group's effort now that military requirements were ceasing to be the predominant influence in the group's work, and they emphasised the importance of bringing industry into partnership with the group. The committee expressed their belief "that the two new groups which have taken the place of the old Industrial Group should be well equipped to take economic advantage of the progress of nuclear science."

23. The committee made a number of specific recommendations, the majority of which were accepted by the Authority without reservation. The Committee's recommendations, together with the observations thereon of the Minister for Science, are set out in Appendix III.

Finance

24. The Authority's Estimates for 1959-60 were presented to Parliament on 10th February, 1959, as part of the Atomic Energy Vote (Civil Estimates Class IX, 7) and were approved for the net sum of £92,433,010.

25. A Supplementary Estimate of £10 was presented to Parliament on 2nd February, 1960, and approved on 22nd March. Its main purpose was to obtain sanction for the Authority to use savings on the original grant to increase from £95,000 to £336,350 the contribution to the high temperature gas-cooled reactor experiment (the Dragon Project), one of the international atomic energy projects to which the Authority contribute. The higher subscription was required because the project succeeded in getting under way more quickly than had been expected.

26. The Authority's Estimates for 1960-61 were presented to Parliament on 16th February, 1960, at a net total of £93,293,000. Increased expenditure, mainly on salaries and wages, other current expenditure, grants to the National Institute for Research in Nuclear Science, and contributions to international atomic energy projects, is largely offset by reductions in payments for raw materials and services, and by increased Appropriations-in-Aid.

Accounts

27. The Authority maintain a commercial system of accounting 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. This system also provides detailed information for management on the cost of products and other activities, which is assuming increasing importance

with the rising volume of civil sales. In addition to the commercial accounts, the Authority maintain records necessary to meet the requirements of Parliamentary accounting.

28. The Balance Sheet as at 31st March, 1959, prepared in the form directed by H.M. Treasury under section 4 (3) of the Atomic Energy Authority Act, 1954, was submitted to the Comptroller and Auditor General on 26th November, 1959, and will in due course be presented to Parliament.* (The Operating Account is withheld from publication in the interests of national security.)

29. A notable feature of the Balance Sheet is the continuing growth in the capital employed in the Authority's activities. The Balance Sheet value of the assets on the setting up of the Authority at 1st August, 1954, was approximately £150 million and by 31st March, 1959, this had increased to approximately £450 million.

CHAPTER III

PRODUCTION PLANTS

Introduction

30. The year saw the completion of the expanded capacity for the production of fissile material under the increased defence programme authorised in 1955. This included bringing up to full power the last three Chapelcross reactors and completing the planned expansion of the Capenhurst isotope separation plant.

31. The output for the year of fissile material rose by 40 per cent. and of electricity by over 300 per cent.

32. At the end of the year the bulk of the new Springfields uranium production and fuel element assembly plant was in operation in preparation for the start-up of the civil power programme.

33. Greatly increased use has been made of the Calder and Chapelcross reactors for experimental irradiation programmes, principally reactor physics studies and fuel element proving trials in support of the civil power programme. In authorising these experiments judgment has to be exercised to maintain a balance between satisfactory operating conditions and the need to provide maximum support to the civil power programme.

34. The present scale of the Authority's operations is illustrated by the capital value of the production plant at the Capenhurst, Springfields, Windscale and Chapelcross sites, which now exceeds £175m. and by the total labour force, which exceeds 12,000.

35. Steady improvements have been achieved in the efficiency of existing plant.

Uranium Production

36. Commissioning of the bulk of the new Springfields uranium production plant was completed during the year. In particular, the new

* Ordered by The House of Commons to be printed on 2nd May, 1960, and now on sale at H.M. Stationery Office (price 1/-). The Balance Sheet together with the Authority's Foreword is reproduced at Appendix V.

uranium concentrate purification plant utilising an improved solvent has been successfully brought into operation.

37. In the original concept of the new plant it had been decided to use a new method, involving fluidisation techniques, for converting uranium nitrate into tetrafluoride, an essential step in the manufacture of the metal. It was intended that this process should be continuous and the product cheaper. It was appreciated that considerable teething troubles would be encountered and a full scale prototype unit was therefore built. Initial operation of the prototype unit revealed problems of stability, of corrosion and of the efficient recovery of some of the reagents, in particular the hydrofluoric acid. The majority of these problems have been overcome and the prototype plant is now operating as a production unit yielding uranium tetrafluoride of good quality at the design throughput.

Fuel Element Production

38. The manufacture of uranium cartridges for the Calder and Chapelcross reactors is now being carried out on the production lines of the new factory at Springfields. The new fuel element production lines have been designed to meet the requirements of the nuclear power programme and of the Authority's reactors and will, when running at full capacity, be capable of an output of more than 300,000 uranium metal fuel elements per annum.

39. The manufacture of the first fuel charges for the civil power stations at Bradwell and Berkeley was about to start at the end of the year. Reactor proving trials had indicated the need for changes in the detailed design of some components which, at this late stage, had caused some difficulties, but these were being overcome as rapidly as possible.

40. The failure in service of a fuel element leads to serious loss of reactor operating time and if undetected can provide a hazard to the continued operation of the reactor. It is therefore of vital importance to prove the soundness both of the fuel element design and of the production and inspection methods adopted. Very considerable effort has been devoted to commissioning the new production lines and improved inspection methods have been introduced. Although research and development and out-of-pile proving trials can make a great contribution towards establishing the basic soundness of a design, only reactor proving trials on a statistically significant scale can finally prove both the design and the production and inspection methods. Because even a very small number of failures is important, the proving trials must be carried out on a considerable scale to demonstrate the required degree of integrity: thus in the case of Calder and Chapelcross reactors the maximum percentage of failures that could, to date, be attributed to defective welds is of the order of 0.005 per cent. Consequently a new weld arrangement or manufacturing technique would need to demonstrate a comparable or better performance in proving trials.

41. Proving trials on the final design of the fuel elements for Bradwell, Berkeley, Hinkley Point and Hunterston during the past year have involved the manufacture of large numbers of prototype fuel elements during the commissioning period in the new factory.

42. To meet demands for fuel elements of novel type for new research reactors or for experimental purposes, a new general purpose metallurgical

shop has been built and production of uranium oxide fuel elements for the advanced gas-cooled prototype reactor at Windscale started during the year. Although the tonnage of fuel elements required for this prototype reactor is quite small by comparison with the throughput of the factory for the main production reactors, the number of individual pieces in each fuel assembly is substantial and requires the manufacture to be undertaken on a production basis.

Calder and Chapelcross Reactors

43. At the beginning of the year five reactors were in operation ; four at Calder and one at Chapelcross. The remaining three reactors at Chapelcross were brought to full power during the year and at the end of the year all eight reactors were operating in accordance with production programmes. It is of interest that the electricity sent out from the Chapelcross station now represents some 20 per cent. of the base load of the South of Scotland Electricity Board.

44. The fact that all eight Calder Hall type reactors have been commissioned and operated with relatively little trouble is a tribute to their designers and constructors.

45. The year was one of noteworthy improvements in reactor operating procedures, resulting in significant increases in both the availability and the rating of the reactors. The availability was greatly increased by a 50 per cent. reduction in scheduled shut-down time achieved by streamlining of charge and discharge schedules and detailed planning of their integration with maintenance schedules. Including the scheduled closures for recharging the reactors, an operating availability in excess of 80 per cent. was achieved : this is an important achievement in relation to the major use of this type of reactor as a base-load power station.

46. The thermal output of the reactors was increased to 15 per cent. above the design capacity ; but re-blading of the turbines is necessary to allow an equivalent increase in the electricity generation.

47. Reactor trials showed that the present maximum fuel element operating temperature can be raised with no loss of reliability. Modified operating conditions are therefore being introduced which will further increase the rating of the reactors.

48. Significant improvements in commissioning measurements were achieved as the result of advances in the techniques of control rod calibration, in the determination of reactor shut-down characteristics, and in methods of studying the coolant flow pattern.

49. To support the programme of fuel element proving trials and experimental irradiations, a wide range of versatile fuel element handling grabs and other handling devices has been developed. Development of television equipment and techniques has extended the range of investigations utilising internal inspection of the reactors under active conditions.

50. The commissioning of the Chapelcross cooling pond for the storage of irradiated fuel elements required development work to overcome viewing problems and to define methods of water treatment and effluent filtration. Considerable effort was also directed to the development of methods of

inspecting the steel pressure shell during the life of the reactors and the results have been applied to the fourth Chapelcross reactor. The experience gained should prove of value in dealing with the same problem in the case of the civil power stations.

Plutonium Extraction Plants

51. The chemical extraction plants at Windscale, which process the irradiated fuel discharged from the reactors, continued to operate satisfactorily and to process increased quantities of fuel elements. The plant for the purification of the uranium was modified during the year to reduce the activity discharged from the factory, and as a result of this modification and other changes in operating procedure the activity released during the year was reduced in spite of the considerably increased throughput.

52. Increased primary separation capacity is required to handle the irradiated fuel arising from the civil power programme. A new primary separation plant due to be in operation in 1963 is now under construction at Windscale. During the year results obtained by operation of a highly active pilot plant and by supporting laboratory work allowed the broad principles of design to be established; definition of operating characteristics is in hand and considerable work has been carried out in the instrumentation of the plant primarily to define adequate methods of criticality control.

Isotope Separation

53. The major construction programme at Capenhurst was completed in November, 1959, when the last of the planned extensions to the diffusion plant was brought into operation. Attention is now being concentrated on an intensive study of the working of the plant to improve its efficiency and economy. The collection and use of information concerning the performance of the numerous stages of the isotope enrichment process has been greatly assisted by the application of automatic data processing equipment.

CHAPTER IV

REACTOR DEVELOPMENT PROGRAMME

54. The objectives of the reactor development programme were set out in the Fifth Annual Report, paragraphs 67-71. The first aim is to ensure the successful construction and operation of the nuclear power stations now under construction. At the same time advanced reactors must be developed that will provide progressively cheaper power. During the year under review the national energy position became easier, but this did not affect the objectives of the long term reactor development programme.

55. The Authority have given the highest priority to their work in support of the electricity generating boards' reactors. These reactors will have high capital costs but will operate at base load because of their high capital and low fuel costs. Reductions in capital costs are essential if nuclear power is to be competitive not only at base load but also at the

lower load factors at which nuclear power stations will have to operate when substantial nuclear capacity has been built. Whilst there has been a steady reduction in the capital costs of the successive stations using magnox canned natural uranium fuel, the development of more advanced reactors provides the best method of achieving further substantial reductions.

56. The development of reactors beyond the present type falls into two stages. The first envisages reactors with low capital costs obtained with the aid of slightly enriched fuel. The second stage is the development of reactors having both low capital costs and small net consumption, or even a net gain (breeding), of fissile material. For the first stage the Authority have concentrated on the advanced gas-cooled reactor and for the second on the fast breeder reactor and the high temperature gas-cooled reactor.

57. This chapter reviews the progress of work on the reactor development programme during the year. The main features are summarised in the following paragraphs.

58. A large effort has been devoted to the support of the magnox* stations, particularly on the development of fuel elements to provide good performance with reliability. Development work in aid of the civil stations has continued at Calder Hall and at Chapelcross.

59. Progress in the advanced gas-cooled reactor system has so far been encouraging. The construction of the prototype at Windscale proceeded on programme. Studies indicate that the system should be capable of substantially lower capital costs than magnox stations and that its prospects are good.

60. As regards the longer term systems, development of the fast reactor proceeded steadily and the experimental reactor at Dounreay came into operation at low power. The majority of the Authority staff working on the high temperature gas-cooled reactor system were seconded to the Dragon project, under the auspices of the Organisation for European Economic Co-operation.

61. Other work on reactors included a design study of a steam-cooled, heavy water reactor and a variant of it, the steam generating heavy water reactor. Schematic designs for various systems of marine propulsion were prepared.

Magnox Reactors

62. The basic concept of this system has been proved over several years at the reactors at Calder Hall and Chapelcross, which have demonstrated the reliability of the system. Work on this reactor system remained the largest element in the Authority's reactor development programme. It was directed to ensure the maximum reliability and the lowest possible generating costs for magnox systems; for although the cost of power from the earlier magnox stations will be somewhat higher than that from the latest design of coal fired station, the magnox system still retains scope for substantial reductions in power costs. The work on this system in the year under review is classified below under the headings reactor physics, graphite moderator, and fuel elements.

* The gas-cooled, graphite-moderated reactors under construction for the electricity generating boards are known as magnox reactors from the magnesium alloy used to can the natural uranium fuel.

Reactor Physics

63. Two aspects of reactor physics have received considerable attention: changes in reactivity with length of irradiation, and the moderator temperature coefficient, that is, the inter-relation of reactivity with the temperature of the graphite moderator, and the implications of these changes upon the design of the reactor control systems.

64. The Calder reactors have provided direct information on the build-up of plutonium, the effects of which were forecast from basic studies. These studies are continuing with particular emphasis on the effects of plutonium on neutron spectra, flux distribution and temperature coefficients, and facilities have been set up for the study of lattices containing plutonium and uranium at temperatures up to 400°C. As part of the programme the fuel charge in one Calder reactor was left in the reactor much longer than usual (see paragraph 70) in order to simulate the nuclear conditions characteristic of the civil reactors. Measurements of the variations in reactivity as irradiation proceeds are valuable checks on theoretical predictions. In addition the BICEP* programme as described in the Fifth Annual Report (paragraph 76) continued, and fuel plates spiked with plutonium have been used for studies of the behaviour of reactor lattices with a plutonium content comparable to that built up in the operation of a civil reactor.

65. As the plutonium content builds up with increasing irradiation, an increase in the temperature of the moderator leads to an increase in reactivity. The reactor is then said to have a positive temperature coefficient, and, above a certain value, this accentuates tendencies to vary from the normal operating levels of the reactor. Theoretical and experimental studies were made to determine the best control systems for reactors with positive temperature coefficients. As part of these studies, the Authority have during the past year set up at Risley a large general purpose computing centre. The work has shown that, to control variations resulting from a positive temperature coefficient, different parts of the core may have to be controlled separately: multiple-zone control systems have been designed for the magnox reactors. Special control experiments were also carried out at Calder Hall and Chapelcross and although these reactors are not large enough to require separate control of different parts, the experiments have confirmed the theoretical basis of the computer calculations.

Graphite Moderator

66. In the past, knowledge of the rate of build-up of Wigner energy under the operating conditions of the civil reactors was limited, and conservative design specifications were introduced after the Windscale incident in order to ensure a safe operating life of 20 years for the civil stations. To give this guarantee with the knowledge then available required raising the bulk graphite temperature by sleeving the fuel channels of civil stations. Subsequent experiments both in materials testing reactors and at Calder Hall showed that the rate at which Wigner energy builds up decreases more rapidly than had been expected as irradiation proceeds. On the strength of this information the Authority decided to withdraw their recommendation that fuel channels should be sleeved.

* British Industries Collaborative Exponential Programme.

67. Irradiation is also known to cause dimensional changes in graphite. The experiments on Wigner energy storage also gave considerable additional information on the dimensional changes in graphite known to be caused by irradiation and should lead to improved designs of graphite structures.

68. As pointed out in the Fifth Annual Report (paragraph 161) the reaction between graphite and carbon dioxide under the influence of irradiation has been studied. Further information from the Calder Hall reactors has been supplemented by measurements on samples in the materials testing reactors DIDO and D.M.T.R. The work has shown that this reaction is not likely to present problems in magnox reactors.

Fuel Elements

69. The main technical problem outstanding is civil fuel element performance under irradiation. A major source of background information is provided by study of the performance of Calder fuel elements in the reactors at Calder Hall and Chapelcross. Since these reactors were commissioned nearly 200,000 elements have been loaded and irradiated. These large numbers provide a useful and statistically sound basis for assessing the reliability of the fuel elements; the failure rate from all causes has in fact been well below 0.1 per cent. Nevertheless a large number of the irradiated elements has been examined in order to establish the causes leading to failure. In addition an important programme has been set in hand for the testing of civil fuel elements in which groups of reactor channels have been loaded with fuel elements designed to simulate those proposed for the civil magnox power stations. These experiments, which are continuing, have proved invaluable in revealing, at an early stage, weaknesses in design such as excessive vibration of the fuel elements in the coolant gas stream and will enable remedial action to be taken before large scale production is due to start.

70. The Fifth Annual Report (paragraph 74) pointed out the importance of ensuring that fuel in the civil stations has an available heat content averaging 3000 MWD/Te. As mentioned in paragraph 64, one of the Calder Hall reactors is being used for a special experiment to investigate physics problems associated with long burn-up. By March, 1960, the average irradiation level of Calder fuel elements in this reactor had reached over 700 MWD/Te, a number of channels had exceeded 1000 MWD/Te and a number of elements had achieved 2000 MWD/Te. (The design life of Calder elements is much lower than that for civil station fuel.) Performance in the hot parts of the reactor was very satisfactory but, as expected, numbers of elements failed in the coolest region due to the insufficient ductility of Calder-type magnox when subjected to slow straining by the growth of uranium. Magnox for civil fuel elements has a finer grain and has been chosen to give a can of greater ductility at low temperatures.

71. The other phenomenon which may limit fuel element life is the swelling of uranium at high temperatures due to the agglomeration of fission product gases. Swelling has not shown at Calder but it may well apply to civil fuel at high burn-ups, particularly if fuel is subjected to thermal

cycling. The design of the civil fuel elements allows for this swelling and for the decreasing ductility at low temperature, and information from a continuing research programme indicates that civil fuel elements should have an available heat content equivalent to 3000 MWD/Te when equilibrium has been achieved.

72. In order to maintain normal operation of the civil reactors it is desirable to detect leaks in cartridges before any considerable amount of oxidation has taken place. Various improvements on the existing systems of detection were studied with a view to meeting the more stringent requirements of the civil reactors.

73. The fuel development programme increasingly requires the examination of large numbers of highly irradiated fuel elements. In order to deal with these and the very large numbers which will arise from the operation of civil magnox stations at home and abroad, the Authority have begun the construction at Windscale of very large and heavily shielded caves for examining fuel elements and of metallurgical laboratories, utilising the blower houses of the original Windscale piles.

Advanced Gas-Cooled Reactor

74. As the next development in gas-cooled reactor systems, the Authority have proceeded with the advanced gas-cooled system (A.G.R.). This reactor is fuelled with slightly enriched uranium oxide pellets canned in stainless steel or beryllium; it is moderated by graphite and cooled by carbon dioxide. The coolant gas outlet temperatures will be about 150°C higher than those of the magnox system. Recent studies have confirmed that the A.G.R. system offers the best prospect for the early achievement of competitive nuclear power in the United Kingdom.

Prototype A.G.R.

75. The construction work on the prototype advanced gas-cooled reactor at Windscale reported in the Fifth Annual Report (paragraph 80) has continued and should be completed by the spring of 1961 as planned. By March, 1960, the main reactor biological shielding was finished and the containment up to mid height. The construction of the reactor vessel was well advanced, and the heat exchangers were being erected. Good progress was also being made in the manufacture and installation of the ancillary equipment.

76. The most important rôle of the prototype reactor will eventually be the study of the irradiation performance of large quantities of fuel elements. The experience gained in the development of fuels for the magnox system has underlined the necessity for such large-scale testing.

Reactor Physics

77. The construction at Windscale of the experimental zero energy, high temperature research reactor HERO was started in September, 1959. It will be used to study the physics of the A.G.R. system. The features of HERO were described in the Fifth Annual Report (paragraph 178). Initial experiments will be carried out on beryllium and stainless steel-clad uranium oxide fuels. Later experiments will use reactor fuel containing plutonium to simulate the state of A.G.R. type reactors after prolonged burn-up of fuel. Differential heating and cooling arrangements will enable

fuel and moderator temperature coefficients to be determined. Meanwhile, experimental work is in progress using exponential stacks.

78. The formation of plutonium as fuel burns leads to a positive moderator temperature coefficient of reactivity in the A.G.R. as in the magnox reactors (see paragraph 65). In view of the higher rating, and because the beryllium used as a canning material is also significant as a moderator, the problems of control are increased. From experimental and theoretical work that has been carried out, it has been shown that a simple system will suffice to control the power output of the Windscale prototype A.G.R. However, power producing A.G.R. reactors would be appreciably larger, and the situation would be more complicated. A considerable amount of work, both theoretical and experimental, has therefore been devoted to the control of large A.G.R. systems. To facilitate control the coolant gas may be passed through the moderator before introducing it to the fuel channels; by this means the temperature of the moderator is maintained at a level close to that of the inlet gas temperature, and thus suffers a much smaller temperature change with change of power level. This re-entrant core arrangement has also been adopted for the Windscale prototype A.G.R., in order to demonstrate its value for application to the larger power production reactors.

79. The adoption of the re-entrant core will still leave the temperature of the core sufficiently high to avoid the build up of stored energy in the graphite.

80. Although, as stated in paragraph 68, the carbon-dioxide/graphite reaction is a negligible problem for the magnox reactors, it is known that this reaction increases with flux and coolant gas pressure in such a way that under the more stringent conditions in the A.G.R. the loss of graphite over the lifetime of a reactor would no longer be negligible. A large programme of work has been undertaken on this problem, utilising both the Authority's material testing and production reactors. It has been established that the presence of one or two per cent. of carbon monoxide in the coolant produces a marked reduction in the loss of graphite under irradiation.

Fuel Element Development

81. Until last year, much of the information available on enriched uranium oxide as a fuel came from the United States and from Canada. While co-operative programmes on this material have continued during the last year, an increasing amount of information has become available from irradiation work carried out by the Authority in the U.K. Development of large-scale manufacturing processes for slightly enriched uranium oxide pellets has been undertaken and already several tonnes of such pellets have been successfully made to design specification. As part of this work, a continuously operating sintering furnace has been developed which has greatly improved the efficiency of the manufacturing process.

Canning Materials

82. Beryllium was chosen as the preferred canning material for the A.G.R. system because of its good nuclear properties and good thermal conductivity. Its disadvantages are that it is toxic, it becomes less ductile

under irradiation because of the formation of helium, and it contributes to the positive temperature coefficient problems mentioned in paragraph 78.

83. The beryllium laboratories of the Authority have had considerable success in the last year in the development of production and fabrication processes for beryllium under satisfactory safety standards. Industry has been able to take over the processes, and is now manufacturing beryllium tubes and components.

84. Loss of ductility under irradiation continued to be of concern, but the preliminary results obtained during the year from the large irradiation programme were reasonably encouraging.

85. In parallel with the development of beryllium as a canning material the use of stainless steel is being investigated. The disadvantages of stainless steel (high neutron absorption and low thermal conductivity) have been mitigated by the development of greatly improved heat transfer surface, which enables the total amount of stainless steel to be kept small. Both types of canning will be tested in the Windscale A.G.R.

Civil A.G.R. Study

86. Design studies were carried out to optimise the A.G.R. system for large stations. These studies suggested that higher thermal efficiencies would be possible than were earlier assumed. These benefits derive from development of improved heat transfer surfaces, from re-optimisation of temperature and steam conditions, from improved pressure vessel design and from a re-assessment of power plant efficiencies. In order to check that forecasts for a civil A.G.R. power station were based on sound assumptions, a further study was carried out by the Authority jointly with the Central Electricity Generating Board. This has confirmed the promise of considerable reductions in capital cost and in total cost of power generated compared with magnox stations.

Fast Reactor

87. The fast breeder reactor system offers the prospect of low-cost power, because of the potentially low capital costs and low fuel cost. The capital cost should be low because the very high heat rating of the fast reactor leads to a small core and because a high operating temperature gives a high thermal efficiency. The eventual fuel cost should be low because these reactors will breed more plutonium than they consume. These fundamental advantages are indisputable, but a great deal of work will be necessary to establish that they can be commercially exploited. However, on the basis of the present information, the Authority believe that a power-producing fast breeder reactor system will be the best and most economic way of using plutonium.

88. The plans for the development of fast breeder reactor systems are as follows. Information and experience are to be gained on the Dounreay fast reactor, which became critical in November, 1959. This reactor will gradually be worked up to full output. It will then provide the necessary environment for testing various designs for fuels and fuel elements suitable for a full-scale power-producing fast reactor. A prototype power-producing

reactor may be built for operation about the year 1967, the development of which will enable a commercial power station to be specified. Whereas the fuels for the prototype will be tested in the Dounreay fast reactor, the neutron physics will require study in a facility which allows ready reassembly of the core into various configurations. It will not be possible to do this in the Dounreay fast reactor once it has come to full power, and a zero energy facility will be provided.

Dounreay Fast Reactor

89. Good progress was made during the last year. Following the first stage in the commissioning, as reported in the Fifth Annual Report, paragraph 77, the charge of 120 tons of sodium and potassium alloy was prepared and charged into the primary and secondary heat exchangers. The reactor was then made ready for operation after a very detailed testing programme had been carried out to ensure the reliability of every component. The reactor became critical in November, 1959, and was then run at low power (100 Watts), but at high temperature, in order to test under operating conditions the reliability of the components and safety devices. Some trouble was experienced through formation of oxides in the coolant, and improvements were made to the oxide clean-up circuits. In general, experience during start-up confirmed the Authority's confidence in the potentialities of this reactor system.

90. During the initial stage of low power operation, the physics programme required for testing the control problems of fast reactor systems was started. At the conclusion of this initial low power stage, the reactor was shut down for the programmed modifications to the core, involving the fitting of an adaptor to part of the core, so that other, more advanced, types of fast reactor fuel elements can be tested.

91. Knowledge of this system has been further increased through cordial and helpful collaboration with the United States Atomic Energy Commission and with the Power Reactor Development Company of America. Information and visits have been exchanged under these agreements covering the Enrico Fermi, EBR II and Dounreay reactors, and associated zero energy work. Visits were also exchanged with the Russians, who are now operating a plutonium oxide fuel fast reactor experiment of 5MW thermal.

92. A start has been made during the past year on the study of some suitable fast reactor systems for civil power production, and the optimisation of the characteristics of such systems. These studies will pave the way for the investigation of the design of a prototype, on which effort will be increasingly devoted in the coming year.

High Temperature Gas-Cooled Reactor

93. The high temperature gas-cooled reactor (H.T.G.C.) is an attempt to reduce nuclear power costs by carrying the technology of the gas-cooled, graphite-moderated reactor system beyond the limitations of the A.G.R. It looks an increasingly promising source of power for the 1970's.

94. In the H.T.G.C. reactor high heat rating per kilogramme of fuel and high gas temperature are achieved by using an all-ceramic fuel element in which a can of graphite surrounds a graphite sleeve or rod which is

impregnated with fuel; the moderator itself thus forms the heat transfer surface. The primary fuel is highly enriched uranium-235, but net consumption of fissile material can be reduced by incorporating thorium in the fuel elements for conversion under irradiation into the fissile material uranium-233. It might be possible to start the system with plutonium, rather than with uranium-235.

95. The Dragon experiment, a joint project under the auspices of the Organisation for European Economic Co-operation (see Fifth Annual Report, paragraphs 85 and 282), will test the principles of the H.T.G.C., and almost all the effort devoted by the Authority to this system during the year has been related to this experiment at Winfrith. Good progress was made during the year in setting up the project, in the design of the experimental H.T.G.C. reactor, and in the associated research and development work.

96. The Dragon experimental reactor will test the major items of technology: fuel elements, gas cooling circuits and methods for purging the system of fission products. It will operate initially with uranium highly enriched in the isotope 235 as fuel and thorium as fertile material. On account of its small size, the Dragon reactor will not show a high conversion factor, but nevertheless should give valuable information on the physics involved and a reasonably long burn-up for the fuel elements.

97. Because of its high operating temperature, the H.T.G.C. system is designed to use graphite in place of metal for canning the fuel. Ordinary reactor graphite is not suitable for the fuel element can because it is permeable and would allow fission products to diffuse into the coolant gas and so require complex plant to purge the gas of the fission products. The Authority, therefore, initiated an extensive programme with the collaboration of industry and of the Royal Aircraft Establishment for the development of graphite with low permeability but sufficiently free from neutron absorbing impurities. Graphite of the required degree of impermeability has now been made, but its performance under prolonged irradiation has yet to be established. The study of irradiation behaviour and of the mechanism by which fission products diffuse through graphite is, therefore, an important feature of the present programme.

98. Uranium/thorium/graphite fuel elements have been irradiated at high temperatures up to a high proportion of their design life, and have given encouraging results; dimensional changes were small, and the changes in permeability and thermal conductivity of the graphite container were determined.

99. The zero energy reactor ZENITH, which was designed to support the work on the H.T.G.C., was completed. Commissioning started in September, 1959, and over a period of a month the temperature of a dummy core was raised to 750°C by electrical heating of the circulating gas (nitrogen). It proved necessary to modify the heating arrangements but the reactor physics work continued with the reactor unheated. Fuel elements were loaded into the core during November and December, and the reactor became critical shortly before Christmas. Measurements have been made to determine the flux pattern and the effectiveness of the control devices in a core similar to that to be used in the Dragon reactor.

Steam Generating Heavy Water Reactor

100. As reported in the Fifth Annual Report (paragraph 82) the use as coolant of steam, instead of carbon dioxide, in heavy water-moderated systems offers substantial advantages. During the last year, in the course of the design study of a steam-cooled heavy water (S.C.H.W.) reactor prototype, a further development of this concept has taken place; instead of generating the steam in external heat exchangers, it is now proposed that the water should be evaporated in the reactor core itself. This idea of a steam generating heavy water reactor (S.G.H.W.) offers savings on capital cost since the light water coolant in the core would contribute towards moderation and the investment of heavy water would be reduced; furthermore, there would be no need for external heat exchangers.

101. The immediate object of study is a reactor using water and steam coolant in pressure tubes inserted through a heavy water container, steam being separated outside the reactor before being returned for superheat. The combination of the two different moderators and the use of the boiling principle introduces novel problems in reactor physics and stability, and the performance cannot at present be predicted to the required accuracy. Preliminary physics experiments will be carried out in DIMPLE to assist in assessing the feasibility and performance of the system. Work has also proceeded on experimental investigations of heat transfer problems in water/steam systems and on a feasibility study of a possible prototype power reactor.

102. A decision on whether to proceed with the construction of an S.G.H.W. will depend upon the results of this further work which will be reviewed later this year, and upon the availability of both technical manpower and financial resources.

Marine Reactors

Submarines

103. The Authority have continued to give advice to the Admiralty on the safety aspects of the "Dreadnought" submarine, which, as mentioned in the Fifth Annual Report, paragraph 72, is an American "Skipjack" pressurised water reactor installed in a British hull. In addition facilities and accommodation have been provided at Dounreay together with help in the establishment of the Admiralty's development and training organisation.

Merchant Ships

104. The Authority were represented on the Committee for the Application of Nuclear Power to Marine Purposes and its sub-committees which assessed proposals put forward to H.M. Government by industry for a 65,000 ton commercial tanker. H.M. Government subsequently invited certain firms to make more detailed proposals in the form of tenders to the Ministry of Transport. The Authority have undertaken to help in the assessment of these tenders when they are received. The two reactor systems for which tenders were invited were a boiling water reactor and an organic-liquid-moderated reactor.

105. The Authority have made design studies of possible marine reactor systems for the above committee, and from this work have drawn the general conclusion that reactor systems on known techniques will not

compete on an economic basis with conventional ship propulsion. Considerable improvements will be required before economic operation is likely. The Authority are continuing studies of organic-liquid-cooling and boiling water systems, and the possibilities of steam generating and steam-cooled heavy water systems for ships.

106. The Authority have helped the Ministry of Transport to prepare draft regulations governing the safe operation of nuclear ships at sea and in port.

Research Reactors

107. Most of the Authority's research reactors fall into one of two categories: those which deal with the neutron physics of various reactor assemblies, i.e. the sub-critical assemblies and zero energy reactors; and the materials testing reactors, where the object is to produce a flux of radiation into which samples can be placed for irradiation testing. The use of several of the sub-critical and zero energy facilities in elucidating the neutron physics of various reactor systems has already been referred to in previous paragraphs.

108. Two reactors which fall outside the common categories deserve mention: GLEEP, Britain's first reactor, has continued to be used extensively to check the nuclear quality of commercially produced graphite: it has also been used to measure the reactivity changes in irradiated fuel elements. The swimming pool reactor LIDO is being used to test the effectiveness of various shielding materials and in the study of the neutron physics of reactor lattices; the team doing this work has been augmented recently by staff from the consortia.

Materials Testing Reactors

109. Irradiation work carried out in the Authority's three large materials testing reactors (DIDO, PLUTO and D.M.T.R.) has been increasing in significance. For example, these high flux reactors have played a very important role in accelerating tests of the behaviour of graphite and of small specimens of fuel and cladding materials.

110. The light water-moderated research reactor HERALD at Aldermaston started operation on 29th February, 1960.

111. The past year has seen an increase in the demand for irradiation work and the Authority have found it necessary to plan for increased use of materials testing reactors overseas.

CHAPTER V

GENERAL RESEARCH AND DEVELOPMENT

Introduction

112. In other chapters of this report the results are reported of research directed primarily towards particular projects: the production plants in chapter III, reactor development in chapter IV, controlled thermonuclear research in chapter VI, and health and safety in chapter IX. There remains

a great deal of research and development of a more general nature. Some representative examples of such work are reported in this chapter.

Nuclear Physics Research

113. Research in nuclear physics is undertaken first to extend our knowledge of the structure of the nucleus and second to provide accurate measurements of the cross-sections and other nuclear properties needed for reactor design. Detailed understanding of the arrangement of nucleons within nuclei and of the nature of the extremely strong forces which hold nucleons together is still imperfect. Further knowledge is sought by assembling a wide range of data about reactions between individual nucleons and between nucleons and nuclei, and then examining these data for systematic relationships and comparing them with the predictions of theoretical models of nuclei based upon various assumptions about the intra-nuclear forces and the structure of the nuclei. The data are obtained in bombardment experiments conducted over a very wide range of energies and other experimental conditions.

114. One major group of experimental studies is concerned with the basic nucleon-nucleon interaction, i.e. the behaviour of nucleons when they collide with one another in free space, uncomplicated by the proximity of other nucleons as in nucleon-nuclear reactions. Recent advances in the theory of nucleon-nucleon scattering would make it possible to use more data than are at present available. An extensive programme of work with the synchrocyclotron at Harwell has been devoted, during the past year or so, to acquiring these data in the energy range 20 to 150 MeV. For example, a study has been made of the change in the state of polarisation of polarised protons after they have been scattered by hydrogen. The polarisation referred to is a sensitive indication of the mechanism of the interaction between the particles (and also of the interaction between particles and nuclei).

115. Other nucleon-nucleon interaction experiments have been concerned with the number of neutrons scattered by protons at different angles to the path of the beam of incident neutrons, the latter being produced in the synchrocyclotron by allowing fast protons to knock neutrons out of a target within the machine. This scattering has been measured for neutrons of energies between 20 and 120 MeV using the time-of-flight method.

116. The cyclotron has also been used for some experiments concerned with the interaction of a high-energy nucleon with a nucleus. The reaction studied was that between a proton and a carbon nucleus leading to the emission of two protons and the transmutation of the carbon nucleus to a nucleus of boron-11. In this experiment the angular distributions of the emitted protons have been measured and interpreted in terms of the momentum distribution of certain protons in the carbon nucleus. All of the data obtained in these cyclotron experiments are pertinent to the optical model of the nucleus and further define the parameters that must be used to make the model correspond with reality.

117. The interaction of 14 MeV neutrons with nuclei has been studied by measuring the energy and angular distributions of the protons emitted in

(n,p) and (n,np) reactions. These measurements show that such reactions proceed predominantly by way of a compound nucleus. However, some of the more energetic protons observed are due to direct interactions. Cross-sections have been measured for about 30 nuclei between sodium and tin. These results agree very well with the cross-sections predicted by statistical theory of nuclear reactions, providing further evidence that in this energy region the compound nucleus hypothesis provides a good description of nuclear reactions wherever the cross-section is large; this is a new fact of some theoretical importance.

118. The study of interactions between nucleons and nuclei has also been pursued at fairly low energies, using the 5 MV Van de Graaff generator and the newly completed 12 MV tandem electrostatic accelerator at Harwell. Examples of the work done with these two machines include studies of the polarization of neutrons and protons following their interaction with nuclei. The part of the nuclear interaction responsible for polarization (the spin-orbit interaction) has not been carefully studied in the past and these difficult experiments are throwing new light on this aspect of the subject.

119. The particle beam of the 5 MV accelerator can also be produced in very short bursts. In conjunction with electronic timing devices capable of measuring short time intervals to an accuracy of a few millimicroseconds, bursts of protons have been used in experiments to measure the lifetimes of excited energy levels of magnesium-25 and aluminium-25, produced by bombarding magnesium. These experiments constitute a significant test of the collective model of the nucleus.

120. Efficient particle detectors are much needed in this kind of work and a new detector has been developed in which a p-n junction in a semiconductor such as silicon or germanium is used as a solid-state ion chamber to produce an electrical impulse when a nuclear particle traverses the junction. High energy definition ($\frac{1}{2}$ per cent. resolution or better) is attainable in a small and simple device; the detector is likely to have widespread applications in nuclear research. The properties of the detector are such as to make it possible, in many experiments, to dispense with large magnetic spectrometers costing thousands of pounds.

121. A new accelerating machine came into operation at Harwell in November, 1959, when the Neutron Project Laboratory started work. The machine will provide intense bursts of neutrons which can be used, in the time-of-flight method, to make precise measurements of the neutron cross-sections for various nuclei over a wide range of energies. The machine incorporates a linear accelerator capable of accelerating electrons to 30 MeV; the energetic electrons strike a target of mercury and release gamma rays which in turn release neutrons from a uranium target. The intensity of the neutron pulse is increased some tenfold by using in this target a sub-critical assembly of enriched uranium, in which neutron multiplication takes place, though without reaching the critical condition for a self-sustaining reaction.

122. This powerful pulsed neutron source with its sub-critical neutron-multiplying assembly also makes possible studies of certain aspects of the

fission process, and of other neutron interactions, which were previously impracticable. Its primary use however will be for the measurement of all the cross-sections, for fissile and fertile and for structural material, needed for the thermal reactors of the power programme, work which will occupy a large team of scientists for several years.

123. An understanding of the physics of fast reactors requires detailed knowledge of the interactions of neutrons over a wide range of energies with both fissile and structural materials and with likely coolants such as sodium metal. The aim of experimental work at Aldermaston, which at present is carried out with the 6 MV and 3 MV electrostatic generators, is to contribute to measurements of fast neutron scattering and of capture cross sections of neutrons emitted in the fission of uranium and plutonium isotopes and other similar data, all of which can be used to predict the critical size, breeding ratio and other properties of a fast reactor.

124. A large heavily shielded liquid scintillation counter has been developed for the study of neutron emission in fission. Accurate data are now available for 14 MeV neutrons and the measurements are being extended to cover a wide range of neutron energies. The apparatus can also be used to study neutron capture reactions and neutron emission in (n, 2n) and (n, 3n) reactions. Selection of incident neutron energy is achieved by moving the assembly around a suitable target which is bombarded by protons or deuterons from the electrostatic generator.

125. An important innovation in the technique of studying the elastic and inelastic scattering of neutrons was the introduction of a detector which provides complete discrimination against gamma rays. With incident neutrons of about 4 MeV, it has been found that the background in the detector can be reduced by an order of magnitude by a combination of better shielding and gamma ray suppression.

126. The experimental study of ^3He induced reactions has continued at Aldermaston to yield valuable data on nuclear energy levels in the lighter nuclei. By the introduction of a gas stripper into the accelerating tube of the 6 MV Van de Graaff generator, it has proved possible to produce target currents of 1 μA of doubly ionized helium in the energy region 6 to 11 MeV. At these higher energies, reactions occur mainly as a result of direct, rather than compound, nucleus interactions, so that angular momentum transfers may be inferred as in the well-known deuteron stripping reactions. It has been found that (^3He , d) reactions are particularly satisfactory in this respect, since they show well defined angular distributions which do not vary rapidly with ^3He bombarding energy. Moreover, for a given target nucleus, (^3He , d) reactions lead to the same residual nucleus as to (p, γ) reactions which have been intensively studied in the past. The new precise data on energy levels in ^3He induced reactions have therefore been of great value in the interpretation of much earlier work.

127. The tandem electrostatic generator at Aldermaston has operated very satisfactorily during the past year. Beams of protons and deuterons with energies up to 12.5 MeV have been used in inelastic scattering and reaction studies, and most recently energetic oxygen ions have been used to investigate the Coulomb excitation process. In Coulomb excitation, the bombarding ion does not enter the nucleus but transfers energy to it through the

relatively long range electric and magnetic fields. An accurate theory of Coulomb excitation exists, and the process is particularly valuable for investigating those states of nuclei which arise from the *collective* motions of the nucleons. Heavy ions, such as those of oxygen, are particularly suitable for Coulomb excitation studies, and are readily accelerated in the tandem to energies of about 35 MeV. The Coulomb excitation process itself is being studied in detail, and low lying energy levels of both light and heavy nuclei have been investigated.

Experiments connected with the Theory of Relativity

128. A recent German discovery that under certain conditions the frequency of gamma rays emitted from radioactive nuclei is very precisely defined has made it possible to test the principle of equivalence postulated in the general theory of relativity. A team at Harwell (which included a visiting Guggenheim Fellow from the U.S.A.) has begun a programme of experiments to exploit the narrow width of the gamma radiation from iron-57.

129. One experiment has been to test the change in frequency (red shift) caused by the earth's gravitational field. Another has been to measure the change produced by accelerations up to 65,000 times that of gravity using a source at the centre of a very fast cylindrical rotor and an absorber at the periphery. The expected effect was found.

Solid State Physics

130. A fundamental experiment has been carried out in the realm of solid state physics using lithium isotopes. An important discrepancy has existed between observed thermal conductivities of dielectric crystals at low temperatures and the theoretical predictions for perfect crystals. It has been suggested that the discrepancy is due to the presence of isotopes which disrupt the periodicity of the crystal lattice and increase the thermal resistance, and two theories for this effect have been published. Measurements have been made at Capenhurst, in conjunction with university scientists, of the thermal conductivity of single crystals of lithium fluoride containing various relative concentrations of the isotopes lithium-6 and lithium-7 in the temperature range 10° to 90°K. A change in thermal resistance with isotopic concentrations is observed but the results fit neither of the theories previously advanced. A new theoretical treatment is in good agreement with the experiments on lithium fluoride and also with published observations on a wide range of crystals containing known concentrations of point imperfections.

131. In recent years several instances have been published in which the heavier species of isotopic substances have been shown to be more volatile than the lighter species and recently Swiss scientists have given a theoretical explanation of this phenomenon. Boron trifluoride exhibits this behaviour so that $^{11}\text{BF}_3$ has a higher vapour pressure than $^{10}\text{BF}_3$. Measurements have been made directly of the relative volatility of the two isotopic species using highly separated material. The measurements are approximately in agreement with the theoretical predictions.

Radiation Chemistry and Nuclear Technology

132. Since radiation, especially neutron and gamma radiation, is capable of causing physical and chemical changes in materials, stability under radiation is usually an essential requirement for components of nuclear reactors and for the chemical reagents employed in fuel processing plants. Besides producing structural damage in fuels and other solid materials, radiation brings about chemical reactions in coolant and moderator systems which may considerably affect the performance of a reactor. Likewise the decomposition requires that the activity of the fuel put into the plant shall not exceed a certain level and thus dictates a minimum period for which the fuel must be left to "cool" radioactively after being taken out of the reactor; the decomposition may also reduce extraction efficiency. Much of the work on radiation chemistry at Harwell has been undertaken in connection with the problems of radiation damage in reactors and in fuel processing plants.

133. The first investigation was concerned with the solvent used in the present plutonium separation plant at Windscale; this solvent is dibutoxydiethyl ether (commonly called butex). One reason for the choice of butex was its relative stability to radiation. A detailed investigation was carried out with the aid of the 2 MV Van de Graaff electron accelerator at Harwell. This work provided a good basis for understanding the role of solvent decomposition at various critical points in the plant.

134. A study of the gamma-radiolysis of a simple oxygenated solvent, methyl acetate, has shown how complicated the degradation of a simple ester can be. Twenty-three products were characterised and their radiation yields were determined. Their nature suggests that, with the exception of the carbonyl bond, every bond in the molecule may break on exposure to ionizing radiation. The observed products are largely formed by combination or disproportionation of the eight possible radicals arising from the primary disruptions. The related symmetrical ketone acetone gives fewer products but a similar pattern of disruption seems to be indicated.

135. In recently constructed chemical plants, the solvent system tributyl phosphate in kerosene has been used. A study of the radiolysis of tri-alkyl phosphates at Harwell has shown that, in addition to hydrogen and light hydrocarbons, dialkyl- and smaller amounts of mono-alkyl phosphoric acids are produced. The radiation yields of these acids decrease steadily on passing from the trimethyl to the tributyl ester. The triamyl ester is only slightly more stable than the latter compound. These yields are markedly altered by the addition of water, nitric acid, hydrocarbon diluent and uranium nitrate. These esters can also be degraded by ionizing radiation in aqueous solution. The detachment of an alkyl group has been studied using the corresponding set of mono-alkyl phosphoric acids. In the absence of oxygen, phosphoric acid is formed. In oxygenated solutions larger yields are obtained and in addition hydrolysable acyl-phosphates, aldehydes and peroxides are formed. In both cases, the yields of phosphate diminish as the length of the alkyl chain is increased.

136. Detailed knowledge of this kind assists understanding of the possible effects of fission-product radiation on the behaviour of extraction columns, since alkyl phosphoric acids are strong complexing agents for important metallic ions. The application of such knowledge to particular conditions is being pursued at Windscale and at Dounreay.

137. There is a growing demand for a more detailed knowledge of the behaviour of the system carbon-dioxide/carbon-monoxide/graphite under irradiation. These studies are aimed at determining the basic parameters that affect the rates of the reactions. In the first experiments, gas was circulated over graphite in an apparatus in BEPO. These demonstrated that the temperature has no appreciable effect on the rate at which carbon monoxide is produced from carbon dioxide and graphite over a temperature range from 100°C to 600°C. Above the latter temperature there is a marked increase in the rate, caused presumably by a purely thermal reaction. When the experiment is carried out in a sealed apparatus, a steady-state concentration of carbon monoxide is attained as a result of competing forward and back reactions. Similar experiments in DIDO at 400-500°C have demonstrated that the amount of surface oxide present (i.e. oxygen chemisorbed on active sites on the graphite surface) has a marked effect on the rate of the radiation-induced carbon monoxide formation. The relationship between carbon weight loss and carbon monoxide production has been obscured by weight changes caused by thermal and radiation-induced degassing during the experiments and by changes in the condition of the surface oxide.

138. In another group of experiments, the behaviour of carbon-14 incorporated in samples of graphite, during irradiation in sealed tubes containing various mixtures of carbon monoxide and carbon dioxide, is being studied at 80°C. Transport of carbon to the gas phase takes place in all mixtures, even in pure carbon monoxide. The rate of transfer is affected by gas composition and by pre-treatment of the graphite.

139. The influence of geometrical factors on the radiation-induced reaction producing carbon monoxide is being studied in sealed tubes. By using a wide range of gas pressures and ratios of graphite to gas in a variety of geometrical arrangements, a picture is being assembled of the complex factors which control the competition between gas-phase destruction of the active species and diffusion of those species to the carbon surface, where they can react. It is already possible to separate the total reaction in a static system into that resulting from irradiation of the gas in the pores of the graphite and the (less efficient) reaction at the superficial surface due to irradiation of the bulk gas in the rest of the tube.

140. The reactions between pile graphite and other gases such as hydrogen and nitrogen in the presence of radiation have also been studied. There is a slow production of methane in the case of hydrogen whereas there is no measureable reaction with nitrogen below 650°C.

141. A rather different subject of study has been the radiation chemistry of the liquids proposed as moderator and coolant in the organic-liquid-moderated reactor mentioned in paragraph 104. The liquids are commercial mixtures of organic compounds known as polyphenyls. The

reactor system was first tried in the United States and the radiation chemistry has been studied both in American laboratories and at Harwell.

142. It has been known for a long time that benzene is more stable to ionizing radiation than a paraffin hydrocarbon. Benzene has a comparatively low boiling point so that it has no special advantage in a reactor over, say, water.

143. The polyphenyls however have quite high boiling points. It has been shown by American workers that their stability to radiation is high and that the main products of such decomposition as does take place are hydrogen gas and higher polyphenyls which are themselves soluble in the original liquid. The result is that the viscosity of the liquid does not rise quickly to unacceptable levels and no solid material is deposited.

144. The radiolysis has been studied with the electron beam from a 2 MV Van de Graaff machine, with high intensity gamma rays, and with neutrons from the BEPO reactor. It has been shown that the radiation yields for the breakdown of the lower polyphenyls at high temperatures in BEPO are markedly higher than those obtained using electron and gamma radiation. Exposures of benzene, biphenyl, or terphenyl containing small amounts of triphenyl boron to the pile flux have led to the conclusion that the yields (per 100 eV absorbed energy) are increased to still higher values when the decomposition is induced by the densely ionising recoils resulting from neutron collision with a boron-10 nucleus, which leads to the formation of a lithium-7 nucleus and the release of an alpha particle. The integral yields of decomposition of benzene by protons of various initial energies also increase steadily as this energy is decreased from 4 MeV to lower values. All this evidence suggests that the linear rate of energy transfer in the tracks of the ionizing particles is an important factor in determining the decomposition of these unsubstituted aromatic hydrocarbons.

145. Prolonged irradiations of Santowax-R, a commercial mixture of isomeric terphenyls, at 350°C in the reactor have shown that the rate of breakdown decreases continuously with increased polymer content—to half the initial rate at 30 per cent. polymer and to approximately one-quarter at 50 per cent. polymer. This decrease is smaller than was expected from previous work at lower doses.

146. The viscosity of the irradiated material increases rapidly beyond a polymer content of 50 per cent. to an extent dependent on the temperature. The increase in density is less pronounced.

147. The rate of breakdown of Santowax-R in a pile increases very rapidly in the temperature range 400–420°C. When some provision is made for possible temperature excursions, it seems unlikely that a terphenyl coolant could be used at a bulk temperature higher than 370–380°C.

148. Fully deuterated biphenyl and paraterphenyl have also been examined. They are markedly more stable to electron irradiation than their hydrogen counterparts, but only slightly more resistant to irradiation in the BEPO reactor. This is to be expected if the linear energy transfer in the particle tracks is an important factor in determining stability. It is doubtful if any economic advantage would result from the use of deuterated moderator-coolants of this class.

149. A number of other materials has been examined but so far nothing has been found which is superior to the polyphenyls and current design studies of organic liquid moderated reactors are based on their use.

Radioactive Aerosols

150. An investigation is being made at Harwell on the nature and properties of radioactive aerosols. An "aerosol" is a suspension in air of particles so small that they have an inappreciable rate of fall under gravity. There are large numbers of such particles in the air near the ground—thousands in each cubic centimetre in the open air and tens or hundreds of thousands in each cubic centimetre in industrial atmospheres. The mean diameter of the particle is about a hundred-thousandth of a centimetre. These particles, which are usually known as Aitken nuclei, are formed in vast numbers during combustion processes, also when metals are heated to red heat, and by electric sparks. Aitken nuclei act as condensation centres for water vapour in air if the air is suddenly cooled, for example, in a cloud chamber, and by such means the number present can be measured. They also act as carriers for the electrical charge in the atmosphere.

151. It is now known that most of the radioactivity in the air is associated with Aitken nuclei. A natural source of such activity is the emanation of the naturally-occurring radioactive gases radon and thoron from the soil. These gases diffuse upwards into the atmosphere and undergo radioactive decay; the decay products, which are also radioactive, are isotopes of polonium, lead and bismuth, and become attached to the Aitken nuclei in the air. An artificial source of radioactivity is the fission products produced in high altitude nuclear explosions; these also are found to attach themselves to particles of similar size to Aitken nuclei.

152. There is evidence that radioactive iodine can exist in the atmosphere either as a vapour or adsorbed on particulate matter. The adsorption of even a single layer of iodine molecules can be important because the specific activity (i.e. the radioactivity of unit mass) of radio iodine is high.

153. It is important to know the exact form in which radio iodine may be found in practice, because methods of removing iodine from streams of gas which are efficient for vapour may be inefficient for iodine adsorbed on very small particles. Most forms of chemical gas absorbers, which might be used for removing the activity, depend for their action on the diffusion of the gas to a collecting surface. Small particles do not diffuse to surfaces as rapidly as gas molecules but they can be removed by high efficiency fibre filters.

154. Laboratory experiments on the release of iodine in air and carbon dioxide at very low vapour concentrations, have been made. In these experiments the iodine has been released by heating irradiated uranium, in which the iodine occurs as a fission product. In the course of these experiments efficient combinations of filters and chemical absorbers have been found. In addition to this work, the form in which ordinary stable iodine occurs naturally in the air has been studied, because the radioactive and stable isotopes may be expected to exchange with each other. Another subject of research is the deposition of radioactivity from the air to the ground; useful information was obtained during investigations following the Windscale accident in October, 1957, and the results have been published.

Criticality Calculations

155. In considering the design of production plants, careful attention has to be given to the possibilities of criticality. Considerable technical work has been undertaken to back particular design studies, and in addition a more generalised study has been undertaken. A unified theory has been checked against American experimental results and very good agreement has been obtained, the theory erring a little on the side of safety. Fundamental studies have been carried out on criticality calculations for water-moderated uranium lattices of low enrichment and this work gives close agreement with published experimental results. Calculations have also been made of the criticality of lattices of irradiated uranium bars. A combination of theoretical and empirical methods has been used to predict criticality data for homogeneous systems moderated by water and having as fissile material 93 per cent. uranium-235, plutonium, and less than 5 per cent. uranium-235 respectively. Where experimental checks are available, they give good agreement.

Research on the Applications of Radioisotopes

156. Work has continued in the Wantage Research Laboratory on the application of radioisotopes, especially in industry. Thus the method of fluorescence spectroscopy, using radioactive sources, has been applied to measuring very thin surface coatings. Instruments based on this and a related technique have been used industrially to measure metal coatings about a ten-thousandth of a centimetre thick, and also the thickness of ink on paper.

157. Radioactive tracers continue to be applied in new ways. In the electro-plating industry, the modes of action of some additives commonly used to brighten and level the plated deposit have been elucidated for the first time with the help of tracers. The tracers were detected by micro-autoradiography, in which the active material is made to take a photograph of itself.

158. In the development of fuel element cans for power reactors, tracers have been used to identify and locate constituents of the metal such as might lead to failure in operation. A method has also been devised for testing fuel element cans for incipient leaks, using krypton-85 gas as a tracer. By similar methods, leaks at a rate less than one ten-thousandth of a cubic centimetre in a year can be detected in small components such as transistors.

159. By tracer methods, the rate of flow of liquid in closed channels can now be measured with an error of less than one part in two hundred; this is an improvement in both accuracy and convenience over established methods. Measurements of this kind are important in commissioning hydro-electric generators. Similar techniques have been adapted as a means for detecting leaks in the effluent pipeline at the Atomic Energy Establishment, Winfrith.

160. Further work has been done at Wantage on the use of large sources of gamma-radiation for sterilisation and other applications. Reference was made in paragraph 211 of the Fifth Annual Report to the use of gamma ray sterilisation of disposable plastic hypodermic syringes and similar

medical equipment; the advantages are that these cheap thermoplastic products can be thrown away after having been used once, at a cost no more than that of cleaning and resterilising ordinary types of syringe and other medical instruments. Gamma radiation is also ideal for sterilising rubber appliances which, like thermoplastics, are unable to stand high temperatures; the high penetration of this radiation permits sterilisation after the appliances have been packed in double sealed containers. For several months 10,000 catheters a week have been sterilised in an installation at Harwell in which spent fuel elements from DIDO and PLUTO are used as sources of radiation.

161. A pilot scale plant for irradiating packages of materials with gamma rays has been built at Wantage to use, at first, 120,000 curies of cobalt-60. Eighty per cent. of the capacity of this plant is reserved for sterilisation by manufacturers of medical equipment, for clinical trials and for packaging and storage tests before full-scale production. The remainder of the capacity is taken up in the research and development programme of the Technological Irradiation Group. The first industrial gamma-ray sterilisation unit in the world, referred to in paragraph 207 of the Fifth Annual Report, has been completed in Australia and 150,000 curies of cobalt-60, supplied by the Authority, have been installed. Further cobalt sources of up to 500,000 curies have been ordered for extensions to the plant.

162. In industrial chemical applications of radiation, the method of coating synthetic fibres by gamma-ray-induced graft polymerization, mentioned in previous Annual Reports, has been extended in a recent application in which coatings capable of absorbing dyes were applied.

Production of Protactinium-231 and Technetium

163. As a result of a collaborative effort between the Authority and universities, relatively large quantities of two rare elements have been extracted and made available for basic research. More than 60 tons of solid residues have been subjected to a chemical process for the recovery of protactinium-231. These operations have resulted in the separation of more than 100 grammes of this element which represents probably the largest stock in the world. Almost 20 grammes of technetium have been separated from about 100 tons of radioactive waste solution. This is the first time that gramme quantities of this element have been made available in the United Kingdom.

Isotopic Analysis

164. Isotopic analysis has an important part to play in the field of atomic energy, not only in extending scientific knowledge but also in the Authority's economics. There is, therefore, a continual demand for improved instrumentation, particularly for analysing uranium for its fissile isotope uranium-235. Two of the developments at Capenhurst are described in the following paragraphs.

165. A 12" radius sector-type mass spectrometer has been successfully developed for the very precise determination of changes in uranium-235 concentration when the sample is in the form of a gas (uranium hexafluoride). The instrument can detect a change of 5 parts in 100,000.

166. To improve the absolute accuracy with which uranium-235 concentrations can be determined it is necessary to have isotopic standards. Over the past two years there has been a programme of work to prepare such standards which can be made generally available. The primary standards consist of two samples of uranium oxide prepared from electromagnetically separated uranium-238 or uranium-235 which have been very carefully analysed for both isotopic and chemical purity. By reference to these primary standards, bulk amounts of secondary standards have been prepared that are highly enriched and depleted in the uranium-235 isotope. Thus within the isotopic range of these secondary standards, samples of any uranium-235 concentration can be blended in which this concentration is known to an accuracy of 0.1 per cent. of the actual uranium-235 concentration.

Mass Spectrometry

167. A mass spectrometer has been developed at Capenhurst for the analysis of the active species present in gas/solid chemical reactions. The particular problem which was in mind when the work was commenced was the elucidation of the carbon-dioxide/graphite reaction under irradiation, but the instrument finally developed will be of general application. The instrument has been designed to study reactions at gas pressures up to 2 atmospheres and in favourable conditions to detect active species down to a level of 1 part per million or better. The mass spectrometer is a standard sector type machine incorporating two new techniques for the analysis of trace components in gases. A molecular beam inlet system is used to allow short-lived species direct passage to the mass spectrometer ion source; a chopping technique has been devised which enables wanted AC signals from the inlet system to be separated from unwanted DC signals arising from the background ions in the instrument.

168. Efforts at Aldermaston to develop improved methods of ion beam detection have met with success. One, a secondary electron scintillation technique, will detect single ions. Another method distinguishes and compares monatomic ions with molecular ions of the same mass.

Gas Bearings

169. The development of the atomic energy industry has required many new approaches in the more traditional fields of engineering. This has called for a close collaboration by engineers and physicists to study the effects of unusual conditions on normal engineering practice and to devise new solutions to well established engineering problems. This can well be demonstrated in the field of lubrication. Here, current development in gas-cooled reactor technology has called for mechanisms to operate either unlubricated or lubricated solely with the gas that is being circulated.

170. Basic studies have been made of the friction and wear behaviour of materials in reactor coolant environments at high temperatures. It has been found that in carbon dioxide and helium both wear rates and friction coefficients can vary greatly with temperature. Low-chromium alloys show the greatest variation, whilst high-chromium alloys give little change between ambient temperature and 400°C. It is known that surface oxide films can have a marked influence on friction and surface damage. Least

wear rates were, in fact, obtained with low-chromium alloys under conditions where visible surface oxidation occurred. Ordinary rolling contact bearings running unlubricated have also been studied under similar conditions. Experimental life-load curves for the bearings have been determined and the bearing wear has been measured and analysed. This work has built up a considerable background of knowledge of what can be achieved with such ordinary bearings under reactor conditions.

171. The alternative solution of using the gas which is being circulated as a lubricant has led to a study of the possibilities and applications of gas bearings. Thus, detailed investigation into the load-carrying capacity and vibration characteristics of self-acting and externally pressurised journal bearings and thrust plates have been investigated.

172. For self-acting journal bearings existing theories of load-carrying capacity fit experimental results if isothermal conditions in the gas film are assumed. Four separate modes of half-speed whirl have been distinguished and correlated by theory. Bearings up to 7" in diameter have been investigated. Investigations of the spiral-groove thrustplate self-acting bearing have also been made and a modified theory developed which is in good agreement with the results both for load-carrying capacity and vibration properties. The problem of surface distortion due to the heat developed by friction in the gas film has also been explained. In externally pressurised bearings various modes of vibration have been distinguished, particularly pneumatic-hammer synchronous whirl and half-speed whirl. These whirls of the shaft can be either cylindrical or conical and experimentally observed values are related to theory.

173. As a result of this gas bearing work, a peripheral gas-bearing compressor has been developed for the circulation of gases in reactor loops and other closed systems. At a relatively high pressure ratio where low mass flow is generally required, the peripheral type compressor best meets these requirements. The machine developed consists of a motor unit, the rotor being mounted on a pair of gas bearings, and an impeller unit, also mounted on a pair of gas bearings, the two units being connected by a quill shaft. The whole machine is totally enclosed and built to a very tight vacuum specification. It will handle all gases that do not react with the motor winding. Various sizes of units have been built covering the range 7-60 h.p.

Flash-Radiography

174. Considerable progress has been achieved at Aldermaston in the provision of short duration radiographs of systems opaque to ordinary light and moving at high speed. To this end special low inductance Marx generators have been constructed giving a single voltage pulse of 1 MV or 2 MV with a duration of order 0.2 micro-seconds. These generators are believed to have appreciably better performance than any comparable generator for which published information is available.

175. To work with these generators special X-ray tubes have also been developed, with both hot and cold cathodes. In order to get good resolution and high dose the design of the tube has been concentrated on getting an X-ray source the size of which is of the order of 2 mm. in diameter.

176. A 30 MeV linear accelerator has been installed to provide a source of pulsed gamma rays of even greater penetrating power. This accelerator is an early experimental model built at Harwell, which has been modified and adapted in various ways to provide an intense burst of gamma rays lasting for a time of the order of 0.2 microseconds.

Very-High-Speed Cameras

177. Very-high-speed cameras were originally developed at Aldermaston to record the growth of an atomic explosion during the first few millionths of a second. Today much improved designs are making important contributions to our knowledge of pinched discharges in controlled thermonuclear reaction work, and A.W.R.E. cameras are used in this connection both at Harwell and at Aldermaston.

178. Two types of mechanical very-high-speed cameras are manufactured at Aldermaston. One, the streak camera, records along a length of film the size of a light source which is varying with time, the other, the framing camera, produces individual pictures at intervals on a strip of film.

179. The light entering either type of camera, through a suitable lens, is directed on to the surface of a rapidly rotating steel mirror, from which it is reflected on to a stationary strip of photographic film. Thus the light streaks across the film and is recorded as such in the streak camera. From examination of the film after development it is possible to measure the size of the light source at any specific time over a total period of 12 or 25 millionths of a second, depending on the mirror speed.

180. By focussing the entering light on the mirror surface and placing a number of lenses in an arc between mirror and film it is possible to obtain a series of individual pictures. With the mirror rotating at 300,000 r.p.m. and with 90 lenses in such a camera, the time between each picture is one seven millionth of a second. Each picture is exposed for one ten millionth of a second. In such a camera the mirror has a long life. Mirror speeds as high as 400,000 r.p.m. are also available, but then bearing wear limits the number of runs. These very high speeds are obtained by means of a compressed air turbine drive. The mirror itself spins in a vacuum.

181. A third type of very high speed camera is made which takes a single picture with an exposure time of one ten millionth of a second, using a Kerr cell shutter. This cell contains a special liquid through which the light will pass only as long as a suitable voltage is applied to it. Thus the timing here is electronic.

Technology of Inert Gases

182. A special study of inert atmosphere systems has been made at Aldermaston for chemical and metallurgical processing where reactive impurities in the atmosphere cannot be tolerated above a few parts per million. Plants for argon purification, processing chambers and control systems have been developed. Instruments concerned with measuring traces of all likely types of impurities have also been developed and are being exploited commercially.

CHAPTER VI

CONTROLLED THERMONUCLEAR REACTIONS

Work at Harwell and in Industry

ZETA and Sceptre

183. In the Fifth Annual Report (paragraphs 100 to 106) reference was made to experiments at Harwell on ZETA. This is a ring shaped apparatus in which deuterium gas is heated to high temperatures by passing through it a large pulse of current (up to 200,000 ampères); the result is a "pinched" discharge, since the electromagnetic forces associated with the current cause the gas to be compressed inwards and so to move away from the walls of the containing tube. Reference was also made to a similar but smaller apparatus, Sceptre III, which was built (with financial assistance from the Authority) at the laboratories of Associated Electrical Industries Limited at Aldermaston Court, and to a further similar device, Sceptre IV, then nearing completion also at Aldermaston Court.

184. Initial experiments on ZETA showed that, although the passage of gas currents of up to about two hundred thousand ampères caused the bulk of the gas to be compressed away from the torus walls, there was an excessive loss of energy from the gas during the current pulse. The rate of loss of energy from ZETA was such that the whole of the energy stored in the gas at any one time was being lost in one ten-thousandth of a second (this time is known as the energy containment time). Because this time is small compared with the period of the current pulse, the temperature of the gas rose rapidly during the early part of the current pulse, but then failed to rise further.

185. During the past year, the stored energy supply and the stabilizing magnetic field supply of ZETA were both increased by about six times. As a result, gas currents of up to 800,000 ampères were obtained. This made it possible to operate at considerably higher gas pressure. However, the increase in current has not led either to a substantial increase in the gas temperatures achieved or in the energy containment time. The exact mechanism by which the energy is lost depends on the discharge conditions (current, pressure, axial magnetic field) but the primary cause of the energy loss is likely to be that the configuration of plasma and associated magnetic fields is hydromagnetically unstable, as is confirmed by recent theoretical work. Experimental elucidation of the physical phenomena in the ZETA and Sceptre plasmas has continued successfully throughout the year.

186. Sceptre IV was brought into operation in November, 1959. It is similar to Sceptre III, but has a perfect toroidal shape and a more uniform axial magnetic field, and has been operated at currents up to 480,000 ampères. It has not resulted in ion or electron temperatures higher than those in Sceptre III.

187. Theoretical studies have suggested that a necessary, though perhaps not a sufficient, condition for stability is that the current can be made to flow in a thin skin on the surface of the ionized gas. It is known that such a surface current is produced if the current is made to increase sufficiently rapidly at the beginning of the current pulse, but for technical reasons a

sufficiently rapid rate of rise of current cannot be obtained with either ZETA or Sceptre. An experiment, known as I.C.S.E. (Intermediate Current Stability Experiment) is therefore being designed, in which the current will rise fast enough to produce a skin effect. Furthermore, theory suggests that hydromagnetic stability can be achieved if an additional stabilizing magnetic field is applied outside the plasma; and this requirement is also incorporated into I.C.S.E.

188. The object of the experiment is to investigate the stability of this improved "pinch" configuration, and to check the main predictions of present stability theory. Thus although the apparatus is aimed at producing certain definite conditions, I.C.S.E. is being designed so that many of the parameters affecting stability can be varied over a wide range. The achievement of hydromagnetic stability may not be sufficient since other sources of instability in plasmas are known to be possible. I.C.S.E. will essentially be a large scale experiment in plasma physics.

189. The design of this experiment is now well advanced, and orders have been placed for some of the main components. The apparatus will be erected at the Culham Laboratory.

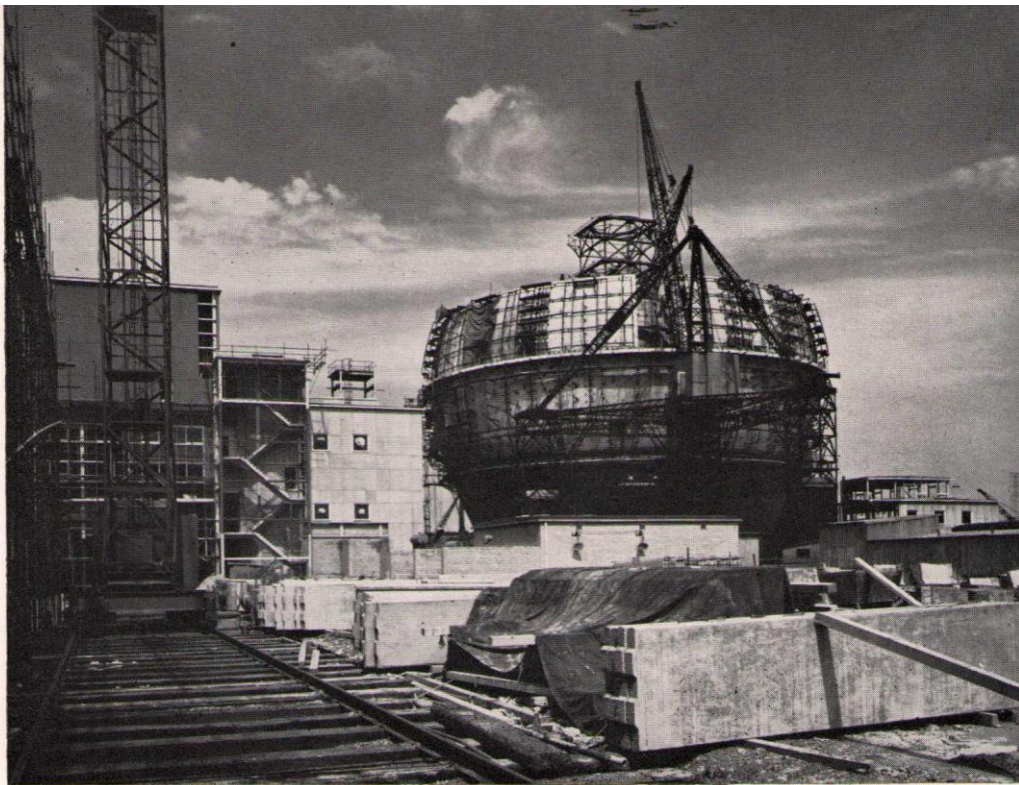
Other plasma physics experiments

190. During the past year work continued on a number of other plasma physics experiments at Harwell. Three examples of such work are given below.

191. Theoretical considerations made by Alfven in 1942 predicted that hydromagnetic waves could be propagated in the joint presence of a magnetic field and a plasma. Because of the importance of these Alfven waves, an experiment was undertaken to demonstrate their existence. The velocity of propagation of the disturbance was found to agree closely with the theoretical value for the velocity of Alfven waves. A similar experiment was performed almost simultaneously at the University of California.

192. In order to investigate some of the theoretical predictions about the stability of a pinched discharge, experiments were continued with cylindrical systems. All the results obtained so far can be explained qualitatively in terms of hydromagnetic stabilities.

193. Experiments were made on ZETA, by members of the National Bureau of Standards, Boulder, Colorado, U.S.A., which demonstrated, for the first time in a laboratory, the propagation of electromagnetic waves in the so-called "whistler" mode. These waves have been known for many years as a form of radio atmospheric, due to lightning flashes. It is thought that the low frequency part of the lightning signal is propagated along the lines of the earth's magnetic field through the plasma formed in the extreme upper regions of the atmosphere. This medium is highly dispersive so that when the signal is received at the other end of the line of force, the original signal becomes a whistle of steadily decreasing pitch. The experiments reproduced this phenomenon by propagation of 10 cm. waves (the appropriately scaled wavelength for the apparatus) through the magnetised plasma in ZETA.



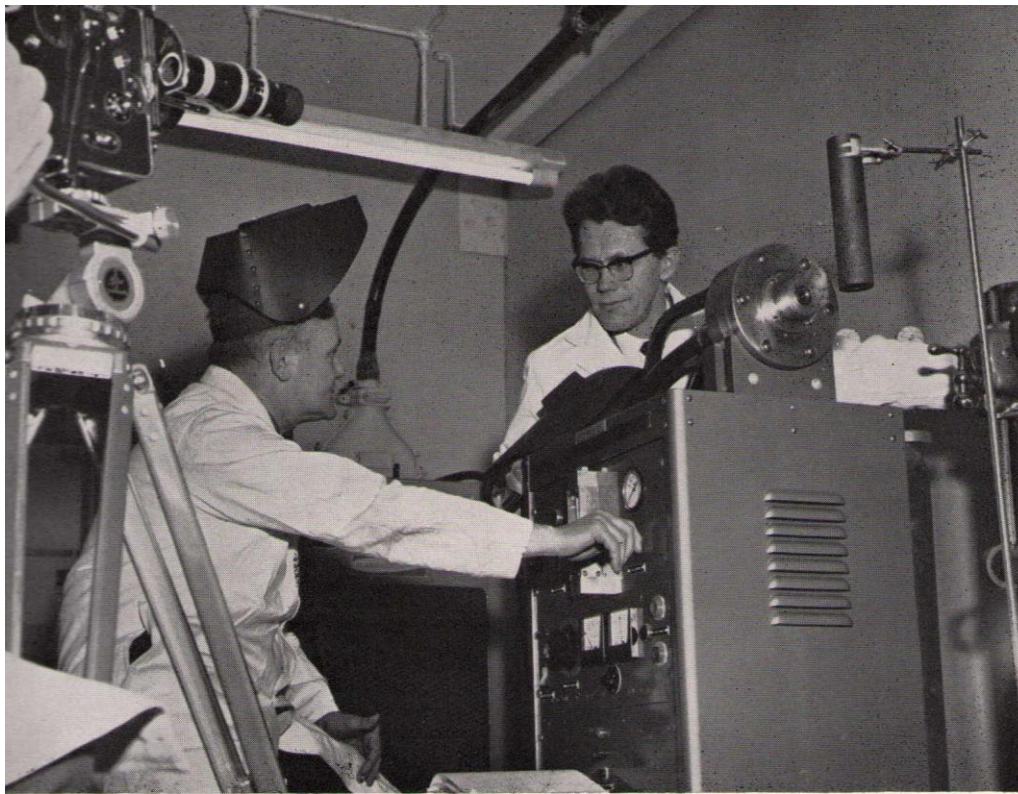
ADVANCED GAS-COOLED REACTOR

The prototype A.G.R. is now under construction at Windscale. Recent studies have confirmed that this system offers the best prospect for the early achievement of competitive nuclear power in the United Kingdom.

RADIOISOTOPES

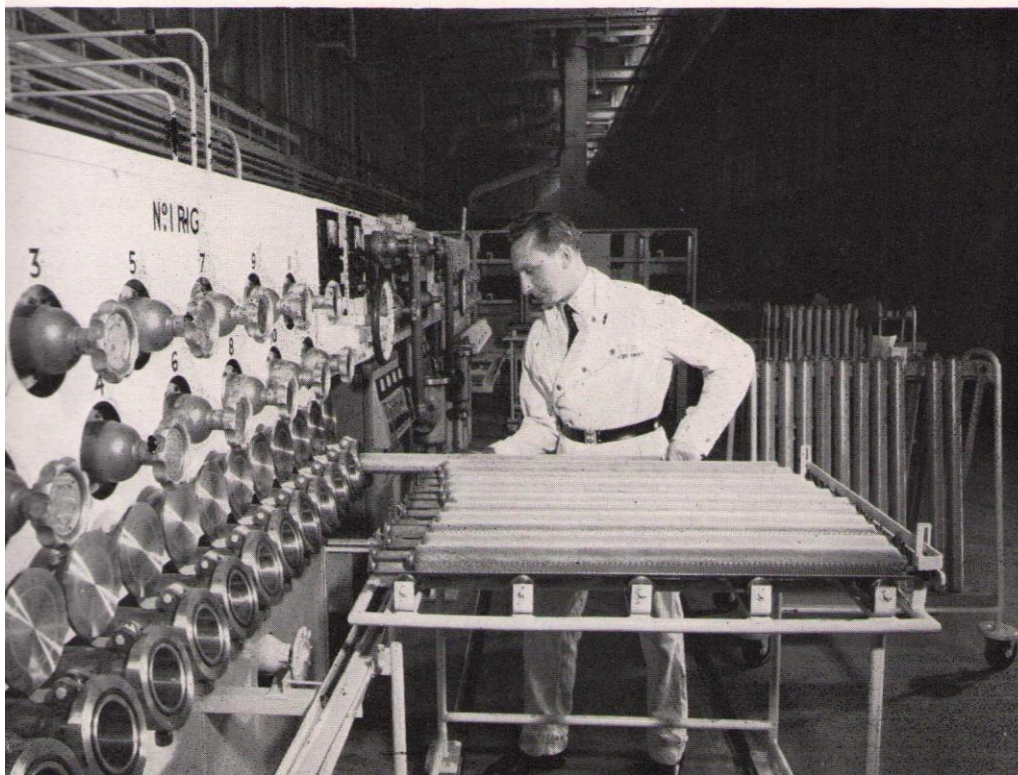
Two new laboratories were brought into commission at the Radiochemical Centre, Amer-sham, during the year. Isotopes to the value of £1.1 million were sold through the Centre during 1959/60, an increase of 25 per cent over the previous year.





DRAGON PROJECT. Scientists and engineers from twelve European countries are working on the O.E.E.C. Dragon project at Winfrith, Dorset. The aim of the project is to develop an experimental version of the high temperature gas-cooled reactor. The photograph shows Mr. T. A. J. Jaques (U.K.) (left) with Mr. B. Aarset, of Norway.

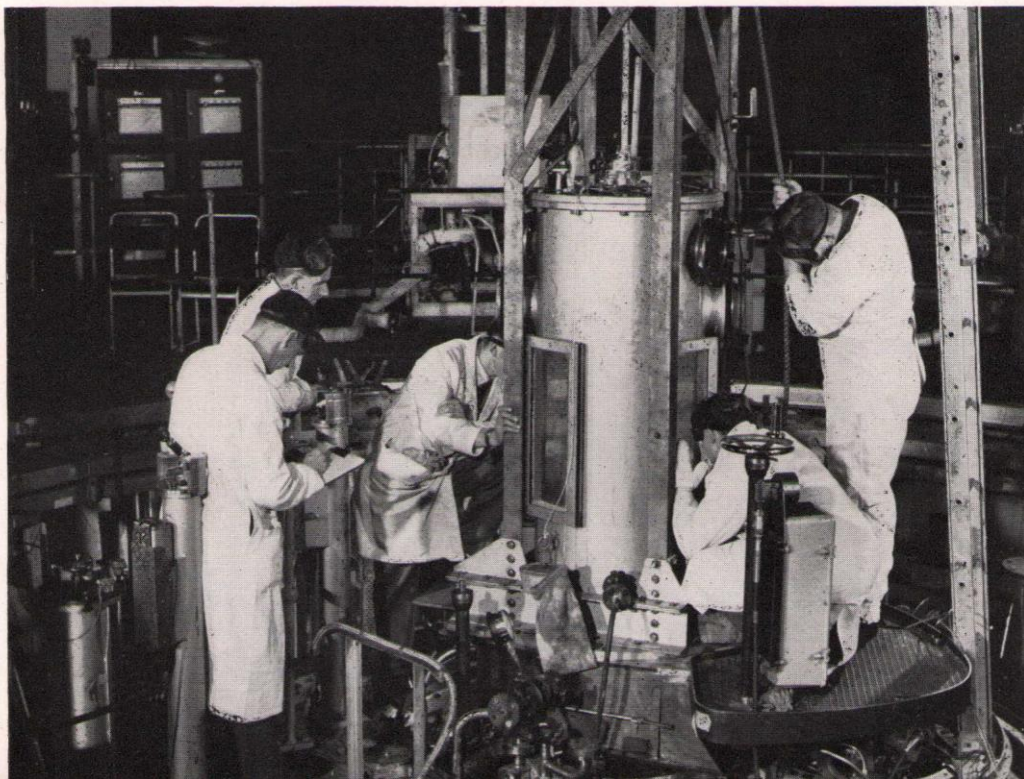
FUEL FOR REACTORS. New fuel element production lines at Springfields have been designed to meet the requirements of the nuclear power programme. At full capacity they will have an output of 300,000 fuel elements a year.

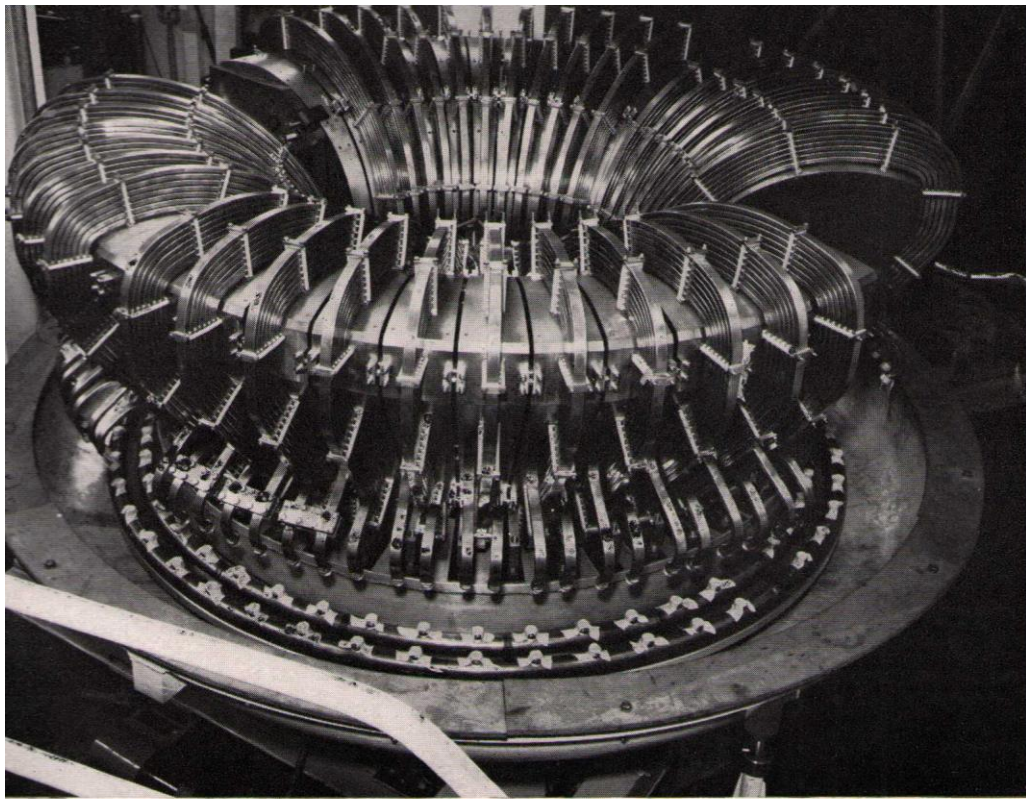




CALDER OPERATION SCHOOL. A total of 406 engineering students have attended the Calder Operation School since its inception in 1957 to obtain practical experience in operating a nuclear power station of the Calder Hall type. In the photograph are students from Austria, Greece, Italy, Japan and Spain.

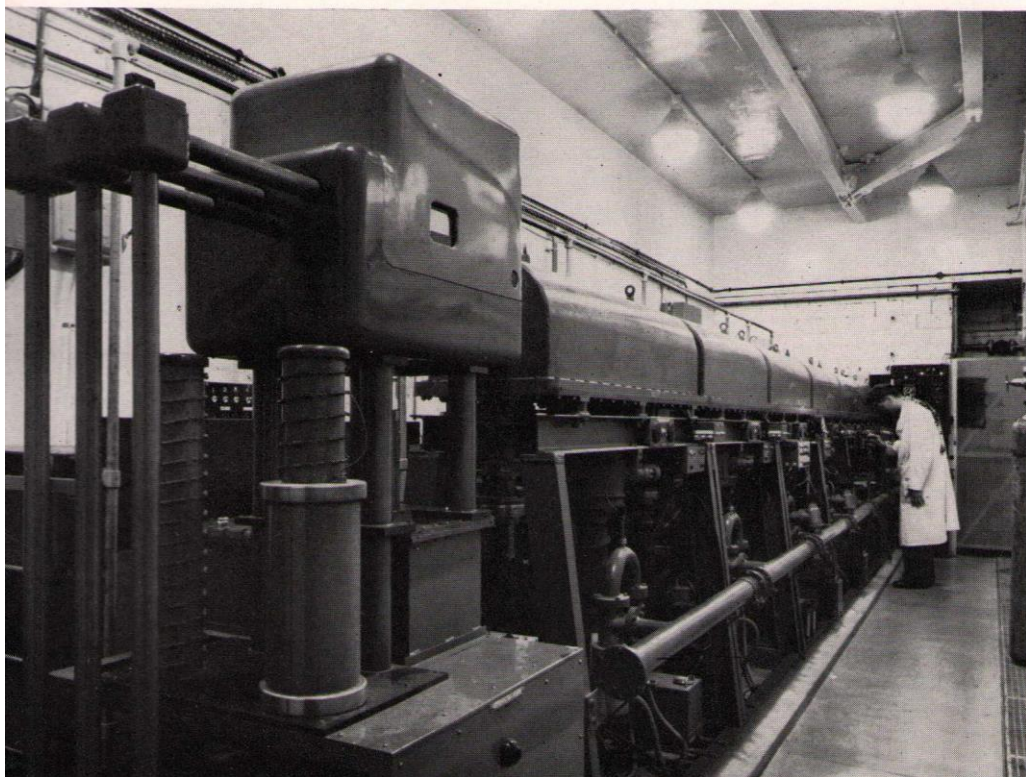
FAST BREEDER REACTOR. The experimental fast breeder reactor at Dounreay began operation in November, 1959. The photograph shows fuel elements being loaded into the core. This system offers the prospect of low-cost power, because of potentially low capital costs and low fuel cost. A prototype power producing reactor may be built for operation about 1967.





ALDERMASTON. The photograph, taken during construction, shows the magnetic circuit of a large spectrograph used for precision analysis of charged particles from nuclear reactions. It is used with Aldermaston's Van de Graaff generator. The magnet weighs 12 tons and its containing vessel is 10 feet in diameter.

HARWELL NEUTRON PROJECT. Research in nuclear physics is undertaken to extend knowledge of the structure of the nucleus and provide accurate measurements of the nuclear properties needed for reactor design. A new linear accelerator capable of accelerating electrons to 30 MeV came into operation at Harwell in November, 1959.



194. In addition to the intrinsic interest of the laboratory experiment, it is hoped that this phenomenon, which has already been used for experiments in the outer atmosphere, can be used to determine many of the plasma conditions inside devices such as ZETA.

Technological development

195. Considerable progress was made, in collaboration with industrial firms, in solving the formidable technological problems associated with the production and control of currents in the million-ampère range, and in the development of methods of torus construction to withstand the severe conditions expected in experiments such as I.C.S.E.

Overseas collaboration

196. International collaboration in the field of controlled thermonuclear reactions increased markedly as a result of the declassification of virtually all work in this field. Six scientists from the U.S.S.R. Academy of Sciences, Moscow, and the Leningrad Electro-Technical Institute visited Harwell in April, 1959, and gave a number of lectures at Harwell and in London on their work. A meeting of European scientists was held at Harwell in June and was attended by about 30 overseas delegates from nine European countries. Numerous visits of short duration were made by Authority staff to other countries, and two members of the staff have been attached to U.S.A.E.C. laboratories for a year. Close collaboration with the United States was maintained both by such visits and by means of small meetings between U.S. and United Kingdom scientists. World wide collaboration continued at a variety of international conferences.

Work at the Atomic Weapons Research Establishment

197. Research continued on various types of pinched discharge in hydrogen and deuterium gas at low pressure. Very low inductance condenser banks were used with stored energies up to a maximum of about 50 kilojoules.

198. A detailed study was made of a fast pinching discharge in a straight tube between metal electrodes. It was found that large currents always build up outside the central plasma column near the walls when the total current in the tube rises very rapidly. As a result, heating and containment of the central plasma are limited, and the energy input to the gas never exceeds that at the first pinch (maximum temperature achieved 3,000,000° Kelvin). Attempts to increase the temperature by increasing the voltage across the tube only resulted in earlier appearance of wall effects with no appreciable gain in heating. Up to the time of the first contraction, a significantly greater amount of energy goes into the gas than into the magnetic field when the current rises very rapidly; for slowly rising currents, more energy always goes into the magnetic field than into the gas, which is a less desirable state of affairs.

199. Many new and interesting results were obtained in the study of θ mode discharges in which the current flows in a circular path around the axis of the discharge tube. A magnetic field appears inside the tube as soon as the current begins to flow in the surrounding primary single turn

coil and some of this field may be trapped by the annular current sheath formed inside the discharge tube. The trapped magnetic field may persist for a time greater than a half cycle of the current, so that a configuration may arise in which the field within the plasma sheath has a direction opposite to that outside the plasma. This trapped reversed magnetic field has a very important influence on many properties of θ mode discharges, and much effort has gone into its study. Ultimately however, it is hoped to minimise and if possible eliminate the trapped field by careful control and preionization of the gas before the main compression field is applied.

200. High speed photography of the discharge looking along the axis revealed a well defined plasma sheath which implodes rapidly towards the tube axis and then oscillates or "bounces" between the trapped magnetic field and the field outside. The frequency of the sheath oscillations can be obtained either from analysis of photographs or from the response of a very small magnetic probe placed on the tube axis. Since the plasma does not reach the probe until the late stages of the discharge, its indications are quite reliable and reproducible. They confirm and extend the information obtained from photographs, and clearly demonstrate the existence of reversed fields in certain circumstances. Observations and measurement of the frequency of the sheath oscillations are valuable as it is then possible to deduce directly the mass of ionized gas in the sheath.

201. Time-resolved spectroscopic techniques in both the visible and ultra violet regions have been developed, and are being used in the study of θ mode discharges. Pure hydrogen or deuterium give too little radiation for study, and about 1 per cent. of oxygen is usually added. Oxygen VI lines are very strong where the ionized gas crosses the tube axis, and electron temperatures in the region of a million degrees Centigrade have been observed.

202. In the Fifth Annual Report, paragraph 118, reference was made to the fact that a small group at A.W.R.E. was considering methods of building up a plasma by injection and trapping of hot ions in a suitable magnetic field configuration. This line of research is being pursued actively elsewhere. The experiments planned at A.W.R.E. are on a small scale, and involve the injection of a beam of neutral atoms, equivalent energy 30 keV, into an arc running along the axis of coils which provide a magnetic mirror field. Some of the neutral atoms will be ionized in their passage through the arc and will therefore be trapped within the magnetic field region.

203. In order to assess the feasibility of various injection schemes for building up a plasma from high energy particles, it is necessary to have accurate quantitative information about the various interactions that occur between beams of fast particles and the common gases. Particularly important is the interaction between fast molecular and atomic hydrogen ions and hydrogen gas, and it was apparent at the 1958 United Nations Geneva Conference on the Peaceful Uses of Atomic Energy that there existed considerable discrepancies between the results of Russian and American work in this field. An extended series of experiments by a new method based on the detection of individual particles, and therefore not subject to the uncertainties associated with the detection of neutral

beams, has been completed at Aldermaston. The new results, as well as providing the more accurate quantitative data required for the C.T.R. programme, provide new insight into the mechanism of collision processes between fast ions and atoms.

Culham Laboratories

204. During the year the Authority reconsidered their previous decision to move controlled thermonuclear research from the Atomic Energy Research Establishment, Harwell, to the Atomic Energy Establishment, Winfrith, and concluded that, because the project will, for some years, be concerned with basic studies, they should seek a site near to the A.E.R.E. and the National Institute for Research in Nuclear Science (both at Harwell) and to Oxford University. A site of 175 acres on the former Royal Naval Air Station at Culham was chosen as the best site of adequate size and with good communications to meet this requirement, and the Authority accordingly sought planning permission to develop this site as a thermonuclear and plasma physics research centre.

205. This approval was granted in January, 1960, and work has started on the Culham site. The first building to be erected will be for I.C.S.E. and its associated facilities; these are scheduled for completion during 1961. Further buildings will follow to accommodate the remainder of the research and supporting services to be moved from A.E.R.E., Harwell, and a small team from A.W.R.E., Aldermaston, so that within four or five years the new laboratories at Culham should approach their planned size of 1,000 total staff.

206. The Culham Laboratories will form a large autonomous unit within the Research Group of the Authority, on similar lines to the A.E.E. at Winfrith. As the basic scientific research for which Culham is planned is not classified, it will be possible to make arrangements for free international collaboration, and for visiting scientists from other countries to share in the work.

CHAPTER VII

NUCLEAR WEAPONS

207. The voluntary suspension of nuclear weapon tests has necessitated some changes in the programme and organisation of the Atomic Weapons Research Establishment. However, work on the application of nuclear weapons to military needs continues in accordance with a programme approved by the Ministry of Defence. Considerable mutual benefit has accrued from active collaboration with the United States within the terms of the Defence Agreement of July, 1958 (Cmnd. 537).

208. Methods of detecting violations of a possible agreement on the suspension of nuclear tests have been a subject of close study at A.W.R.E. The long-range signals from an atomic explosion vary in kind and intensity according to whether it occurs in space, in the ionosphere, in the air, underground or underwater, but in general the signals closely resemble similar signals produced by natural causes. Some of the methods which can be used for detection were developed and used originally in geophysical,

astrophysical or communications research. These, and still more recently developed methods, are now being used to contribute to the considerable fund of information on geophysical and astrophysical phenomena which is required to enable the weapon signals to be distinguished from the natural signals and accurately identified.

209. Examples of the kind of signals which are being studied are changes in atmospheric pressure produced by an explosion taking place at heights below 100,000 feet and auroral effects in the upper atmosphere from an explosion at heights of many hundreds of miles. If exploded at heights of 10,000 miles or more, the weapon would be expected to display some of the characteristics of a small and very short-lived star, and some of the methods used in studying solar behaviour could be used for its detection. A number of problems raised in the Geneva discussions are being studied.

210. Explosions occurring in the atmosphere may be detected in several ways, in particular by radiochemical analysis of the airborne dust which is widely distributed. This test is specific and is not subject to interference from natural causes. At the other extreme, underground explosions must be detected by seismic signals, and there are many thousands of earthquakes throughout the world each year which produce comparable signals. Thus the problem of detection of underground explosions is a very difficult one and is attracting considerable attention in all quarters. To date the only method of discrimination is by the direction of the first motion of the body waves, the P waves, recorded at various sites, and this discrimination will only be achieved in suitable practical conditions by the most advanced instrumentation.

211. To aid our understanding of the mechanism of seismic coupling, the way in which the explosive energy is converted into a seismic wave, and the way in which this effect varies with the environment, natural or man-made, an experimental programme has been started. Firings of chemical explosives underground have taken place in Derbyshire, at Glenridding in Westmorland and at Callington in Cornwall. Several university departments and organisations concerned with geophysical research are collaborating in the field work. In addition, theoretical studies and microscale experiments are being made. A typical laboratory experiment is the simulation of a nuclear explosion at a depth of say a thousand feet below ground by an ounce of chemical explosive fired in a concrete cube with dimensions of only six feet.

CHAPTER VIII

RAW MATERIALS

Uranium

212. The Authority's commitments under their long-term uranium contracts are now greater than their immediate requirements, and they will for some years hold larger uranium stocks than they need. This is mainly due to the slowing down of the nuclear power programme, together with reductions in initial uranium loadings which have followed from design improvements in the magnox reactor.

213. The change from scarcity to surplus has been world-wide. Paragraph 39 of the Authority's Fifth Annual Report stated that future orders for uranium were likely to be limited and the forward price would fall "even lower than \$8 per lb.". This has already proved true. Uranium reserves continue to increase and the introduction of nuclear power has been slower than was once expected. It is now improbable that uranium producers outside the United States will make any substantial new sales of uranium for the next decade. Such prices as are quoted will not for many years be market prices in the true sense, since they will refer to the terms on which small quantities only may have been sold. The demand for uranium is unlikely to build up again until sometime in the 1970's.

214. A significant event during the year was the announcement by the U.S. Atomic Energy Commission in November, 1959, that its options on Canadian uranium would not be taken up after the expiry of the current contracts in 1962-63. This announcement seemed to indicate that it was unlikely that the U.S.A.E.C. would place new orders outside the U.S.A. for many years, and could have meant that the Canadian uranium mining industry, built up with such great skill and effort since 1953, would be left without a market in 1963. Proposals were therefore worked out by Eldorado Mining & Refining Limited, in conjunction with the U.S.A.E.C. and the Authority, to spread the current contracts over a longer period. As a result of these "stretch-out" proposals negotiations have been in train whereby output will be concentrated on the low cost producers and the other plants will close down. Delivery rates of the plants which remain in production are not to be increased, and thus deliveries will be spread over a longer period, in some cases up to December, 1966. A feature of the proposals was the undertaking by the U.S.A.E.C. and the Authority to make advance payments to enable the surviving mines to meet the current loan obligations of those mines whose contracts they have taken over.

Combined Development Agency Contracts

215. Supplies of uranium concentrate to the Agency continued during the year from South Africa, the Belgian Congo, Australia and Portugal.

United Kingdom Contracts

216. Supplies to the Authority continued from Canada, from Mary Kathleen in Queensland and from the Harmony Gold Mining Company in South Africa; in accordance with agreements reached earlier, deliveries commenced from two companies operating in the South Alligator River area of the Northern Territories of Australia. By agreement between the Rhokana Corporation and the Authority, Rhokana's small uranium plant at Mindola in Northern Rhodesia was closed.

Geological Investigations

217. The Authority's prospecting offices in British Guiana, Swaziland and Tanganyika were closed during the year. The uranium survey started in the U.K. by the Atomic Energy Division of the Geological Survey of Great Britain has not disclosed any significant uranium deposits: the Authority will not sponsor any further prospecting for uranium in the U.K. A sampling investigation in the Buller Gorge area of South Island, New Zealand, to assess occurrences of uranium, has been almost completed. An assessment of the potential beryl resources of Southern Rhodesia and Uganda is being continued.

Beryllium and Helium

218. Purchases of beryl ore were suspended during the year. Supplies of beryllium metal in the form of ingot, powder and flake have been purchased, mainly from producers in the U.S. and in France, for development and research work for the advanced gas-cooled reactor. Potential sources of helium for the high temperature gas-cooled reactor are kept continually under review.

Technical Services

219. Technical services continued to be provided by the Radiochemical Laboratory of the National Chemical Laboratory at Teddington, the Atomic Energy Division of the Geological Survey of Great Britain and the Mining Division of the Colonial Development Corporation. The Warren Spring Laboratory of the Department of Scientific and Industrial Research has now taken over the mineral dressing research work formerly undertaken by the Mineral Dressing Group of the Atomic Energy Research Establishment, Harwell. The Geological Instrument Section of the Electronics Division, A.E.R.E., is being closed down as it would no longer be justifiable for the Authority to continue research on instruments for the prospecting and mining of uranium. The section has, however, made a major contribution during the past year to the study of beryl resources by the development of instruments using the gamma neutron technique, both for assay purposes and for the detection of beryl in the field.

CHAPTER IX

HEALTH AND SAFETY

Organisation

220. The review of the Authority's health and safety organisation described in Chapter X of the Fifth Annual Report was undertaken against the background of an acute shortage of specialised staff. The vigorous recruitment campaign during 1958 and 1959 made good some of the more serious gaps and, as the new staff gained experience, it became possible to separate responsibility for advice on the control of day to day operations in the Authority's establishments from the formulation of policy in the health and safety field.

221. From 1st July, 1959, a new Authority Health and Safety Branch, independent of the Groups, was established with the following responsibilities:—

- (a) to advise the Authority on the formulation of their health and safety policy, and to disseminate this policy for application by Heads of Groups and Establishments ;
- (b) to apply this policy to the assessment and inspection of reactors and plants (including laboratories) ; and
- (c) to provide the focal point from which the Authority's external relations in the health and safety field will be conducted.

222. The creation of this new branch does not alter the principle that all Authority staff are responsible through the normal management chain of command for the safety of operations under their control. The health and safety aspects of the work at each establishment remain the responsibility of local specialised organisations whose function is to advise the head of the establishment and to co-operate with the Authority Health and Safety Branch in the development of Authority policy and practices. These local organisations provide a suitable range of health and safety services and carry out appropriate investigations and research in the health and safety field.

223. The new Authority branch is divided into three divisions; the Safeguards Division, which is located at Risley and has responsibility for assessing the safety of reactors and plants, for the associated technical studies and for providing an inspection service; the Radiological Protection Division, which is located at Harwell and is concerned with radiation and other hazards affecting Authority employees and the general public; and the Administrative Division, which provides general services to the two technical Divisions and, through staff in London, deals with the non-technical work of the branch, including liaison with Government departments.

224. In view of the reorganisation, it is not possible to make direct comparisons with the staffing position in previous years. In general, however, the position has improved, though important gaps remain both in the groups and in the Authority Health and Safety Branch. Most new recruits require special training; to meet a need for specialised training an advanced Radiation Protection Course was held at Harwell between October, 1959, and January, 1960. A second course is being held from April to June, 1960. The lecturers are mainly Authority staff but valuable contributions are also made by specialists from other organisations.

Health and Safety Training

225. The Veale Committee submitted its final report in February, 1960. The report will be published in April*, and the recommendations will be studied by the Authority and by the Government Departments concerned.

226. As a result of the first interim report of the Veale Committee (referred to in paragraph 220 of the Fifth Annual Report) special post-graduate university courses in radiobiology and radiological physics have been introduced. An M.Sc. degree course of twelve months' duration was started in September, 1959, by Birmingham University and suitably qualified students may proceed to a Ph.D. degree after a minimum of two further years' study and research. In addition, there has been an increase in the number of students on the courses in biophysics and radiophysiology in the Institute of Cancer Research and on the course in radiation physics run jointly by The Middlesex Hospital Medical School and St. Bartholomew's Hospital Medical College. A one year course for a diploma in biophysics is planned to start in Edinburgh University in October, 1960, and successful students will be able to register for a Ph.D. degree.

227. The Veale Committee also submitted a second interim report recommending a pilot summer school to give background training. In co-operation with the Delegacy for Extra-Mural Studies of the University of Oxford,

* H.M.S.O. Code Number 88-2556—5s. 6d.

a course was organised at New College in August, 1959. It was attended by senior civil servants, Medical Officers of Health, officers of the three Services, managerial and executive staff from industry (both nationalised and private), water engineers, river board officers and a trade union official. The experience gained was invaluable to the Veale Committee in framing the recommendations in their final report.

228. The Authority wish to record their gratitude to Sir Douglas Veale and the members of his committee for the effort they devoted to their task over a period of twenty months.

Protection of the Staff

229. The maximum permissible levels adopted by the Authority are based on the advice of the Medical Research Council which, during the year, considered revised recommendations made by the International Commission on Radiological Protection. The principal changes were the replacement of the maximum permissible weekly dose by the introduction of a maximum permissible thirteen-week dose, and the introduction of a "dose for age" formula to control cumulative exposures. The Authority, on the advice of the Medical Research Council, had already adopted the thirteen-week period for control purpose.

230. During 1959 there were fourteen occasions when the maximum permissible exposure (3 rads* in thirteen weeks) was exceeded. This compared with twenty-five occasions in 1958 and fifty-four in 1957. In every case steps were taken to ensure that long-term dose limits were not exceeded. In some establishments, the individual doses are so low as to make the evaluation of aggregate dose difficult. In order to extend the measurement of doses to lower values, investigations are proceeding into the issue of films, for measuring individual radiation doses, for a long period.

231. It is of interest to record that the Trade Union Side of the National Joint Industrial Council have congratulated the Authority on their "fine record", in the health and safety field, and have said that, in their view, the Authority's safety policies are producing highly satisfactory results.

General Industrial Hygiene

232. Every effort has been made to maintain the high standards which the Authority have set themselves in this field, despite temporary accommodation difficulties in some places following rapid increases in staff numbers. Close medical supervision has been maintained of employees working with specially toxic materials. Special attention has also been given to the noise problem of working conditions at Capenhurst with the assistance of a Royal Air Force Acoustic Team.

Industrial and General Safety

233. The Authority have continued to keep a close watch on all the problems of conventional industrial safety, and all available publicity and training media are used. The accident statistics recorded in previous annual reports have shown that the accident frequency rates are low.

* A rad is a unit of absorbed dose of radiation.

234. A revised form of recording lost-time accidents was introduced from 1st January, 1960, and it is hoped in future reports to present more detailed information.

Protection of the Public

235. The main potential public health problems arising from the work of the Authority are associated with waste disposal and with the transport of radioactive materials. The Authority have continued to work in the closest consultation with the Government departments empowered under the Atomic Energy Authority Act, 1954, to authorise the discharge of radioactive waste, and have undertaken to act for two years as the agents of the Ministry of Housing and Local Government in the operation of the national disposal service proposed in the Radioactive Substances Bill. In relation to transport of radioactive and other toxic materials, the policy of the Authority is to ensure that, as far as possible, the containers used are acceptable for normal public transport. During the year there has been continuing consultation with Government departments and with the various transport authorities. The Authority have also been associated with two working panels of the International Atomic Energy Agency which have been convened to prepare regulations for the safe transport of radioactive substances by air, land and sea.

Radiological Protection Research and Investigations

236. A wide range of health and safety problems has continued to be studied during the year. Some notable examples are:

- (a) developments in the measuring techniques applied to the monitoring of fall-out from nuclear weapons tests.
- (b) The marine programme for extending knowledge of the uptake of radioisotopes by seaweed, sea fish and other species of marine life has been continued. A start has also been made on controlled studies of the uptake from fresh water of strontium-90 by fish and of this and other radioisotopes by common aquatic plants.
- (c) The Authority's work on the diffusion and dispersion of gases and particulates has continued. The Weapons Group is undertaking experiments to determine the concentration and particle size down wind from fires and small explosions involving radioactive materials.
- (d) Experiments have been continued with the technique of whole-body monitoring described in paragraph 233 of the Fifth Annual Report.
- (e) A comparative assessment on an operational scale is in hand with a view to evaluating a type of monitoring film which may be satisfactory both for routine purposes and for measuring a high single dose exposure occurring as the result of an accident. The high level personal dosimeter has also been improved.
- (f) Reference is made in paragraph 150 in chapter V to the Research Group work on aerosols.

Safeguards Work

237. The Authority have worked closely with the Ministry of Power to assist in the establishment of the Inspectorate of Nuclear Installations

required under the Nuclear Installations (Licensing and Insurance) Act, 1959. The Authority will continue to advise on the technical aspects of the licensing of nuclear reactors and plants both during the interim period while the inspectorate is being established and subsequently, though on a diminishing scale. Arrangements are being made by the Authority to train some of the Ministry's inspectors.

238. The Authority have advised the Admiralty on the safety aspects of the prototype submarine reactor under construction at the Admiralty Reactor Test Establishment, Dounreay, and of the submarine Dreadnought. Safety assessments have also been made of a number of designs for nuclear ship propulsion units and the Authority have continued to work closely with the Ministry of Transport on the principles of safe design, construction and operation of nuclear merchant ships.

239. Technical studies have been made of pressure circuit failure, the conditions for fuel and graphite failure, the strength of reactor components under accident forces and fission product release from uranium fuel. Investigations have also been made into neutron flux instability, shutdown heating, high temperature chemical reactions in advanced gas-cooled reactor systems and gas cleaning.

International Co-operation

240. The scale of activity in the international field has increased steadily during the year. The Authority have been able to contribute to a number of studies organised by the international bodies concerned, notably the International Atomic Energy Agency.

CHAPTER X

INFORMATION SERVICES

241. The continuing growth of public interest in atomic energy has shown itself during the year by a marked increase in the number of requests from outside organisations for advice and help in disseminating information on this subject. Requests for material on British progress in atomic energy came to the Authority from all over the world.

Press

242. During the year the Authority instituted a "Scientific and Technical News Service," which describes new instruments, processes and equipment developed by the Authority. The new service aroused considerable interest abroad, particularly in the United States and Canada, and gave rise to many enquiries for patent licences both at home and from overseas.

243. A two-day course for journalists at the Harwell Reactor School was attended by leading correspondents of the national and technical press, and by a party of Euratom journalists who were visiting atomic installations in this country. The Euratom visitors were among 128 journalists from fifteen countries who visited the Authority's establishment at Winfrith

in July, when a press conference was held to outline the functions of the establishment and of the Organisation for European Economic Co-operation Dragon project.

244. In June, 1959, journalists visited the Atomic Weapons Research Establishment at Aldermaston for the first time, to see a newly installed tandem accelerator. Other press visits were organised for the opening of Chapelcross; to the neutron project at Harwell and to the computer section of the Development and Engineering Group at Risley.

Exhibitions

245. A travelling exhibition, "Atoms at Work", was shown in Sheffield (November), Bradford (January) and Bristol (March). A series of lectures and film shows was arranged at each location. The total attendance was between 18,000 and 20,000.

246. The Industrial Group staged an exhibition at Annan in May, 1959, (in connection with the official opening of the Chapelcross nuclear power station) and at Stromness in July. In May, also, the Atomic Energy Research Establishment, Harwell, exhibited at the International Convention on Transistors and Associated Semi-Conductor Devices in London. The Radiochemical Centre, Amersham, staged an exhibit at the 7th European Congress of Haematology in London in September. The Development and Engineering Group had a stand at the Industrial Efficiency and Safety Exhibition in Manchester in November and provided an exhibition in the City Museum at Derby in January, 1960. As in previous years, the Authority stand at the Physical Society Exhibition (January, 1960), attracted considerable attention. Exhibits were presented by A.E.R.E., Harwell; A.W.R.E., Aldermaston; and Patents Exploitation Branch, London. An isotopes exhibit at the Central Library in Manchester (February) coincided with visits by a team of isotope consultants from the Wantage Research Laboratory to industrial firms in the area. A.W.R.E., Aldermaston, showed recent work on beryllium at the Engineering Materials and Design Exhibition in February.

247. Over a million people visited the Authority stand at the Milan Samples Fair in April, 1959. The display included a multi-language cinema with simultaneous soundtracks in Italian, French, German and English and a working model of Calder Hall designed to illustrate the manner in which it is controlled during operation. In the same month the Authority co-operated with the Board of Trade and the Nuclear Energy Trade Associations' Conference to provide a United Kingdom atomic energy exhibit at the Hanover Trade Fair. Part of the Milan exhibit was re-shown at the 6th International Exhibition of Electronics and Nuclear Energy in Rome in June/July. The Radiochemical Centre, Amersham, exhibited at the 9th International Congress of Radiology at Munich in July.

248. In addition to exhibiting on their own account, the Authority loaned models and other display materials to learned societies, universities, schools, museums and other organisations at home and overseas.

Films

249. The film "Metals of the Nuclear Age" gained an honourable mention at the Harrogate Festival of Films in the Service of Industry. The Authority won three awards at the International Festival of Technical, Industrial and Agricultural Films in Rouen for "More Power from the Atom", "Radioisotopes in Industry" and "Metals of the Nuclear Age".

250. Seven films were completed during the year. "Full Power" and "Refuelling" were made primarily for the instruction of operators of Calder Hall type reactors. "Nuclear Power in Britain" (first shown at a conference of the Franklin Institute in Philadelphia) gives a résumé of progress with the nuclear power programme. "Winfrith Pipeline" shows the construction of the effluent disposal system of the Atomic Energy Establishment. "The Dounreay Fast Reactor" and "The Dounreay Project" record construction work at Dounreay.

251. During the year the Authority produced the first two issues of a film-magazine for the information of their own staff on new developments and projects.

252. About 135 prints of films are issued monthly by the Authority film library for showing in the U.K. (in addition to issues by the Central Office of Information). Authority films, many of them in foreign language versions, were shown in over 30 foreign countries during the year, in some cases by the Authority, but chiefly by the Central Office of Information and the British Council.

Publications

253. New publications during the year included "Atom 1959", an illustrated summary of the Fifth Annual Report; illustrated booklets on the Development and Engineering Group and on the Radiochemical Centre, Amersham; a leaflet on the nuclear power programme; four leaflets on the applications of radioisotopes; and two Technical Information Sheets ("Ionising Radiation; Calculation of Gamma Dose" and "Chain Reaction"). A new edition of the "Glossary of Atomic Terms" was also published. The circulation of "Atom", the Authority's monthly bulletin, rose from 10,500 to 13,300. Three thousand of these went overseas monthly.

Photographs

254. Over a thousand new negatives were added to the Photographic Library during the year. Enquiries for photographs averaged 100 a week and over 300,000 prints were supplied to newspapers, magazines, universities, schools, authors and others all over the world.

Libraries

255. The Libraries of the Atomic Energy Research Establishment at Harwell and of the Development and Engineering Group headquarters at Risley have continued to provide a scientific and technical information service for industry, including the supply of unpublished reports and information of commercial value to organisations having appropriate agreements with the Authority.

256. A subscription service for unclassified and declassified reports has been instituted ; subscribers obtain either each report as issued or those in particular subject categories.

257. By arrangement with Micro Methods Limited of East Ardsley, Wakefield, Yorkshire, all the Authority's unclassified and declassified reports issued between 1947 and December 1956 are available in micro-form from this company. Many of these reports were hitherto available only on loan from the Authority's libraries. On a continuing basis any similar report which for one reason or another is not put on sale from Her Majesty's Stationery Office, who act as the Authority's selling agent, can be purchased from Micro Methods Limited. All available reports are listed in the Authority's monthly "List of publications available to the public", the distribution of which now exceeds 2,000 copies.

258. Sets of microcards have been sent to those of the Authority's depository libraries in the U.K. which have expressed a wish to have them. Stafford County library has been added to the Authority's depository libraries in the U.K. A complete list of such libraries will be found in the "List of publications available to the public".

259. Weekly information bulletins of atomic energy literature references, taken from British and foreign sources, have also been distributed without charge from Harwell and Risley to many addresses in the U.K. and overseas.

The Authority's Schools

Harwell Reactor School

260. Three standard courses were held during the year and co-operation with the Colleges of Advanced Technology at Birmingham, Bradford and Salford in connection with these standard courses was continued.

261. The second and third Control and Instrumentation of Reactors Course, each of two weeks' duration, were held. A second course was organised on behalf of the O.E.E.C. for university professors and lecturers from the O.E.E.C. countries.

262. In order to benefit from the accumulated experience at the Atomic Energy Establishment, the final three weeks of the standard course will in future be held at Warmwell, near Winfrith. The Control and Instrumentation of Reactors Course, and the second week of the senior technical executives course, will in future be held in Bournemouth.

Calder Operation School

263. Seven standard courses were held during the year of which three were for overseas students. A special one-week course was held for senior technical executives. One hundred and sixty four British and 53 overseas students attended courses during the year. Four hundred and six students have attended the school since its inception in 1957.

264. During the year there was a heavy demand for training for the operating staff of the consortia, the Central Electricity Generating Board and the South of Scotland Electricity Board. The Production Group reactors at Calder and at Chapelcross, and the associated Calder Operation School, have become focal points for the training of nuclear technologists on an international scale.

Training programme for C.E.G.B. Operating Staff

265. The training programme for C.E.G.B. nuclear power station operating staff continued during the year. The programme comprised a course at the Calder Reactor School and practical experience on the operation of the Calder reactors. Engineers from the C.E.G.B. staff are being incorporated in the operating team which will commission and operate the prototype advanced gas-cooled reactor now under construction at Windscale. It is envisaged that these engineers will remain attached to the Authority for three or four years.

Isotope School

266. The Isotope School, now at Wantage, held a total of 14 courses during the year. These included several of the general isotope courses first given nine years ago, as well as the specialised courses on radiological protection, isotopes in medicine and auto-radiography, which have been available for two or three years. Innovations during the year included advanced courses for specialists on isotopes in radiochemistry, in physics and measurement, in analytical chemistry and in radiobiochemistry, all of which represent further extensions of the policy of providing courses to suit particular needs.

CHAPTER XI

COMMERCIAL OPERATIONS

Revenue

267. During the year the Authority's revenue from commercial operations amounted to almost £20 million made up of sales, mainly of fuel elements for the civil power programme, radioisotopes, graphite and electricity; of payments for services such as consultancy and training; and of fees under licence agreements.

Sale of Goods and Electricity

Fuel Elements

(i) Power Reactors

268. Sales of nuclear fuel, which will exceed in value all other civil sales made by the Authority, are handled by the Commercial Directorate of the Production Group at Risley.

269. The Central Electricity Generating Board and the South of Scotland Electricity Board nuclear power stations have two nuclear reactors per site and each reactor requires between 250 and 400 tonnes of fuel for the initial charge. The value of these charges is of the order of £5 million and £8 million respectively. After commissioning, the annual rate of fuel replacement is expected to be between one fifth and one quarter of the initial charge.

270. Several thousand tonnes of natural uranium fuel will be supplied by the Authority during the next few years and much of the production planning and supply organisational work involved was undertaken during

the year. A fuel element is a precision article. Although mass production methods of manufacture are necessary, each element must be subjected to individual treatment and rigorous inspection. There may be 100 or more fuel elements per tonne of fuel so that a typical reactor may contain over 30,000 individual uranium cartridges.

271. Power reactors are being constructed in Italy and in Japan by the Nuclear Power Group and by the General Electric Company Limited respectively. Construction contracts have been signed between these British companies and the Societa Italiana Meridionale per l'Energie Atomica, in Italy, and the Japan Atomic Power Company. The Authority have negotiated heads of contract for the supply of fuel with both these organisations. The detailed fuel and reprocessing contracts, which still have to be negotiated, will necessarily be lengthy documents involving many matters not previously the subject of commercial agreement. The Italian station at Latina and the Japanese station at Tokai Mura are single reactor sites and will require about 290 and 200 tonnes of nuclear fuel respectively for the initial charges. The annual consumption of nuclear fuel of each station after commissioning will be about 65 and 50 tonnes respectively.

(ii) *Research Reactors*

272. Enriched uranium fuel is manufactured by the Authority for their own materials testing and research reactors and also for other similar reactors both at home and overseas. During the year a fuel supply and reprocessing contract was signed with the Danish Atomic Energy Commission and their D.R.3 materials testing reactor at Risø is now operating on fuel supplied by the Authority. The Authority also supply enriched fuel elements for the Hifar materials testing reactor operated by the Australian Atomic Energy Commission. Negotiations are proceeding for the supply and reprocessing by the Authority of research reactor fuel for two reactors under construction in Germany. Enriched fuel has been supplied by the Authority for research reactors manufactured in the United Kingdom.

273. Several U.K. universities have installed sub-critical assemblies for teaching purposes. Each assembly utilises about 5 tonnes of natural uranium supplied and fabricated by the Authority. Educational bodies are now becoming interested in reactors using enriched fuel and it is expected that the Authority will be called upon to supply two or three fuel charges totalling about 10 kilos of uranium-235 during the next few years.

Marketing of Radioisotopes

274. The Authority sold through the Radiochemical Centre radioactive isotopes for civil purposes to a value of £1.1 million in 1959-60, an increase of 25 per cent. over the previous year. Over half the sales (60 per cent.) continued to be for export. Medical users took half of the total of 35,000 deliveries during the year. Fifteen per cent. of deliveries (about one-quarter of the total sales value) went to industry and the remainder went to various research users.

275. The financial and commercial policies of the Radiochemical Centre were reviewed following the reorganisation carried out last year (see paragraph 199 of the Fifth Annual Report) and the costs chargeable for isotope

production in the Authority's reactors and as a contribution towards fundamental research were brought up to date. Despite resulting increases in charges for irradiations in the Harwell reactors, the trading account for the centre showed a small profit for the year. Technical improvements and increased output offset the greater costs of facilities, labour and radiological protection.

276. The price of carbon-14 was reduced during the year by about one half, thus encouraging a more liberal use of an isotope of outstanding value in biochemical research.

277. Two new laboratories were brought into commission at Amersham at the end of the year. One is for the synthesis of organic compounds labelled with carbon-14 or with tritium, the demand for which compounds has increased ten-fold in the past ten years. The other laboratory is for the manipulation of radium and related elements.

278. The Authority have given progressively increasing attention to promoting the use of radioisotopes in industrial and other applications. They have collaborated with the Department of Scientific and Industrial Research and with industrial users, and have made use of exhibitions, lectures and the press. Products have been advertised at exhibitions at scientific gatherings, notably the Ninth International Congress of Radiology at Munich and the Seventh European Congress of Haematology in London.

279. Two new catalogues ("Radioactive Chemicals" and "Radioactive Sources") were issued during the year. These include nearly 1,000 items which are in regular production. They cover the whole range of radioactive products offered for sale through the Radiochemical Centre; primary isotopes, labelled compounds and radiation sources. A new illustrated booklet is available describing the work of the Radiochemical Centre.*

Graphite

280. As stated in the Fifth Annual Report, paragraph 277, the Authority are responsible for the provision, and for the inspection and testing, of the nuclear quality graphite required as moderator and for other purposes in connection with all aspects of the U.K. nuclear power programme. A single reactor core may contain as much as 4,000 tons of graphite. Deliveries of graphite for Bradwell and Berkeley nuclear power stations are nearly complete and deliveries for Hunterston and Hinkley Point are more than half completed. Quantities of graphite for small reactors and for research purposes have also been supplied.

Electricity

281. The electrical energy produced as a by-product by the Authority's Calder Hall and Chapelcross plants is sold to C.E.G.B. and S.S.E.B. Financial terms negotiated with the electricity boards depend upon the availability of supply and the cost of alternative electricity generation by conventional plants.

Miscellaneous Sales

282. Miscellaneous sales were made of uranium, depleted uranium (uranium in which the fissile isotope 235 has been reduced to below the

* "The Radiochemical Centre", H.M.S.O. 5s.

natural level of 0.7 per cent.), nuclear chemicals, and special metals of which the Authority have sponsored development. Uranium is used as a pigment for ceramics and the depleted material is supplied mainly for this purpose. As a general rule the Authority do not intend to engage in the commercial supply of non-fissile materials, but pre-commercial production of rare nuclear materials is often undertaken by the Authority for their own purposes and small surplus quantities can then be offered to industry.

New types of nuclear fuel

283. New designs of nuclear fuel elements are being devised by the Authority and by industry. The feasibility and probable cost of manufacture need to be known before development of a particular reactor system can be pursued. Enquiries of this type are increasing and the Authority are examining a variety of fuel designs and are giving guidance on the economics of design from the manufacturing standpoint.

Collaboration with the Consortia

284. Collaborative research and development in the field of gas-cooled, graphite-moderated reactor systems continued during the year between the Authority and the four consortia of British firms that are closely associated with this system. An extension of this collaboration in connection with other systems, in particular with the steam generating, heavy water-moderated reactor, is under consideration.

285. A new collaborative research agreement, to replace the original collaboration agreement between the Authority and the consortia, which had lapsed, was signed during the year. Under the new agreement a joint programme of research and development was drawn up by an executive committee composed of nominees from the Authority and from the consortia. The cost of implementing the programme is borne in equal shares by the four consortia. The Authority contribute to the common pool of information, which derives from the programme, results from their own substantial research programmes in a similar field. The Authority and the consortia share the benefits from this pooling of information.

286. The agreement known as the British Industries Collaborative Exponential Programme (BICEP) was signed during the year. (See Chapter IV, paragraph 64.)

Access Agreements

287. The Authority have continued their policy of entering into agreements with firms requiring access to Authority-owned information and experience in specialised fields. A number of agreements relating to the nuclear propulsion of ships have been negotiated and were awaiting signature at 31st March, 1960. Agreements in this field are also being negotiated with Admiralty contractors in connection with the submarine nuclear propulsion programme.

Attachment Agreements

288. A large number of staff from the C.E.G.B. and from industry are attached to the Authority's design offices and laboratories. Whilst receiving

training in numerous fields of nuclear power they also make a welcome and valuable contribution to the Authority's work.

Consultancy

289. The Authority act as consultants to the C.E.G.B. and to the S.S.E.B. for the nuclear parts of the power stations at present under construction, by British industry at Berkeley, Bradwell, Hinkley Point, Hunterston and Trawsfynydd. Consultancy agreements also have been concluded with Agip Nucleare in connection with the nuclear power station now under construction by the Nuclear Power Group at Latina, Italy, and with the J.A.P.C. in connection with the nuclear power station which is to be constructed at Tokai Mura, Japan, by G.E.C. Limited. The Authority also have acted as consultants to the Italian organisation Società Ricerche Impianti Nucleari for the design of laboratory facilities for the handling of radioactive materials.

Patents and Licensing

290. The Authority continue to file patent applications to protect their inventions and have now granted a large number of licences in a wide variety of fields; they have also consented to some sub-licensing. The principal licences are those granted to the consortia (see Fifth Annual Report, paragraph 273) covering patents necessary for the design and construction both in the U.K. and overseas of nuclear power stations of the Calder Hall type. These licences will also be valid for the advanced gas-cooled reactor system.

291. Licence agreements with two chemical plant manufacturing and design groups are in an advanced state of negotiation. These agreements will grant licences, under Authority-owned patents, for the design and construction, either in the U.K. or overseas, of chemical processing plants for the production of uranium billets from ore, and for the treatment by chemical separation of irradiated nuclear fuels. Technical staff from the two companies involved have received a thorough and comprehensive training in the Authority's establishments. Gas bearing techniques, in which field the Authority hold a leading position, also have been the subject of licence agreements.

292. Negotiations are proceeding with various foreign organisations regarding the possible grant of licences by the Authority for the manufacture overseas of natural uranium fuel elements by the Springfields process.

293. Special effort has continued to be devoted to the exploitation by licence of individual patents. The application of Authority-owned patents to general industrial uses is increasing.

Select Committee on Estimates

294. The Select Committee on Estimates (see chapter II) examined certain aspects of the Authority's commercial policy. The committee noted that in the present state of development of nuclear power there is no actual experience of the maximum burn-up that may be achieved by the civil fuel elements fabricated by the Authority for the C.E.G.B. The committee agreed that, in the circumstances, risk-sharing between the Authority and the C.E.G.B. of any loss that may be incurred if the expected burn-up of about 3,000 MWD/Te is not achieved, was the correct approach

to the matter. The committee had no criticism to make about the Authority's method of recovering their costs of developing reactor systems for use in the U.K. nuclear power programme.

CHAPTER XII

INTERNATIONAL RELATIONS

295. International activity in the field of atomic energy continues to grow and the Authority have participated fully in this increased activity. In addition to fulfilling their obligations under bilateral and multilateral agreements, Members of the Authority and many of the staff have acted as technical advisers in connection with international discussions on such problems as the suspension of nuclear test explosions, third party liability in relation to land based reactors and nuclear ships, and safeguards against diversion to military purposes of nuclear materials and equipment.

296. The several specialised international agencies dealing with the problems arising from the peaceful applications of nuclear energy have now, for the greater part, defined their respective functions; duplication of effort is, as a welcome result, gradually being reduced.

International Atomic Energy Agency

297. The Authority have continued their support of the work of the International Atomic Energy Agency. They have released many members of their staff to take part in conferences, symposia and working parties, and to serve on missions sent to advise member countries less advanced in nuclear techniques. Authority staff contributed substantially to the Agency's Conference on Waste Disposal held at Monaco in November, 1959. Several senior scientists have been seconded to work for varying terms as members of the Agency's staff.

298. During the year an agreement was concluded between H.M. Government and the Agency relating to the provision of 20 kgs. of uranium-235 from the United Kingdom for Agency purposes.

299. The Authority are considering on behalf of the Agency a project for research at Harwell into low-cost methods of producing calcium-47, an isotope which could be of great use in medical and other research if its present high cost could be reduced.

300. The Authority have loaned 6½ tons of heavy water to the Agency free of charge for a joint dosimetry experiment to be carried out at the Vinca reactor in Yugoslavia. The purpose of the experiment is to measure radiation levels; the resulting information will be used in computing radiation doses for medical purposes.

301. Eighteen holders of I.A.E.A. Fellowships have now received training at Authority schools or establishments (including five who were awarded free places at the Wantage Radiation Laboratory); six others are due to start training shortly. They have come from sixteen countries in Europe, Asia and South America.

302. The Chairman of the Authority led the U.K. delegation to the third annual General Conference of the Agency in Vienna in September, 1959.

Sir John Cockcroft and Sir Alan Hitchman were also members of the delegation. Among the resolutions adopted was one put forward by the U.K. recommending the Agency to press on urgently with its work on the preparation of manuals and codes of practice in the health and safety field. The Chairman of the Board of Governors of the Agency visited Harwell and Amersham in June, 1959.

European Nuclear Energy Agency

303. (i) *Dragon Project*. At the first meeting of the Board of Management held at Winfrith on 1st June, 1959, Dr. Sigvard Eklund of Sweden was elected Chairman of the Board, and Mr. C. A. Rennie of the Authority's Research Group was appointed Chief Executive. During the year a team of scientists and engineers from the twelve European countries associated with the development of this joint project has been assembling at Winfrith, and the project is now well under way. Of the 128 professional staff engaged on the project at 31st March, 1960, 71 had been seconded from the Authority's staff and 3 from U.K. industry. Fifty-four came from overseas. Constructional work on buildings to house the experimental high temperature gas-cooled reactor will start shortly and a ceremony to mark this is to take place in April. The first contracts for equipment have been placed, including one for the design, manufacture, erection, commissioning and operation of a fuel element experimental plant which has been awarded to a U.K. firm. The Authority, acting on behalf of the Dragon Board of Management, concluded an agreement for exchange of information concerning the Dragon reactor on the one hand and the similar reactor to be constructed in U.S.A. on the other.

(ii) *Halden Reactor*. The boiling water reactor at Halden in Norway, which is being operated jointly by certain member countries of the European Nuclear Energy Agency, became critical on 29th June, 1959, and was formally declared open by H.M. King Olav on 10th October. Two members of the Authority's staff have been working on the project for over a year. At the meeting of the Halden Committee on 9th February, 1960, Dr. Schonland, Director of the Atomic Energy Research Establishment, was elected Chairman for the ensuing year.

(iii) *Eurochemic*. The Authority, although not a shareholder in this joint project, have signed a Letter of Intent designed to serve as a framework for specific services to be rendered to the project by the Authority or by British firms.

(iv) *Conference on Industrial Prospects in Nuclear Energy*. Sir William Cook, Dr. J. M. Hill and Mr. D. E. H. Peirson, Secretary of the Authority, presented papers at a Conference at Stresa in May, 1959, on the financial and commercial problems involved in the exploitation of nuclear energy, which was attended by some 500 industrialists and others from O.E.E.C. member countries.

(v) *European-American Nuclear Data Committee*. The Authority are represented on a new committee on nuclear reactor data which has been set up under E.N.E.A. auspices and with full United States and Canadian participation. Authority staff also serve on other E.N.E.A. committees, notably that on Health and Safety.

Euratom

304. During the year action has been taken to implement the co-operation agreement between H.M. Government and the European Atomic Energy Community (Euratom) signed in February, 1959. The first meeting of the United Kingdom/Euratom Continuing Committee for Co-operation took place in London on 4th December, 1959. Lord Hailsham, the Lord Privy Seal and Minister for Science, and the Chairman of the Authority, Lord Plowden, represented the U.K.; and M. Etienne Hirsch, President of the Euratom Commission, and M. Emmanuel Sassen, a member of the Commission, represented Euratom. The Committee reviewed the plans for co-operation proposed by the Joint Working Group at executive level, particularly concerning advanced gas-cooled reactor, fusion, and fast reactor techniques. MM. Hirsch and Sassen also visited the Atomic Energy Research Establishment at Harwell and the Bradwell nuclear power station.

305. The U.K./Euratom Joint Working Group has met either in Brussels or in London on four occasions. The U.K. representatives are Mr. D. E. H. Peirson, Secretary of the Authority, Mr. H. Cartwright, Director of the Industrial Power Branch, Development and Engineering Group, and Dr. Dunworth, Deputy Director of the Atomic Energy Establishment, Winfrith. As a result of arrangements made at Joint Working Group meetings, a number of Euratom specialists have visited Authority establishments during the year; discussions have been held on methods of reactor planning and programming; and a joint symposium on fast reactors was held at Risley and Dounreay. Authority representatives took part in a Euratom Conference on corrosion in nuclear reactors.

Central Treaty Organisation

306. The CENTO Institute of Nuclear Science (formerly the Bagdad Pact Nuclear Centre) was formally opened at Teheran by His Imperial Majesty the Shahanshah of Iran on 23rd June, 1959. The centre, which is under the direction of Mr. H. A. C. McKay of the Authority's Research Group, has held two courses during the year; a general radioisotope course and a special agricultural course, for students from Iran, Pakistan and Turkey. The Authority have offered to accept free of charge a limited number of research workers from those three countries at the Wantage Research Laboratory for the purpose of investigation applications of radioisotopes particularly relevant to those countries. Plans for research projects at the centre in addition to the regular courses are at present under consideration. Assistance has been given in geological prospecting for uranium and thorium. An analytical chemist from the Research Group is at present on loan to the Pakistan A.E.C.

Co-operation with other International Organisations

307. Authority staff have continued to take part in the work of the European Atomic Energy Society and the European Organisation for Nuclear Research (C.E.R.N.). The C.E.R.N. synchrotron achieved its full design energy on 24th November, reflecting great credit on the team under the direction of Mr. J. B. Adams. Mr. Adams himself is returning to the Authority's Research Group to take charge of research into controlled thermonuclear reactions.

308. The Authority have continued to participate in the work of various United Nations bodies such as the Scientific Committee on the Effects of Radiation, the Food and Agriculture Organisation, the International Labour Organisation, the International Standards Organisation and the World Health Organisation.

Commonwealth Countries

309. (i) As in previous years a number of Commonwealth workers have been trained and employed in the Authority's schools and establishments. Some other aspects of Commonwealth co-operation are recorded below.

Canada

(ii) At the annual conference, held this year in Canada, between representatives of the Authority and of the official Canadian atomic energy organisation, Atomic Energy of Canada Limited, the Authority team was led by Sir John Cockcroft and Sir William Cook. The wide programme of joint work already in hand was reviewed and provision was made for closer collaboration on the development of heavy water reactor systems.

Australia

(iii) The Authority have agreed with the Australian Atomic Energy Commission to undertake a joint programme of research on beryllium irradiation problems. A member of the Authority's staff has been appointed as liaison officer to the Commission for the duration of the programme. As part of these arrangements fuel element testing facilities will be made available to the Authority in the Commission's Hifar reactor at Lucas Heights.

India

(iv) There have been discussions between Members and staff of the Authority and representatives of the Indian Atomic Energy Commission concerning the possible construction of a nuclear power station under the next Indian five year plan. One of the Authority's chemists has been seconded to assist in the Commission's radiochemical work, and another member of the Authority's staff paid a short visit for discussions on health physics and safety problems.

West Africa

(v) The Prime Minister of the Federation of Nigeria and the delegation which accompanied him to the U.K. in September, 1959, visited Harwell for discussions in connection with the impending French nuclear tests. Equipment and facilities for fallout sampling stations to enable accurate measurements to be made were sent to Nigeria and were accompanied by two members of the Authority's staff who instructed the Nigerians in the use of the equipment. Similar equipment was sent to Sierra Leone and the Gambia.

United States of America

310. An amendment to the 1958 Agreement between the United Kingdom and United States Governments for co-operation on the defence uses of atomic energy was signed in Washington in May, 1959, and came into force in July (Cmnd. 733). This makes it possible for the United Kingdom

to buy from the United States component parts of atomic weapon systems other than actual warheads, and for fissile material for defence purposes to be exchanged between the two countries.

311. The Chairman of the United States Atomic Energy Commission, Mr. John A. McCone, visited the United Kingdom in October. In the course of his stay, Mr. McCone visited the Authority's establishments at Harwell and at Aldermaston. Lord Plowden visited Washington in November, 1959. During his visit agreement was reached with the Commission covering exchange of information on the Windscale advanced gas-cooled reactor and the experimental gas-cooled reactor being constructed at Oak Ridge, Tennessee.

312. Exchanges already in hand have been furthered by individual and team visits. Among the latter the more important related to fast reactor development, chemical processing, beryllium, and uranium oxide. The existing close collaboration on fast reactor work was marked by the presence of American attached staff at the start up of the Dounreay reactor in December.

313. Mr. Robert McKinney, appointed by the United States Joint Congressional Committee on Atomic Energy to study United States international policy and programmes in the atomic field, visited the United Kingdom in January, 1960, and had conversations with the Chairman and Members of the Authority.

Other Countries

314. An agreement between the Governments of the U.K. and Spain for co-operation in nuclear research and in the development of nuclear power was signed in January, 1960 (Cmnd. 936). Sir Alan Hitchman visited Madrid to be present at the signing, and had discussions with those concerned with atomic energy developments in Spain.

315. An agreement made in 1956 between the Authority and the Netherlands atomic energy organisation, the Reactor Centrum Nederland, for collaboration in certain fields of reactor development, has been extended for a further three years.

316. Contracts covering the two British type power stations, for which letters of intent had already been issued by the Japan Atomic Power Company to the General Electric Company Limited and by the Italian organisation Agip Nucleare to the Nuclear Power Plant Company Limited (now part of The Nuclear Power Group) have now been signed. Special arrangements have been made for training engineers from Agip Nucleare, including work at Calder Hall, in order that they may gain experience of the operation of gas-cooled power reactors. Numerous discussions have taken place between representatives of the Japanese organisation and the Authority over the reactor designs submitted, and over health and safety considerations. A Japanese team concerned with fuel inspection came to the United Kingdom in October for a programme of discussions with Authority staff and for visits to private firms. Heads of contract for the supply of fuel elements for the Japanese reactor were signed during a visit by representatives of the J.A.P.C. to London in February.

317. The Authority have been closely concerned with the arrangements made by Germany and Denmark for the installation of British research

reactors. Danish and German engineers have been given special facilities to work at Harwell in order to obtain experience. The Danish reactor DR 3, manufactured in the United Kingdom on the basis of the Authority's PLUTO system, and for which fuel had been supplied by the Authority, became critical in January, 1960. Authority specialists are advising on the early stages of its operations.

318. Overseas countries have shown an increasing awareness of the size of the effort needed to back a nuclear power programme and the long period of preparation necessary. This has led to numerous visits and enquiries concerning the British nuclear effort and British type power reactors.

319. Co-operation with overseas atomic energy organisations on research programmes related to the peaceful uses of atomic energy has been close and has covered an ever widening field. M. Pierre Couture, Administrator General of the French Commissariat à l'Energie Atomique, visited Harwell and Calder Hall in June, 1959. Exchanges with the French Commissariat have included other visits made in both directions. In one instance the teams were widened to include representatives of the power generating organisations. Each team thus secured a general picture of the other country's nuclear power programme and of the differences between them in organisation and responsibility.

320. Other exchanges have included discussions in London between H.M. Government and Authority representatives and a Japanese team investigating nuclear ship propulsion. A fast reactor team from the Authority visited the U.S.S.R. in July to see the Russian experimental fast reactor at Obninsk, and in return three Russians specialising in this field visited Dounreay and other Authority establishments in January, 1960. Authority representatives read papers at the Rome Nuclear Conference organised in June, 1959, by the Italian National Committee for Nuclear Research and at a symposium on Nuclear Propelled Merchant Ships sponsored by the West German shipbuilding organisations in Hamburg in November, 1959. Numerous individual contributions were made to meetings of learned societies abroad, and Authority representatives also undertook lecture tours in Italy, Sweden and Finland.

321. Other distinguished visitors to Authority establishments, in addition to those already mentioned, included His Imperial Majesty the Shahanshah of Iran, the Prime Minister of Denmark, and the Chairman of the Argentine Atomic Energy Commission, Rear Admiral Lopez.

CHAPTER XIII

THE AUTHORITY'S STAFF

322. The Authority wish to record their appreciation of the continued efforts and enthusiasm of their employees, both non-industrial and industrial, in all the fields of the Authority's activities. The Authority also wish to congratulate Dr. R. Spence, Chief Chemist, Research Group, who was admitted as a Fellow of the Royal Society in April, 1959.

Senior Staff

323. The Boards of Management of the four Groups, the officers in charge of other establishments, the principal officers in the London Office, the Management Committee of the Authority Health and Safety Branch, and the advisers to the Authority are listed in Appendix II.

Strength

324. The total number of staff employed by the Authority increased from 35,260 on 1st April, 1959, to 38,500 on 31st March, 1960. The total number of non-industrial staff increased from 17,043 to 18,928 and of industrial employees from 18,217 to 19,572. This was a decreased rate of expansion compared with previous years.

325. A rapid build-up of staff, throwing a heavy burden on management, was inevitable during the first five years of the Authority's life to carry out the great volume of work, flowing mainly from Government decisions both in the defence field and in connection with the civil power programme. However, in the light of practical management considerations and of an assessment of the resources it is reasonable to employ on the civil research and development effort, the Authority decided early in 1959 to limit the growth of manpower on research and development for the next three years, i.e. 1959-60 to 1961-62, to an annual rate of not more than 8 per cent. The limitation does not apply to the Authority's work other than civil research and development, e.g. defence work and civil and military production, where specific programmes or production needs determine the manpower required.

Recruitment

326. Within this controlled rate of expansion, recruitment in general has been satisfactory. Difficulty continues to be experienced in recruiting engineers and scientists of sufficient experience and calibre for higher management posts and in obtaining scientific and professional staff in particular disciplines in which there is a national shortage.

327. The improvement in the recruitment of graduate scientists and engineers from the universities, which was noted last year, was maintained in 1959 but a sustained effort is necessary in this field in order to attract a sufficient number of graduates of the right calibre.

328. The Authority, in conjunction with the Civil Service Commission, have continued the experiment started in 1958 of sending interviewing boards to North America to offer Authority and Government Research Fellowships and permanent appointments to suitable young British scientists who are doing research work there. These visits have had sufficiently useful results to justify a further visit in 1960, the outcome of which is not yet known.

329. On the whole, the recruitment of industrial employees has been satisfactory, although difficulties continued to be encountered in some localities in recruiting certain craft grades.

Staff and Industrial Relations

330. The Authority Whitley Council for Non-Industrial Staff continued to operate successfully. In the course of the year many matters affecting the staff were dealt with at formal and informal meetings, held both centrally and locally, between representatives of the Authority and of the staff.

331. The National Joint Industrial Council also continued to operate successfully during the year. In addition to three meetings of the Council and nine meetings of the General Purposes Committee, there were regular meetings of local Joint Industrial Committees at the major establishments. Increases in the national minimum wage rates for industrial employees were agreed on the National Joint Industrial Council in January, 1960. The increases amounted to 10s. 6d. a week for craftsmen and 9s. a week for male general and domestic workers.

332. A central joint committee on Health and Safety matters, comprising representatives of the Authority, the Staff Side of the Authority Whitley Council and the Trade Union Side of the National Joint Industrial Council, has been set up to review the significance for staff of the health and safety measures introduced in Authority establishments and the safety and emergency procedures provided. The committee is complementary to the local joint committees whose establishment was reported in paragraph 307 of the fifth Annual Report and which are now functioning most satisfactorily.

333. The Benevolent Fund for non-industrial staff, established in 1957, and administered under the supervision of the Whitley Council, has continued to make satisfactory progress. Regular financial contributions are being made by a reasonable proportion of the staff. The fund has now become self-sufficient and the annual contribution from the Authority has therefore been discontinued.

334. Benevolent funds for the Authority's industrial employees are administered on a local basis. During the year new industrial benevolent funds were set up at two establishments with initial financial assistance from the Authority.

Superannuation

335. At 31st March, 1960, 34,607 employees were covered by the Authority's superannuation schemes; some 90 per cent. of the total strength. During the year there were discussions with representatives of both non-industrial and industrial employees on the effect of the National Insurance Act, 1959.

336. Pensions to retired employees were supplemented from 1st August, 1959, to the same extent as pensions of public servants under the Pensions (Increase) Act, 1959.

337. Section 2 of the Atomic Energy Authority Act, 1959, enables the Authority to admit to their pension schemes employees of the National Institute for Research in Nuclear Science.

Training

338. The Authority have continued to encourage their junior staff to take part-time courses at technical colleges and colleges for further education leading to National Certificates and other recognised qualifications. Junior staff who show particular promise are selected for full-time university courses or for sandwich courses leading to the Diploma in Technology or to professional qualifications.

339. The provisions for internal training have been further developed. Particular attention has been given during the past year to the training of health and safety staff. A three months' trial course was provided

at Harwell to meet the immediate need for specialised training at an advanced level in fundamental radiological physics and radiobiology. A second course has been planned to start in April, 1960.

340. Increased facilities for craft training have been provided in the Authority's establishments, and during the year 32 student apprentices and 164 craft apprentices were recruited. The first recruitment of student apprentices at Dounreay took place during this period.

341. The Apprenticeship and Training Sub-Committee of the National Joint Industrial Council met twice during the year to review the training arrangements for apprentices and other industrial employees. Particular attention was paid to the experimental scheme which had been instituted at Harwell to train juveniles for laboratory and process work. At present, 30 juvenile non-craft workers are receiving training, and if the scheme proves successful it is hoped to extend the arrangements to other establishments. The sub-committee also reviewed the arrangements for adult industrial employees to receive assistance for external training to improve their skill and knowledge; almost 800 employees are receiving concessions for this purpose.

Housing

342. The number of houses owned by the Authority at 31st March, 1960, was 5,716 with 351 under construction or planned. 1,961 houses have been provided by local authorities for Authority employees coming into their areas and a further 504 are planned.

343. In view of the growth of a number of establishments to a state of relative maturity, there has been a review of policy as regards the provision by the Authority of houses and financial assistance towards housing. Revised arrangements are being discussed with the Staff Side of the Authority Whitley Council and the Trade Union Side of the National Joint Industrial Council.

Hostels

344. Additional accommodation completed during the year has brought the total number of places available for employees in the Authority's hostels to 2,228. A new hostel was opened at Abingdon and a hostel at Aldermaston was further extended.

APPENDIX I
MEMBERSHIP OF ATOMIC ENERGY AUTHORITY
AS AT 31st MARCH, 1960

Chairman

Sir Roger Makins, G.C.B., G.C.M.G.

Full-time Members

Sir William Penney, K.B.E., F.R.S.
(Member for Scientific Research)

Sir Donald Perrott, K.B.E.
(Member for Finance and Administration)

Sir William Cook, C.B.
(Member for Development and Engineering)

Sir Alan Hitchman, K.C.B.
(Member for External Relations and Commercial Policy)

Sir Leonard Owen, C.B.E.
(Member for Production)

Air Chief Marshal Sir Claude B. R. Pelly, G.B.E., K.C.B., M.C.
(Member for Weapons Research and Development)

Part-time Members

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

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

Sir A. Rowland Smith

Sir James Chadwick, F.R.S.

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

Secretary

Mr. D. E. H. Peirson

APPENDIX II
PRINCIPAL MEMBERS OF THE ATOMIC ENERGY AUTHORITY'S
STAFF AS AT 31st MARCH, 1960

LONDON

R. W. Burkitt	...	...	Principal Officer, Commercial Policy
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
H. G. Lindsell, C.B.	...	...	Principal Officer (Establishments)

DEVELOPMENT AND ENGINEERING GROUP

Headquarters, Risley

P. T. Fletcher, C.B.E.	...	...	Deputy Managing Director
A. M. Allen...	...	...	Director of Personnel and Administration
H. Cartwright, M.B.E.	...	...	Director of Industrial Power
H. V. Disney, C.B.E.	...	...	Director of Engineering
Dr. H. Kronberger, O.B.E.	...	...	Director of Research and Development
R. V. Moore, G.C.	...	...	Director of Reactor Design
D. R. Newman	...	...	Director of Finance
T. L. Viney	...	...	Director of Works and Buildings

Dounreay Experimental Reactor Establishment

Dr. R. Hurst, G.M. Director

Research and Development Laboratories

J. Harper Head of Laboratory, Springfields
F. I. Hurley... .. Head of Laboratory, Capenhurst
J. M. Hutcheon Head of Laboratory, Culcheth
K. Saddington Head of Laboratory, Windscale

Southern Works Organisation, Tadley

Col. N. Wilson, C.B.E. Manager

PRODUCTION GROUP

Headquarters, Risley

J. B. W. Cunningham Deputy Managing Director (Technical)
J. C. C. Stewart Deputy Managing Director (Operations)
J. D. Glanville, O.B.E. Director (Commercial)
Dr. J. M. Hill Director (Technical)
Dr. A. B. McIntosh Director (Development)
D. S. Mitchell Director (Personnel and Administration)
K. B. Ross, O.B.E. Director (Operations)
C. J. Turner, C.B.E. Director (Engineering)

Works

S. F. Hines, O.B.E. General Manager, Capenhurst
G. R. Howells, M.B.E. General Manager, Chapelcross
Dr. H. Rogan General Manager, Springfields
T. Tuohy General Manager, Windscale and Calder

RESEARCH GROUP

Dr. B. F. J. Schonland, C.B.E.,
F.R.S. Director

Atomic Energy Research Establishment, Harwell

Dr. F. A. Vick, O.B.E. Deputy Director
L. Grainger Chief Metallurgist
R. F. Jackson Chief Engineer
T. B. Le Cren General Secretary
Dr. R. Spence, C.B., F.R.S. Chief Chemist

Atomic Energy Establishment, Winfrith

D. W. Fry Director
Dr. J. V. Dunworth, C.B.E. Deputy Director

Radiochemical Centre, Amersham

Dr. W. P. Grove Director

WEAPONS GROUP

Atomic Weapons Research Establishment, Aldermaston

Dr. N. Levin Director
E. F. Newley Deputy Director
J. E. Adamson Group Secretary
Admiral P. W. B. Brooking, C.B.,
D.S.O. (Retd.) Assistant Deputy Director
W. J. Challens, O.B.E. Chief of Warhead Development
J. M. High Head of Engineering Services
G. L. Hopkins, O.B.E. Chief of Materials
Dr. H. R. Hulme Chief of Nuclear Research

Foulness Establishment

E. H. Mott, O.B.E. ... Senior Superintendent

Woolwich Common

C. Smith ... Superintendent

Orfordness Establishment

K. Wood ... Superintendent

AUTHORITY HEALTH AND SAFETY BRANCH

Dr. A. S. McLean ... Director

F. R. Farmer ... Head of Safeguards Division, Risley

Dr. W. G. Marley, O.B.E. ... Head of Radiological Protection Division,
Harwell

I. G. K. Williams ... Head of Administrative Division, London

ADVISERS TO THE AUTHORITY

Mr. Anton Gray, O.B.E. ... 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 Non-Industrial and Industrial
Superannuation Schemes and Adviser on
Pension and Taxation matters

Mr. W. F. Jenkins, C.B., C.B.E. ... Adviser on Contracts Matters

APPENDIX III

**SECOND SPECIAL REPORT FROM THE SELECT COMMITTEE
ON ESTIMATES**

SESSION 1959-60

OBSERVATIONS OF THE MINISTER FOR SCIENCE

1. The Minister for Science has considered the 5th Report from the Select Committee on Estimates (Session 1958-59) in consultation with the Atomic Energy Authority, and transmits the following comments to the Committee.

2. The Atomic Energy Authority welcome the Report. They note with particular appreciation that the main impression which the Select Committee wished to record was "that the Industrial Group has carried out its tasks with efficiency and success". This conclusion will be a great encouragement to the Authority and their staff.

3. The Authority have carefully examined the specific recommendations set out in paragraph 209 of the Report. They accept and will implement recommendations (1), (2), (3), (8), (10), (11), (12) and (13). In accepting Recommendation 1, the Authority assume that this recommendation, and paragraph 53, were intended to mean that future Works General Managers ought to be up to the high standard of the present ones. On the remaining recommendations, they comment as follows:—

(4) The Industrial Group should review its procedures to determine whether the early budgets, which are prepared by the separate establishments as the foundation for the Group's first consideration prior to formulating the actual estimates, could be simplified, so that detailed estimating need not begin as early as May of each year (Paragraph 67);

The Authority have reviewed their budgeting procedure and have taken steps to ensure that the original factory and laboratory estimates are prepared on as broad a basis as possible and contain no more detail, particularly in respect of minor schemes, than is essential to ensure the build up of a realistic total. Between the preparation of these original estimates at one end of the process, and presentation of the Authority's complete estimate to Parliament at the other, there are inevitably a number of stages of consolidation and scrutiny not only inside the Authority but also in the Office of

the Minister for Science and the Treasury. Although it might be possible by further compressing the already tight timetable to save about one month, i.e. to start the preparation of estimates by factories and laboratories in June rather than in May, the strain imposed by this compression would be likely, particularly for the factories, to outweigh any advantages.

Recommendation

(5) All applications for sanction of capital projects connected with the development of new reactor systems should include rough forecasts of any further expenditure that might eventually have to be borne by the Authority, if the development project in question proves successful (Paragraph 70);

The Authority agree with the Committee's view of the importance of taking account of long term effects, both in staff and further capital expenditure, of current proposals. They will include in any application for sanction of a capital project connected with the development of a new reactor system a rough forecast of expenditure which may be necessary in the foreseeable future as a consequence of the particular capital project for which sanction is requested. Inevitably, however, the longer the period covered by a forecast the greater the uncertainties. For example, the construction of the experimental fast breeder reactor at Dounreay was sanctioned in 1953. Even now, in 1960, the extent of further expenditure by the Authority on this reactor system is subject to a number of unknown factors; clearly the "unknowns" were even more numerous in 1953. While, therefore, the Authority will continue as far as possible to have regard to long term as well as short term expenditure, they consider that at the beginning of a reactor development project it is a question rather of assessing possibilities than of framing estimates of future capital expenditure in the normal sense of the term.

Recommendation

(6) The Treasury should always be informed of the size of the contingency allowance in a project estimate, and their further sanction should be sought on the basis of detailed and firm estimates for the expenditure of any part of the contingency allowance which forms a significant proportion of the total estimate (Paragraph 79);

The Authority accept that the Treasury should be informed of the contingency margin allowed in project estimates for experimental facilities for which it is impossible to give precise detailed specifications at the outset. The Treasury will also be informed at the next stage of estimating, i.e. the control estimate, what margin has been retained as a working contingency. This margin will consist of allowances of two kinds—

- (a) An amount of money, estimated on the basis of past experience with similar jobs, to meet minor variations in details of design and normal divergencies between estimates and tenders.
- (b) An amount of money to cover technical unknowns of the job.

The first contingency allowance should, in the Authority's view, be under the control of the Chief Engineer of the project; the second should be controlled, through the appropriate Director, by the Group's Board of Management. An allowance of the second type is inevitable in the case of any scheme which contains novel technical features; the only alternative to its inclusion in the project estimate would be to defer sanction until every technical unknown had been fully worked out. In many cases this would be impossible without development experience and in others it would be impracticable, having regard to the timetable set to the Authority by the defence programme or the nuclear power programme. The Select Committee recommend that further Treasury sanction should be sought for the expenditure of any part of the contingency allowance which forms a significant proportion of the total estimate, since they foresee (Paragraph 79) that "some substantial addition or change could be made to the project which might not have been sanctioned if it had been included in the original estimate". The Authority would certainly make a fresh submission to the Treasury if it was felt desirable to make any substantial addition or change to the project other than the working out of the technical development for which the contingency allowance was intended. The expenditure of the contingency allowance is, in fact, likely to be spread over a large number of relatively small items and it

would be impracticable to refer to the Treasury as and when solution of each particular technical problem required expenditure from it.

Recommendation

(7) It should be standard practice in the future to allow design offices sufficient time to go out to tender for all the major components of large civil reactor and plant projects (Paragraph 90);

The Authority accept the general intention of this recommendation. It should be noted that it is the Contracts Branch and not the Design Office which goes out to tender. The Authority's objective is to ensure that the work of the Design Office is so phased as to allow adequate time for the Contracts Branch to go out to tender.

Recommendation

(9) The priority of the fast reactor should now be given special consideration (Paragraph 140);

The Authority fully endorse the Committee's statement (in Paragraph 140) that "the future course of the nuclear power programme will be directly affected by the availability or otherwise of the fast reactor in the early 1970s, which means that its value must be established by about 1966". They regard the fast reactor as an integral part of the nuclear power programme, and will press on with its development as rapidly as possible. The fast reactor experiment at Dounreay was brought into operation on 14th November, 1959. The information derived from its operation will be used in the design of a fast reactor prototype. The Authority would dissent from the specific wording of recommendation 9 only because the fast reactor programme is receiving, and will continue to receive, full technical support.

APPENDIX IV
THE AUTHORITY'S REACTORS AS AT 31st MARCH, 1960

Research and Experimental Reactors

NAME	LOCATION	DATE OF START-UP	PEAK NEUTRON FLUX	MAXIMUM HEAT OUTPUT	MODERATOR	COOLANT	FUEL	PURPOSE
1. GLEEP ...	Harwell	1947	3.7×10^{10} thermal n/cm ² sec.	100 kW	Graphite	Air	Natural uranium metal and oxide	Routine graphite and uranium quality testing; research with oscillator; biological irradiations.
2. BEPO ...	Harwell	1948	2×10^{12}	6 MW	Graphite	Air	Natural uranium	Isotope production and general radiation source.
3. DIMPLE ...	Harwell	1954	about 10^8	100 Watts	Heavy water	None	Varies	Thermal reactor and pile oscillator studies.
4. LIDO ...	Harwell	1956	10^{12}	100 kW	Light water	Light water	Uranium 235	Thermal reactor studies, including shielding.
5. DIDO ...	Harwell	1956	1.4×10^{14}	10 MW	Heavy water	Heavy water	Uranium 235	Nuclear reactor material studies, isotope production, neutron physics, radiation chemistry.
6. PLUTO ...	Harwell	1957	1.4×10^{14}	10 MW	Heavy water	Heavy water	Uranium 235	Nuclear reactor material studies, isotope production, neutron physics, radiation chemistry.
7. D.M.T.R. (PLUTO type)	Dounreay	1958	1.4×10^{14}	10 MW	Heavy water	Heavy water	Uranium 235	Studies on nuclear reactor materials.
8. HORACE ...	Aldermaston	1958	about 10^8	10 Watts	Light water	Light water	Uranium 235	To obtain basic nuclear information on HERALD.
9. Fast Reactor	Dounreay	1959	—	60 MW	None	Sodium potassium alloy	Enriched uranium, plutonium	Development of fast reactor technology (reactor physics, fuel elements and coolant handling).

10. ZENITH	...	Winfrith Heath	1959	10^8 thermal n/cm ² sec.	100 Watts	Graphite	None— Nitrogen used as heating gas	Ceramic elements containing highly enriched uranium oxide	Reactor physics investigations for high temperature gas-cooled systems (Maximum tempera- tures, 800°C in core, 400°C in reflector).
11. HERALD	...	Aldermaston	1960	10^4	5 MW	Light water	Light water	Uranium 235	Neutron physics, radiochemical and nuclear reactor materials studies.

Research and Experimental Reactors under construction

12. AGR	...	Windscale	1961	2.5×10^{13} thermal n/cm ² sec.	100 MW	Graphite	Carbon dioxide	Enriched uranium oxide	To study the advanced gas-cooled power reactor system and to test fuel elements for the system.
13. HERO	...	Windscale	1961	—	A few Watts	Graphite	Carbon dioxide (used as heating gas)	Enriched uranium oxide	Reactor physics studies for the advanced gas-cooled reactor system.

Research and Experimental Reactors of which construction has been approved

14. NESTOR	...	Winfrith Heath	Dec. 1960	10^{11} n/cm ² sec.	10 KW	Light water	Light water	Enriched uranium- aluminium alloy	Source of neutrons for sub-critical assemblies.
15. HECTOR	...	Winfrith Heath	Mid 1962	3×10^8 n/cm ² sec.	Up to 100 Watts	Graphite	Carbon dioxide (used as heating gas)	Permanent fuel: Enriched uranium- aluminium alloy. Central Core: variable.	Oscillator Reactor — reactivity measurements on materials and fuel elements.

Plutonium/Power Producing Reactors (in production)

NAME	LOCATION	DATE OF START-UP	PEAK NEUTRON FLUX	MAXIMUM HEAT OUTPUT	MODERATOR	COOLANT	FUEL	PURPOSE
16-19, Calder ("A" and "B") (4 reactors)	Calderbridge	Station "A" 1956 Station "B" 1958	—	200 MW per reactor (37 MW [E] net)	Graphite	Carbon dioxide	Natural uranium	Plutonium and power production.
20-23, Chapel-cross	Annan	1958 (1st reactor) 1959 (reactors 2, 3 and 4)	—	200 MW per reactor (37 MW [E] net)	Graphite	Carbon dioxide	Natural uranium	Plutonium and power production.

NOTE: ZEUS was dismantled in September, 1957. ZEPHYR was dismantled in June, 1958. HAZEL was dismantled in September, 1958. NERO was dismantled at Harwell and is to be re-erected at Winfrith in 1960. NEPTUNE ceased operation in June, 1959.

APPENDIX V

BALANCE SHEET of the United Kingdom Atomic Energy Authority as at 31st March, 1959.

FOREWORD

1. The fifth Balance Sheet of the United Kingdom Atomic Energy Authority, as at 31 March 1959, 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 1959 is withheld from publication in the interests of national security.

2 The Authority are financed by the Atomic Energy Office (now the Atomic Energy Division of the Office of the Minister for Science) out of moneys provided by Parliament, and as required by the directive issued under Section 4 (2) of the Atomic Energy Authority Act, 1954, the Authority surrender to the Atomic Energy Office all revenues other than those not disclosed for security reasons.

3. In addition to the records to meet the requirements of Parliamentary accounting the Authority maintain a commercial system of accounting appropriate to their requirements, including the division between capital and revenue, to facilitate management control and commercial operation. The conventions adopted in relation to transactions on revenue account 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. Expenditure on fundamental research, including that at Dounreay Experimental Reactor Establishment, is treated as a charge to be borne by H.M. Exchequer.
- (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 Balance Sheet at 31 March 1959 is in conventional form and sets out the assets and liabilities of the Authority at that date.

5. The charge for interest on capital has, as foreshadowed in last year's Foreword, been calculated as if the capital required by the Authority on a long term basis were raised at ruling rates of interest year by year. The rates applied for capital borrowed during 1958-59 resulted in weighted averages of 5·68 per cent. on fixed capital and 4·71 per cent. on working capital.

6. Work in progress is valued at factory cost, including an appropriate share of overheads and interest charges. The valuation of work in progress does not exceed realisable value.

7. 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. A contributory scheme for these workers came into operation from 1 January 1959 with special arrangements for the workers concerned to count service prior to that date towards future benefits.

26 November 1959.

UNITED KINGDOM ATOMIC

BALANCE SHEET AS AT

31 March 1958				£	£
	I. CAPITAL ACCOUNT				
276,683,897	Balance at 1 April 1958	363,754,960			
	Deduct—				
202,672	Adjustments for previous periods	—			
276,481,225		363,754,960			
	Add—				
95,203,965	Net advances from Atomic Energy Office	94,531,770			
18,473,937	Interest on capital	18,510,221			
390,159,127		476,796,951			
	Deduct—				
42,433,428	Net Cost of Operations for the year	43,810,939			
347,725,699		432,986,012			
	Add—				
16,029,261	Adjustment to valuation of work in progress at 31 March 1958	—			
363,754,960	Capital Account at 31 March 1959				432,986,012
	II. RESERVE FOR LOSSES (in lieu of insurance) (see Note 3)				
	Balance at 1 April 1958	2,647,499			
	Add—				
	Amount charged to operating costs in the year	1,945,000			
		4,592,499			
	Deduct—				
	Charged in the year	41,931			
2,647,499					4,550,568
	III. CURRENT LIABILITIES AND PROVISIONS				
8,191,126	Trade creditors and accrued liabilities	10,776,971			
310,000	Superannuation and other provisions	845,675			
					11,622,646
374,903,585					449,159,226
	IV. PRINCIPAL NON-INDUSTRIAL SUPERANNUATION SCHEME				
8,056,445	Balance at 31 March 1959				10,615,336
	V. PROTECTED PERSONS SUPERANNUATION SCHEME				
2,322,588	Balance at 31 March 1959				2,370,202
	VI. INDUSTRIAL SUPERANNUATION SCHEME				
—	Balance at 31 March 1959				656,307
	Notes forming part of this Balance Sheet are appended. (See page 72.)				
£385,282,618					£462,801,071

ENERGY AUTHORITY
31 MARCH 1959

31 March 1958		As valued at 1 August 1954 plus additions at cost	Depre- ciation	
£		£	£	£
	I. FIXED ASSETS, at cost or estimated cost less depreciation			
491,702	Freehold land	559,463	—	559,463
74,215,936	Buildings, ancillary installations housing and hostels	108,653,775	13,447,920	95,205,855
80,163,876	Plant and machinery, motor vehicles, loose apparatus, tools and equip- ment	137,511,440	26,300,766	111,210,674
2,579,964	Furniture, fittings and office machi- nery	3,651,449	474,811	3,176,638
233,684	Capital assistance—assets with assisted contractors	469,523	247,516	222,007
157,685,162		£250,845,650	40,471,013	210,374,637
59,469,134	Assets in course of construction			40,072,191
217,154,296				250,446,828
	II. SPECIAL DEVELOPMENT AND DEFERRED REVENUE EXPENDITURE LESS AMOUNTS WRITTEN OFF			
700,733	Initial production expenses		910,609	
2,586,530	Research and development expenditure in aid of design		2,685,577	3,596,186
	III. LOANS, ADVANCES AND INVESTMENTS			
29,871,330	Loans and advances for the production of uranium, including accrued interest		21,353,465	
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 £12,610)		14,871	21,368,336
	IV. CURRENT ASSETS			
29,159,559	Stocks of raw materials and stores		50,981,790	
88,881,791	Work in progress		113,612,697	
5,601,721	Debtors, deposits and payments in advance		6,983,777	
932,754	Balances with Paymaster-General, with bankers and cash in hand		2,169,612	173,747,876
374,903,585				449,159,226
	V. PRINCIPAL NON-INDUSTRIAL SUPERANNUATION SCHEME FUND			
8,014,846	Amount due from H.M. Exchequer (see Note 4)		10,573,845	
41,599	Insurance policies		41,491	10,615,336
	VI. PROTECTED PERSONS SUPERANNUATION SCHEME FUND			
2,322,588	Amount due from H.M. Exchequer (see Note 5)			2,370,202
	VII. INDUSTRIAL SUPERANNUATION SCHEME FUND			
—	Amount due from H.M. Exchequer (see Note 6)			656,307
£385,282,618				£462,801,071

Plowden, Chairman.
D. Perrott, Member.

NOTES

These notes form part of the Balance Sheet as at 31 March 1959.

1. Capital expenditure authorised but not provided for in these Accounts amounted to £75m. of which £25m. had been committed contractually.
2. The Authority have extensive commitments for the future purchase of uranium concentrates.
3. The Authority do not insure but 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.
4. 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	3,193,096
Excess of contributions and other receipts over benefits and other outgoings for the period 1 August 1954 to 31 March 1959 ...	6,532,434
Interest on funds treated as deposited with H.M. Exchequer ...	848,315
	<u>£10,573,845</u>

The first actuarial valuation of the Scheme will be undertaken as at 31 March 1960.

5. 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 ...	734,511
Provisional valuation of H.M. Exchequer liability in respect of unestablished industrial Civil Servants transferred to the Authority...	360,000
Excess of contributions and other receipts over benefits and other outgoings for the period 1 August 1954 to 31 March 1959 ...	998,683
Interest on funds treated as deposited with H.M. Exchequer ...	277,008
	<u>£2,370,202</u>

The first actuarial valuation of the Scheme will be undertaken as at 31 March 1961.

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

	£
Excess of contributions and other receipts over benefits and other outgoings for the period 1 August 1954 to 31 March 1959 ...	651,357
Interest on funds treated as deposited with H.M. Exchequer ...	4,950
	<u>£656,307</u>

The first actuarial valuation of the Scheme will be undertaken as at 31 March 1962.

I have examined the foregoing Balance Sheet. I have obtained all the information and explanations that I have required, and I certify, as the result of my audit, that in my opinion this Balance Sheet, with the Notes appended, is properly drawn up so as to exhibit a true and fair view of the state of affairs of the United Kingdom Atomic Energy Authority as at 31 March 1959

E. G. Compton,
Comptroller and Auditor General.

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