

UNITED KINGDOM ATOMIC ENERGY AUTHORITY

SEVENTH
ANNUAL REPORT
1960—61



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UNITED KINGDOM
ATOMIC ENERGY AUTHORITY

SEVENTH ANNUAL REPORT

For the Period
1st April, 1960—31st March, 1961

*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
7th July 1961*

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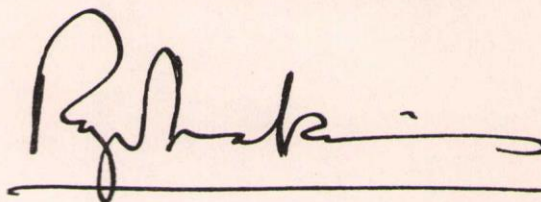
UNITED KINGDOM ATOMIC ENERGY AUTHORITY,
11, CHARLES II STREET,
LONDON, S.W.1.

1st June, 1961

MY LORD,

I have the honour to submit, in accordance with Section 3 (5) of the Atomic Energy Authority Act, 1954, the Seventh Annual Report of the United Kingdom Atomic Energy Authority. This Report covers the period from 1st April, 1960, to 31st March, 1961.

I have the honour to be, My Lord,
Your Lordship's obedient Servant,

A handwritten signature in dark ink, appearing to be 'R. Hailsham', 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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CHAPTER I

GENERAL SURVEY

Introduction

1. During the year 1960/61 the Authority continued to meet their obligations under the weapons programme laid down by Her Majesty's Government, as described in the "Report on Defence 1961" (Cmnd. 1288). The Authority also provided technical assistance in connection with the Geneva negotiations for nuclear weapon test suspension.

2. On the civil side, the development of nuclear reactors to generate electricity on an economic basis remains the Authority's principal objective. Work in aid of the nuclear power stations under construction for the electricity boards, and particularly the development and manufacture of magnox fuel elements, occupied a substantial part of the Authority's scientific and technical resources. The development programmes on more advanced reactor systems continued, and construction of the advanced gas-cooled reactor prototype at Windscale was brought near completion. Studies of possible reactor systems for nuclear ship propulsion, production of radioisotopes and development work on their many applications, furtherance of basic nuclear science, work on health and safety problems, and fulfilment of their international obligations, took up most of the rest of the Authority's scientific effort.

3. The Authority devoted much effort, during the year under review, to the organisation of their resources both of equipment and of manpower to meet the obligations laid upon them by H.M.G. They reviewed the work, present and planned, at all their sites, and all the major segments of the Authority's technical responsibilities. This led to the re-grouping of certain of the Authority's activities, and to changes in organisation, the more important of which are described in Chapter II.

4. In addition, the Authority had in hand a special survey of their future requirements, both of manpower and of money, in order to ensure that their demands on the country's resources did not exceed the minimum needed for the efficient execution of the tasks laid upon them. This survey was additional to the reviews which the Authority carry out from time to time to ensure that their choice of reactor systems for major development effort, and the priorities between them, are firmly based.

Summary of the Report

5. Certain changes in Board Membership took place during the year. A measure of reorganisation, including the appointment of a Deputy Chairman, will take effect from 1st April, 1961. The Authority's Estimates for 1961/62 provide for a net expenditure of £78,071,000, compared with £93,293,000 for 1960/61, a fall of over 16 per cent. (Chapter II).

6. Production of fissile material was up to programme, and improvement in efficiency led to reductions in unit cost. The Calder and Chapelcross reactors sent out more than 2,000 million units of electricity to the grid. In an experiment in a Calder reactor some of the standard fuel elements reached an exposure greater than 3000 MWd(H)/t, far in excess of their designed endurance. Fuel elements were manufactured at Springfields for the Bradwell and Berkeley reactors of the Central Electricity Generating Board, and also for the prototype advanced gas-cooled reactor at Windscale. Modifications were carried out to the Capenhurst diffusion plant to improve efficiency of operation (Chapter III).

7. The Authority continued to devote a considerable development effort to the support of the civil magnox reactors. The programme was concerned mainly with the design and testing of fuel elements and with the control and safe operation of these reactors. The experimental advanced gas-cooled reactor at Windscale was substantially completed during the year, and criticality is planned to take place during the autumn of 1961. The HERO zero energy high temperature reactor reached an advanced stage of construction. A considerable amount of background research and development in aid of the A.G.R. and its fuel element was carried out. The first fuel charge will be mainly of stainless steel-clad elements. The Dounreay fast reactor core structure was modified to enable more advanced fuel element components to be tested. Operation of the reactor at low power has yielded valuable experience of the performance of the non-nuclear parts, and certain improvements have been incorporated. The zero energy breeder reactor assembly (ZEBRA) is under construction at Winfrith. Preliminary study of a prototype fast reactor continued during the year. Construction of the experimental high temperature gas-cooled reactor by the Organisation for European Economic Co-operation Dragon project continued at Winfrith, and the zero energy reactor ZENITH was used in support. A development programme on the steam generating heavy-water reactor is to be carried out in collaboration with Atomic Energy of Canada Limited. The Authority carried out a substantial programme of technical study in connection with the consideration by H.M.G. of the question of nuclear marine propulsion (Chapter IV).

8. Chapter V describes the Authority's general research and development work, under three main headings: first, the scientific problems arising from nuclear power, especially those concerned with materials; second, fundamental research in the many branches of science of importance to the Authority; third, research on isotopes and large sources of radiation.

9. Chapter VI reviews the prospects of thermonuclear research, and describes the various studies which are being carried out in the United Kingdom and other countries. The Intermediate Current Stability Experiment has not been continued. Construction began during the year on the new laboratory site at Culham.

10. Besides carrying out the programme of military development and production laid down by the Ministry of Defence, the Authority have set in hand a programme of seismological research bearing on the detection and identification of underground nuclear explosions. Some of the fundamental research and development work of the Weapons Group is described (Chapter VII).

11. Uranium supply and demand became even more out of balance during the year, and further steps were taken to limit and stretch out the Authority's liabilities (Chapter VIII).

12. The value of the Authority's sales totalled nearly £21 million during the year. Sales of radioisotopes rose by about 10 per cent. The Authority delivered fuel elements for C.E.G.B. power reactors, and for research reactors both at home and overseas. The Authority continued to act as consultants to the electricity boards in the U.K. and to purchasers overseas of British designed nuclear power reactors (Chapter IX).

13. The Authority continued to apply internationally agreed health and safety standards and to contribute to their development. The measures taken to protect the public and the Authority's staff continued to show satisfactory results. Co-operation has been maintained with the government departments concerned with the health and safety aspects of the development of atomic energy and support has been given to a number of international activities in the health and safety field. Effort has continued on a number of research projects and investigations, both in relation to reactors and plants and also in the field of radiological protection (Chapter X).

14. Demand for information on atomic energy, from both home and overseas enquirers, continued to grow, and the Authority continued to keep the public informed of their activities by means of publications, exhibitions, films, etc. An Isotope Information Bureau was opened in the Authority's London office, 11, Charles II Street, S.W.1 (Chapter XI).

15. The Authority's links with overseas countries and with international organisations working in the nuclear field were strengthened by a large number of exchanges of visits and reports, by attendance at international conferences and by attachment of staff from other countries to the Authority's schools and establishments (Chapter XII).

16. The Authority's employees increased in number during the year from 38,500 to 40,840 (Chapter XIII).

CHAPTER II

MEMBERSHIP, FINANCE AND ACCOUNTS

Board Membership and Organisation

17. Mr. John Pears, F.C.A., was appointed a part-time Member of the Authority with effect from 1st May, 1960.

18. Sir Donald Perrott left the Authority on the expiry of his appointment, on 31st July, 1960. Sir Alan Hitchman, while retaining his existing responsibilities for commercial policy, assumed the responsibilities previously exercised by Sir Donald Perrott, and the title of Member for Finance and Administration.

19. Sir Rowland Smith relinquished his appointment as a part-time Member of the Authority on 16th October, 1960. Mr. R. M. Geddes was appointed a part-time Member with effect from 21st November, 1960. The appointments of Lord Citrine, Sir James Chadwick and Mr. C. F. Kearton as part-time Members were renewed until 31st December, 1961; 20th August, 1962; and 16th October, 1965, respectively.

20. In January, 1961, Sir John Cockcroft was chosen as the recipient of the 1961 "Atoms for Peace" Award. In March, 1961, the election of Mr. C. F. Kearton to Fellowship of the Royal Society was announced.

21. In their report dated July, 1959, on the Industrial Group of the Atomic Energy Authority, the Select Committee on Estimates recommended that certain aspects of the Authority's organisation should be reviewed after a reasonable period. This review took place during the year, and on 16th February, 1961, the Authority announced a number of organisational changes to take effect from 1st April, 1961.

22. Sir William Penney has been appointed Deputy Chairman, with primary responsibility for scientific and technical co-ordination throughout the Authority. The Authority's groups have been increased to five: namely, Research, Reactor, Engineering, Production and Weapons. The work of designing and developing nuclear reactors will be concentrated, to the greatest possible extent, in the Reactor Group, and the major development facilities required for this purpose will be under its control. The group will be responsible for the design and development of reactors, and for relations in this field with industry at home and with overseas countries. The Winfrith Atomic Energy Establishment, which has responsibilities in the same field, will be transferred from the Research Group to the Reactor Group.

23. The existing responsibilities of the Development and Engineering Group for the design and construction of plant, works and buildings will be transferred to the new Engineering Group, which will also take over from the Production Group its responsibilities for the design and inspection of fuel elements for production purposes.

24. As from 1st April, 1961, Sir William Cook will be Member for Reactors. Sir Leonard Owen's responsibilities will extend over the Production and Engineering Groups with the title of Member for Production and Engineering.

25. The Membership of the Authority as at 1st April, 1961, is set out at Appendix I.

Finance

26. The Authority's Estimates for 1960/61 were presented to Parliament on 16th February, 1960, as part of the Atomic Energy Vote (Civil Estimates, Class IX, 7), and were approved for the net sum of £93,293,000 (including a sum of £6,250,000 for the National Institute for Research in Nuclear Science).

27. A Supplementary Estimate of £44,000 was presented to Parliament on 5th July, 1960. This was to provide for an increased contribution in 1960/61 by the Authority to international atomic energy projects, following the agreement to extend the boiling water reactor experiment at Halden in Norway by 18 months to 4½ years.

28. The Authority's Estimates for 1961/62 were presented to Parliament on 14th February, 1961, at a net total of £78,071,000 (including a sum of £6,211,000 for the N.I.R.N.S.). The fall of £15,266,000 (over 16 per cent.) in the net total compared with the previous year arises from a decrease of £7,231,000 in gross expenditure, resulting from reductions in uranium purchases, economies effected by the Authority, and a smaller capital programme; together with an increase

of £8,035,000 in Appropriations-in-Aid. The smaller capital programme reflects the completion of the major production plants associated with the military programme and of the initial phases of opening new sites for research and development. The increase in Appropriations-in-Aid is the result of the build-up of receipts from the sale of fuel elements for the civil power programme.

Accounts

29. 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. In addition to the commercial accounts, the Authority maintain records necessary to meet the requirements of Parliamentary accounting.

30. The Balance Sheet as at 31st March, 1960, 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 29th November, 1960, and will, in due course, be presented to Parliament.* (The Operating Account is withheld from publication in the interests of national security.) 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, 1960, this had increased to over £500 million.

CHAPTER III

PRODUCTION PLANTS

Introduction

31. The year under review was one of steadily increasing activity in the production plants. Major new units constructed under the Authority's expansion programme were nearing completion at the start of the year and effort during the year was directed to the elimination of initial operating difficulties, to improving the quality of the product and to achieving a reduction in product costs.

32. In spite of the difficulties inevitably associated with commissioning new plant, all commitments for delivery of fissile materials were met. The production plants additionally supported a large experimental programme aimed at the improvement of the designs of fuel elements for the civil nuclear power stations. Pilot scale production of more advanced types of fuel elements for prototype reactors started during the year.

The Calder and Chapelcross Reactors

33. The eight reactors gave almost trouble-free operation throughout the year. Although these reactors were designed primarily for the production of plutonium, more than 2,000 million units of electricity are being sent out to the grid annually, and at the same time the reactors are providing a most valuable test facility for large scale development work in aid of the civil stations.

* Ordered by the House of Commons to be printed on 17th April, 1961, and now on sale at H.M. Stationery Office (price 6d.). The Balance Sheet together with the Authority's Foreword is reproduced in Appendix IV.

34. Improved efficiency of operation has been sought in two ways: by raising the level of heat output, and by reducing the off-load time required for refuelling and scheduled maintenance. Considerable success has been achieved in both these directions. An improvement in heat output, which has had no adverse effect on fuel element life, has been obtained by raising the fuel element operating temperature, and by adjusting the loading of the reactors to obtain a more even distribution of heat in the reactor core. Electronic computers have been used to calculate optimum loading patterns of fuel elements and absorbers to achieve this heat distribution. As a result of this progressive development work, the gross heat output has been raised year by year as indicated in FIG. I, and is now about 20 per cent. above the design figure.

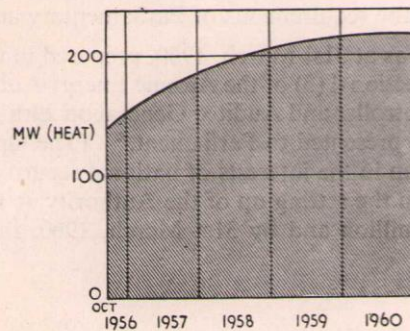


FIG. I. Increase in average reactor power (heat) since start of operation

35. Further small improvements in the heat output can be expected, but the limit of development with these particular reactors is now in sight.

36. The Calder and Chapelcross reactors are so designed that fuel can be replaced only when the reactor is shut down. A fuel change involves the removal from each reactor of about 10,000 radioactive fuel elements, and their replacement with new elements. By careful attention to the organisation of this work, and the planning of the maintenance carried out at the same time, it has been possible to reduce the off-load period from the 11 weeks to carry out the first recharge of Calder number 1 reactor to the present period of about four weeks. This improvement is shown in FIG. II.

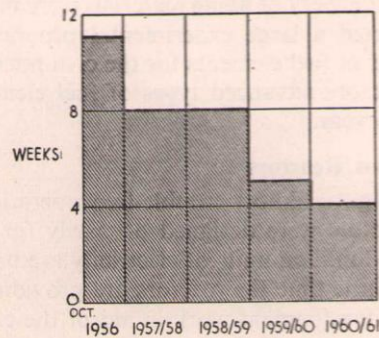


FIG. II. Average time taken to complete the scheduled refuelling and maintenance of Calder and Chapelcross reactors

37. On 31st January, 1961, the Calder number 4 reactor completed 12 months continuous operation, during which period it was generating electricity at full load for 95.6 per cent. of the time. No shut-down due to fuel element failure was necessary during the period, the reactor ultimately being discharged for routine maintenance and change of fuel. The 4.4 per cent. of the time when the reactor was not on full load was composed of: 2.5 per cent. on experimental work; 0.7 per cent. on scheduled maintenance of ancillary equipment; 0.6 per cent. on unscheduled blower maintenance; 0.4 per cent. on unscheduled maintenance of other equipment; and 0.2 per cent. on special tests on fuel elements.

38. The net generation of electricity at Calder and Chapelcross has increased steadily over the last five years as shown in FIG. III.

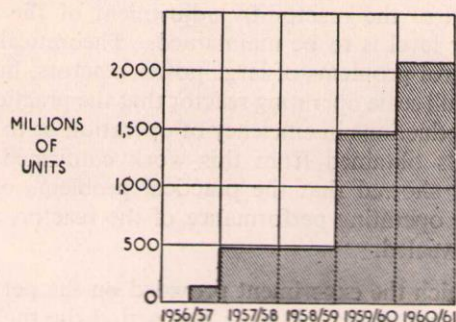


FIG. III. Total annual net generation of electricity at Calder and Chapelcross works

39. The stage has now been reached at which the reactors are capable of generating more steam than can be used by the installed turbine capacity. Modifications were made during the year to some of the turbo-alternators to enable the excess steam to be utilised and the generation of electricity increased; the remainder will be modified during the course of the next 18 months. Moreover, it is planned during 1961 to commence the utilisation of surplus steam available at Calder in the chemical plants and for space heating on the adjacent Windscale site.

40. Mention has been made of the increasing use of the production reactors for experimental and proving purposes. The cost of this is of course charged to the particular experiments. Work has been directed principally towards the proving of the serviceability of the elements for the first civil nuclear power stations and providing irradiation information on which more advanced fuel element designs can be based. As a result of these trials, small but important changes have been made in the design of the fuel elements for the Bradwell and Berkeley stations.

41. The irradiation of specimens of various materials used in the construction of reactors and of fuel elements has been carried out to provide information on irradiation behaviour.

42. An experiment of considerable importance was concluded successfully last autumn in Calder number 3 reactor. This reactor was operated without changing fuel from mid-1958, when it first started operation, until August, 1960.

The experiment had two principal objectives. The first was to establish the probable operating characteristics which would be encountered in a large civil reactor, and the second was to obtain, by a large-scale test, further information on fuel element performance after prolonged irradiation.

43. The operating characteristics of the Calder reactor at an average exposure of 1000 MWd(H)/t were calculated to simulate in several important aspects the operational characteristics of the Bradwell and Berkeley reactors. Nuclear reactors such as those of Calder and Chapelcross, and the types being constructed for the electricity generating boards, are self-regulating when loaded with new uranium fuel. The self-regulating characteristic is such that the reactors will run initially at a steady power virtually in the absence of control from a control circuit or from the reactor operator. As the fuel becomes progressively more highly irradiated the characteristics of the reactor change and it is necessary to control the reactor by adjustment of the control rod positions if a steady power level is to be maintained. Theoretical predictions had been made on the control problems of large power reactors, but it was felt necessary to establish on a full scale operating reactor that the practical problems of control did not lead to reductions in efficiency of operation or to a deterioration in safety. The results obtained from this work confirmed in full the theoretical predictions and showed that the practical problems of control in no way detracted from the operating performance of the reactor, and no new problems of safety were revealed.

44. The information which the experiment provided on the performance of fuel elements was similarly reassuring. During this period the fuel reached an average exposure of more than 1000 MWd(H)/t. A number of channels in the central region of the core reached an exposure of about 1500 MWd(H)/t and a number of elements had been irradiated to over 2000 MWd(H)/t. The standard fuel for the Calder and Chapelcross reactors was not designed specifically to withstand the level of irradiation achieved in this experiment. The fact that it did so, and that the fuel element failures which developed (approximately 2.3 per cent.) were of a type which could be recognised at an early stage and withdrawn at convenient times, gives a measure of increased confidence.

45. In a further long irradiation experiment in another Calder reactor a number of fuel channels had reached 2250 MWd(H)/t and some individual fuel elements had exceeded 3000 MWd(H)/t by early 1961. In the case of the civil power stations an average irradiation of 3000 MWd(H)/t has been assumed. While the Authority have no reason to doubt these assumptions sufficient time has not yet elapsed to test the civil reactor fuel elements to this irradiation.

Fuel Element Production

46. The new fuel element production factory at Springfields was brought into full scale operation during the year and is now manufacturing, on a routine basis, fuel elements for the Bradwell and Berkeley reactors for the Central Electricity Generating Board, and also fuel elements for the Calder and Chapelcross reactors, a considerable number of which are of an experimental or non-standard design. The other main product of this factory is uranium hexafluoride, which is the feed material for the diffusion plant at Capenhurst.

47. The initial year of production of fuel elements for Bradwell and Berkeley was a difficult one for the Springfields factory. The endurance testing of both

Bradwell and Berkeley fuel elements showed that small changes in the design were necessary. This led to a postponement of the start of manufacture of both types of fuel in order to permit the maximum time for further development work and the procurement of modified components.

48. The fuel elements which are being manufactured for the civil power stations are considerably improved versions of those originally adopted for Calder in 1956. Although changes have increased the complexity of the fuel elements and of the manufacturing processes, operating labour per ton of product is little greater than had previously been required for the simpler design of Calder fuel.

49. The production of a much more advanced type of fuel for the prototype advanced gas-cooled reactor at Windscale began during the year. The starting material is uranium hexafluoride enriched in the Capenhurst diffusion plant. This is converted to uranium oxide powder which is then compressed and sintered into ceramic pellets, which are canned in tubes of either stainless steel or beryllium. In addition to elements for the prototype A.G.R., considerable quantities of fuel were manufactured for other research and development projects.

50. During the year the chemical plants at Springfields operated satisfactorily. In particular the main plant for manufacturing uranium tetrafluoride by fluidisation techniques (see paragraph 137) came into full production and is now yielding good quality material at the designed throughput. The original Dryway plant in the old works was in the course of being closed down at the year's end, as the requirements for uranium tetrafluoride can be met by the new process.

Plutonium Extraction Plants

51. During the year under review, the main chemical extraction plant at Windscale, which was constructed to deal with the fuel from the two original Windscale reactors, successfully processed all the irradiated fuel arising from the eight Calder and Chapelcross reactors and small quantities from other sources. This increase in throughput was achieved by modifying the main separation unit and constructing additional facilities for processing the increased quantity of plutonium now being fed to the plant. Some difficulties were experienced during the commissioning of these additional plutonium facilities but these have now been largely overcome.

52. The capital expenditure involved in the modifications making possible this increased output was relatively modest. In view of this and of the improvements in the reactors and processing plants, there has been a steady reduction in the unit cost of plutonium.

53. Work is proceeding on the construction of the new separation plant required to process the irradiated fuel which will arise from the nuclear power stations operated by the electricity boards.

54. Despite the much larger quantity of fuel processed at the works during the year, the discharges of radioactive waste remained well within the authorised limits. Discharges to sea remained at a completely safe level, and operating procedures are continually being developed to reduce discharges still further.

Capenhurst—Isotope Separation

55. The diffusion plant operated smoothly throughout the year and attention to details of operation resulted in an improvement of about 4 per cent. in plant efficiency compared with the previous year. In addition to the highly enriched material taken from the top end of the plant, uranium hexafluoride was drawn off from the cascade at low enrichment to meet the requirements for the prototype advanced gas-cooled reactor and for other research and development projects.

56. There was no major constructional work at Capenhurst during the year, the planned extensions to the plant having been completed in November, 1959. Certain modifications were carried out to improve performance and safety, and these were introduced with little loss of operating time.

57. Better operating procedures have reduced the occurrence of unwanted residues which are formed by the chemical breakdown of uranium hexafluoride. Development work continued on features of the plant in which worthwhile improvements could be foreseen, and some success was achieved in the automation of methods of analysis and measurement. The greatest effort was directed to the possibility of further operational economies.

58. In view of the publicity given over the past year to the centrifuge method of isotope separation, it should be noted that the Authority's predecessor, the Ministry of Supply, in collaboration with British industry, was actively engaged on the development of this method of isotope separation until late 1951. With the success of the diffusion plant as a military project, work on the centrifuge method was abandoned at that time. Since then, great progress has been made in relevant fields such as vacuum engineering, the handling of uranium hexafluoride and the design of gas-bearings, as a consequence of which it has become necessary to review the centrifuge to see what effects the new technologies might have on the centrifuge as a means of separating isotopes and to examine their bearing on the technical aspects of disarmament. A small development programme has therefore been started.

CHAPTER IV

REACTOR DEVELOPMENT PROGRAMME

Introduction

59. The main aims of the Authority's programme of reactor development are to provide support for the first nuclear power stations now under construction for British, Italian and Japanese electricity undertakings and to pioneer more advanced types of reactor systems for the progressively cheaper generation of nuclear power. The division of effort between these two objectives is under continuous review and, while the first civil nuclear stations remain the major commitment, during the past year it has become possible to deploy an increasing number of staff on the longer term aims of the Authority's programme of reactor development.

60. Seven nuclear power stations with an aggregate output capacity of approximately 3,000 megawatts electrical are now being built by industry for, or have been authorised by, the United Kingdom electricity generating boards. This represents about one-tenth of the generating capacity already installed in the U.K. To reach the output capacity of approximately 5,000–6,000 megawatts electrical by 1966 specified in the 1957 programme would have required an exceptionally high rate of capital investment over the next two years. At the same time, the need for such a high rate of installation of nuclear capacity has been removed by the improved supply of coal and oil. In consequence, as announced by the Minister of Power in June, 1960 (Cmnd. 1083), the programme has been modified with the immediate objective of reaching about 5,000 megawatts installed nuclear capacity by 1968. Although the early civil nuclear power stations will not achieve costs of power as low as originally forecast, the latest stations are expected to do so despite the rise in the general price level which has occurred since the forecast was first made. This fall in the cost of nuclear power will continue as more advanced systems are introduced.

61. During the past year further comparative cost studies have been made of various reactor systems. The potential of the magnox system will be restricted by inherent limitations of the fuel materials. The advanced gas-cooled reactor using oxide fuel will operate at higher temperatures and ratings and has the potential of producing power at a lower cost. The studies have also shown that the development of both gas-cooled reactors and of some forms of water-moderated reactor could lead to still further reductions in cost. In the lower power range it is more difficult for nuclear power to compete with conventional generation, but further development and mastery of the technology of these reactor systems may lead to useful application to smaller nuclear stations. The results of these comparative studies are being used in planning the Authority's reactor programme.

62. The Authority have the major responsibility for investigating and establishing the scientific, technical and economic possibilities of reactor systems involving in some cases the construction of an experimental prototype. Thereafter, the main responsibility for technical development and commercial exploitation rests with industry, except for the further development work on fuel and safety. The Authority associate the British consortia with work on the development of new reactor systems to ensure the early transfer of technologies.

63. A comparative economic study of various marine reactor designs was carried out during the year under review; results are reported in paragraphs 116–119. The main conclusion drawn from the studies is that, because of the comparatively small size of reactors required for marine propulsion, and the stringent safety precautions necessary if present reactor designs were installed in a ship, none of the reactor designs at present in an advanced state of development is economic. However, the systems so far proposed are essentially adaptations of reactors originally developed for large land-based power stations. The Authority are now considering the use of more advanced systems which are in a much earlier stage of development, to see whether these show potential for economic marine use. Other work on marine reactors over the year included the continuation of support for the Admiralty nuclear submarine programme.

Magnox Reactors

64. The continued satisfactory operation of the Calder Hall and Chapelcross reactors is reported in Chapter III. The Authority's development effort in support of the civil magnox reactors has been concerned mainly with the design and testing of fuel elements and with the control and safe operation of these reactors. Development work on the magnox system carried out over the past year is reviewed in the following paragraphs.

Reactor Physics

65. A large digital computer programme, STAB, has been set up to enable detailed reactor stability calculations to be carried out on the Authority's computers. The programme has been tested by first calculating the kinetic performance of the Calder reactors and then checking the results from the performance of the reactors themselves. This work yielded a fuller understanding of the effects of temperature coefficients of reactivity. These coefficients provide the magnox reactors with a measure of prompt self-stabilisation, but they can lead to slow movements in power distribution in the reactor core unless they are properly controlled. The STAB programme is also being used by the electricity generating boards for the solution of specific problems which may arise during the charging and operating of the civil magnox stations.

66. An important influence is exerted on the reactivity and kinetic behaviour of magnox reactors by the plutonium which is built up in the uranium fuel as irradiation proceeds. This effect manifests itself in increased reactivity as the moderator temperature rises. Experiments on the effects of plutonium build-up in uranium fuel are being done in sub-critical assemblies or stacks of graphite, uranium and plutonium. Experiments have been carried out at the Atomic Energy Establishment, Winfrith, in the heated sub-critical assemblies SCORPIO I and SCORPIO II. The measured reactivity and temperature coefficient changes have been compared with estimates based on oscillator experiments with small samples, and with the experiment in one of the Calder reactors for investigating physics problems associated with long burn-up and plutonium build-up referred to in paragraphs 44 and 45. The results of this work have confirmed that the control systems designed for the civil magnox stations will ensure adequate operational stability.

67. A number of reactor physics experiments for the BICEP* programme on metal-fuelled, graphite-moderated assemblies were carried out to check points of detail including the effect of vacant fuel channels in a reactor lattice. This collaborative programme between the Authority and the consortia, from which a large amount of physics data on the magnox and A.G.R. systems has accumulated, has now been completed.

Graphite Moderator

68. Data on the rate of accumulation of Wigner energy in graphite under irradiation are still coming forward from specimens in Calder and in materials testing reactors including DIDO, PLUTO and D.M.T.R., although sufficient evidence is already available to predict the rate at which stored energy will accumulate in the graphite core of civil magnox reactors together with its effect on safety. It will be recalled that in 1958 the Authority recommended, as a

* British Industries Collaborative Exponential Programme.

precaution in view of the scanty data then available, that the fuel element channels of the civil reactors should be sleeved, but as more information on the storage of Wigner energy came to hand, the recommendation was withdrawn (Sixth Annual Report, paragraph 66). The latest results at higher irradiations have confirmed the correctness of this decision.

69. Irradiation tests on the dimensional changes induced in graphite are being carried out in DIDO, PLUTO, D.M.T.R. and the Danish Atomic Energy Commission's test reactor DR.3, a British designed reactor similar to PLUTO. Information is being sought which should enable the graphite structure of reactor cores to be designed to closer limits.

Fuel Elements

70. Reference is made to fuel element failures in paragraph 44. These failures were caused either by faulty welds which had escaped detection, or by porosity in the magnox can which developed as the uranium bar grew under irradiation, thus stretching the can. The first type of failure is now very rare, and the latter type develops only slowly and only in the cooler parts of the reactor where the ductility of the magnox is lowest, but where the growth of the uranium is at a maximum.

71. The effects on fuel element life of the dimensional changes of the uranium bar and the lack of ductility in the coarse-grained Calder magnox were foreseen. Accordingly, a fine-grain magnox with increased ductility was specified for the civil reactor fuel element cans. The fine-grain cans will be better able to withstand the dimensional changes of the fuel, but investigation of magnesium alloys with an even higher ductility is being continued.

72. Under civil reactor conditions each atom of uranium will, on average, be knocked out of its position every fortnight, although most of them will return to similar positions in the crystal lattice very quickly. In view of this and of the anisotropic nature of uranium, it is not surprising that irradiation produces dimensional changes. A single crystal of uranium under irradiation will grow in the direction of one axis and will contract in another; the crystal will approximately double its length after a burn-up of 2000 MWd(H)/t at 200°C. To avoid overall growth of the bar the crystals must be randomly orientated so that the net growth is zero. It is also necessary to have a fine-grain structure since large grains near the surface of the uranium bars can grow with little restraint and result in wrinkles. The grain size is refined by heat treatment from a high temperature, but unfortunately this process introduces a small degree of preferred orientation (i.e., departure from randomness), and the uranium bars change dimensions slightly under irradiation. There are alternative methods of producing a fine-grain structure other than by heat treatment, such as alloying with small quantities of molybdenum and chromium. Irradiation experiments on various alloys of this type are now being carried out.

73. Because of the deleterious effects under irradiation of preferred orientation and of a large grain size, it is essential that checks are made on these properties during manufacture of the bar. The degree of random orientation of the crystals cannot be determined directly, but it can be deduced from a combination of measurements of the thermal expansion coefficient and the coefficient of electrical resistivity. The grain size and uniformity can be measured during the production process by a technique depending on the attenuation of ultrasonic pulses within the uranium bar.

74. A further problem affecting the use of metallic uranium as a fuel is the swelling which occurs during prolonged irradiation at temperatures above 500–600°C. This is due mainly to the gaseous fission products xenon and krypton which diffuse through the metal and collect in the metal structure to form gas bubbles (see paragraph 130). Extrapolation of Calder irradiation data has shown that the magnox can should accommodate dimensional changes caused by this mechanism.

75. In order to carry out detailed examination of large numbers of irradiated civil fuel elements, heavily shielded facilities have been set up in which metallographic examination can be carried out remotely. The civil fuel element examination line which will be used initially for Calder fuel elements is being commissioned. Another line, for the examination of A.G.R. type fuel elements, will be completed by the end of 1961.

76. Development work on improved equipment for the examination of irradiated fuel elements continues. For example, for the successful examination of a suspected failed fuel element it is essential that the point at which the leak occurred can be identified. Equipment has been developed for two stages of inspection; the suspected fuel element is pressurised with nitrous oxide and by using a detector sensitive to this gas, it is established whether or not the fuel element is faulty. If it is faulty, the second stage of inspection locates the leak accurately. The sensitivity of the equipment is such that a hole 1/5000-in. in diameter can be located to within an area of 1/6 sq. in. The small area of can is then cut away and the segment subjected to microscopic examination.

77. The out-of-pile testing of pre-production models of civil fuel elements under reactor conditions of gas flow and temperature has continued. Certain weaknesses of design which allowed the fuel element to move in the gas stream have been eliminated. Measurements of the gas forces which cause some deformation of the fins and splitter plates have been made. This type of out-of-pile testing is essential for the evaluation of both single fuel elements and full-length channels and several reactor channel facilities exist in the consortia and Authority laboratories. Other tests which have been carried out include the simulation of temperature and pressure cycles which would occur during charging operations and the smaller but more frequent temperature cycling which occurs during normal reactor operation. These experiments have been carried out in pressurised furnaces and in facilities built to simulate conditions in a reactor channel. The results indicate that, with severe thermal cycling, magnox cans will crack. There is very little thermal cycling in the Calder reactors and this effect is not a problem in those reactors. Work is in hand to establish the likely degree of thermal cycling in the civil magnox stations and its effect on the life of the fuel.

Pressure Vessel Steels

78. For every type of ferritic steel there is a ductile-brittle transition temperature below which the steel loses its ductility and becomes liable to brittle fracture. For this reason, it is important that reactor pressure vessel steels should possess a good notch ductility and that the ductile-brittle transition temperature of plate of pressure vessel thickness should be accurately determined. To investigate this relationship a 4,000-ton crack testing machine is being installed at the Authority's Culcheth Metallurgical Laboratories.

This machine, which is the largest of its kind in the world, will enable a variety of brittle fracture tests including the Robertson and Wells tests to be carried out on full-scale pressure vessel plate. In this machine, steel plate of up to 4-in. thickness is subjected to a tensile load of 4,000 tons; a bullet is fired from a gun into a tapered hole in the plate and the conditions under which a crack is propagated are studied.

79. Irradiation raises the ductile-brittle transition temperature and the relationship between the increase of the ductile-brittle transition temperature and the integrated fast neutron dose has been confirmed from experiments in Calder and D.M.T.R. For example, a pressure vessel steel which has been subjected to the integrated fast neutron dose equivalent to the lifetime of a civil reactor pressure vessel shows an increase of approximately 80°C in the ductile-brittle transition temperature. The civil magnox reactors will be operated in such a way that the temperature of the whole of the pressure vessel will be kept above the predicted transition temperature when the vessel is pressurised.

80. In addition to work on the development of pressure vessel steels, the Authority also gave advice on the inspection of steels and welds used in the construction of the pressure vessels for the civil power stations. This work has involved the development of novel techniques including the use of a mobile linear accelerator instead of conventional X-ray and gamma ray sources for the radiographic inspection of welds carried out on the reactor site.

Advanced Gas-Cooled Reactors

81. The A.G.R. system forms the next phase of development of the graphite-moderated, gas-cooled reactor concept beyond the magnox system. The main objective is to reduce the capital cost of the reactor installation. This is done by raising the steam temperature and thus the thermal efficiency, and by increasing the heat generation rate from a given size of reactor. It is possible to reach the necessary high temperature by using uranium oxide instead of uranium metal as fuel. To extract the heat at the required high rate, the fuel is subdivided into clusters of small rods. Uranium oxide also has the advantage of standing up to irradiation much better than uranium metal and thus has a longer life. However, the use of uranium oxide involves enriching the fuel in the isotope uranium-235. Further studies carried out during the past year confirm the development potential of the A.G.R. for the generation of electricity at competitive costs.

Windscale A.G.R.

82. Construction of this reactor, a 30 MW(E) experimental prototype of a large civil power station, was virtually complete at the end of the period under review. The containment vessel, the turbine hall and electrical equipment, and the fuel element building were finished. The final stages of graphite laying and fabrication of the pressure circuit had been reached. Testing and commissioning of all equipment before fuel loading will start during August, and criticality is planned to take place towards the end of 1961.

Reactor Physics

83. Work on the neutron physics of the A.G.R. system has been continued over the past year at Winfrith and at Windscale. The main problems are to determine the uranium-235 enrichment required to keep the reactor critical

for the projected life of the fuel elements, to predict the distribution of heat production within the fuel elements so that the coolant supply is adequate, and to ensure that complete control of the reactor can be maintained throughout the fuel life. The latter problems have been studied fully for the magnox system (see paragraphs 65 and 66) but the use of enriched uranium oxide in the form of clusters of thin rods complicates the problems in the A.G.R. The BICEP team has therefore carried out exponential experiments with fuel and graphite in the general form required for typical A.G.R. cores.

84. Considerable attention has been paid to changes in reactivity following changes in temperature of reactor components, because in the A.G.R. system these effects are more important than in the case of magnox reactors (see paragraph 66). In the A.G.R. the plutonium content of fuel at discharge is expected to be substantially higher than in a magnox reactor and the geometry of the lattice is more complicated. The fuel element may be canned in beryllium and supported by a graphite sleeve; both of these materials are moderators. The effects of moderator temperature on reactivity must therefore be dealt with as at least three separate components, each with a different effect on neutrons and a different heat transfer relationship to the fuel. To elucidate some of the basic neutron interaction problems with portions of moderator at different temperatures, graphite stacks with special heating arrangements and neutron detectors have been used at Winfrith.

85. At Windscale, the work has followed up the basic developments at Winfrith and is concerned specifically with the problems as they will arise in the Windscale A.G.R. In this investigation, the actual Windscale A.G.R. fuel elements are studied in sub-critical stacks. The special neutron physics problems of the Windscale A.G.R. arise from its small size, the use of control rods and other absorbers in fuel positions. These factors affect reactivity and power distribution, and were not predictable from the earlier Winfrith experiments. The work in progress will enable commissioning of the Windscale A.G.R. to proceed more rapidly.

86. In the Sixth Annual Report, paragraph 77, reference was made to the HERO zero energy high temperature reactor. This had reached an advanced state of construction at the year's end: the civil engineering work was finished and the pressure vessel installed and pressure tested. It is expected to be made critical at the end of 1961, and, during its early operation, will supplement the information on neutron physics arising from operation of the Windscale A.G.R. As a nuclear simulation of the Windscale A.G.R., HERO will enable much of the neutron physics work to be done without interfering with full power operation of the Windscale A.G.R. Subsequently the HERO programme will determine the detailed physics of the commercial A.G.R. reactors.

Graphite Moderator

87. Much attention has been paid to the reaction between graphite and irradiated carbon dioxide under the Windscale A.G.R. operating conditions. In the absence of irradiation, the graphite/carbon dioxide reaction at the operating temperatures of the A.G.R. is negligible. However, irradiation tests in Calder, DIDO, PLUTO and D.M.T.R. indicate that, under the high irradiation intensities of the A.G.R., the reaction would reach significant proportions. The carbon dioxide molecule breaks down under irradiation. One component

of this dissociation consists probably of atoms of oxygen which are chemically reactive and which attack the graphite; this reaction manifests itself as a loss of weight by the graphite. However, small additions of carbon monoxide to the carbon dioxide coolant reduce this weight loss. There are two possible mechanisms which could explain this. The carbon monoxide may combine with the reactive oxygen atoms before these attack the graphite; also the carbon monoxide which decomposes under irradiation deposits carbon in the pores of the graphite. The second effect has been clearly demonstrated, but some doubt exists on the efficacy of the carbon monoxide in removing the reactive oxygen. The effect of these reactions on the strength of the graphite is the subject of intensive study.

88. Besides the work on methods of inhibiting the graphite/carbon dioxide reaction in reactor grades of graphite, investigations into improved graphites with a low permeability to gases and good resistance to oxidation have proceeded on three major lines. Standard graphites impregnated with materials which block the pores have been manufactured. The second line of development has been concerned with varying the ingredients used in the graphite manufacturing process. Better impregnation characteristics have been obtained in one type of graphite by using a more rigorous control over the constituent materials. Finally, new methods for the production of graphite, including cracking hydrocarbon gases on a carbonised matrix, are under development.

Fuel Elements

89. Further development of the fuel pellet production process is now centred on scaling-up and making it continuous. Irradiation of uranium oxide pellets has continued in PLUTO and D.M.T.R. These experiments have confirmed the remarkable ability of uranium oxide to retain fission product gases up to a reasonably high temperature within its crystal structure, although, as the temperature of the uranium oxide is raised beyond this, the release of fission product gases increases. The design operating temperature of A.G.R. fuel elements has been chosen at such a level that the release of fission product gases within the can is slight. Small-scale tests on A.G.R. fuel elements canned in beryllium and stainless steel have been carried out, and so far they appear to be satisfactory.

90. One of the main concerns about beryllium cans in the past was the formation of helium arising from the transmutation of beryllium when bombarded by neutrons. It was thought that the helium atoms dispersed in the crystal lattice would cause brittleness and after diffusion would collect at grain boundaries, form gas bubbles and cause swelling of the material. However, irradiation tests in PLUTO taken to a burn-up of 7000 MWd(H)/t at 600°C show neither swelling nor increase of embrittlement; at 300°C there was some decrease in ductility. Further tests of the effects of irradiation on the mechanical properties of beryllium are being carried out in D.M.T.R. and in a similar reactor, Hifar, in Australia, and by electron microscope techniques (see paragraph 131).

91. On the other hand, tests on the corrosion of beryllium in carbon dioxide have shown that, under the higher temperature conditions in the A.G.R., more corrosion can take place than can be tolerated in an A.G.R. Until the condition under which beryllium stands up to A.G.R. environment is clearly

understood and can be specified, it has been decided to delay the introduction of a large number of beryllium-canned fuel elements into the Windscale A.G.R. Thus, instead of loading a large proportion of the initial charge of the Windscale A.G.R. in the form of beryllium-clad elements it is now proposed to charge mostly with stainless steel-clad elements. Some beryllium-clad elements will be loaded into the cooler parts of the reactor followed by a gradual loading of beryllium-clad elements into the hotter parts as material of better corrosion resistance is obtained.

92. A stainless steel of better corrosion resistance in carbon dioxide than the standard 18 per cent. chromium/8 per cent. nickel alloy has been developed with the co-operation of the British steel industry. As the wall of the fuel can for the Windscale A.G.R. is only 0.015-in. thick, and because it is hoped to reduce the wall thickness of subsequent designs of fuel element in the interests of neutron economy, the new steel must be completely free from inclusions. The detailed design of the fuel element cluster which must allow for expansion of the individual fuel rods and yet ensure that they cannot vibrate was a major problem to which it is thought that a satisfactory solution has now been found. Irradiation tests of uranium oxide canned in stainless steel have been carried out both in PLUTO and in the Atomic Energy of Canada Limited reactor, N.R.X. Quantity production of the stainless steel-clad fuel elements for the Windscale A.G.R. started during the year (see paragraph 49).

93. Apart from the information on the large-scale statistical testing of fuel elements which will accumulate with operation of the Windscale A.G.R., further tests will be accomplished in the four irradiation loops which have been provided in this reactor. The loops will enable A.G.R. fuel elements to be tested under more stringent conditions than in the reactor itself; thus it will be possible to find out the limits to which such fuel elements can be taken, and to follow the fate of a fuel element as a fault develops. Later, the loops will test more advanced types of A.G.R. fuel elements. As with the tests on civil magnox fuel elements referred to in paragraph 77, it is necessary to subject proposed civil A.G.R. fuel element assemblies to full-scale out-of-pile tests. Accordingly, a large endurance loop to test civil A.G.R. fuel elements under appropriate conditions is now being designed.

Civil A.G.R. Design Study

94. The design study for a large civil A.G.R. referred to in paragraph 86 of the Sixth Annual Report was carried forward in more detail during the past year. In contrast to the natural uranium metal fuelled magnox reactor system, most other types of gas-cooled reactor require enrichment either in the form of uranium-235 or plutonium to achieve criticality. Thus the initial fuel cost for the A.G.R. system is affected by the cost of enrichment.

95. The smaller size of the A.G.R. for a given power output relative to the size of the magnox station makes it possible to provide containment without undue economic penalty. The combination of containment and fission product clean-up plant is under investigation as it may prove possible to advise that the siting restrictions applicable to the magnox stations could be relaxed for the A.G.R. civil stations. Whether such advice can be given depends on the outcome of present investigations.

Fast Reactor Development

96. During the year under review, modifications to the core structure of the Dounreay fast reactor (D.F.R.) were completed in order that more advanced fuel elements components could be tested at high temperature and high flux. The reactor was then restarted at low power, and physics experiments with the modified core arrangement were continued. Good agreement was obtained between theoretical predictions based on results from ZEUS (the zero energy facility for D.F.R.) and the experimental results obtained on the D.F.R. The prediction of critical loading of the reactor was accurate to within one fuel element and reactivity controlled by the control rods was closely forecast. In the course of these physics experiments the reactor has operated at powers up to 1.5 megawatts heat.

97. The D.F.R. is experimental and is intended to develop the technology of fast reactors generally. It is already fulfilling this purpose. In such a novel and complex reactor using new techniques, it was not surprising that certain modifications were needed to obtain full design performance. Valuable operating experience on the operation of liquid metal circuits is being gained even with low power operation of the reactor. For example, it was found difficult to operate the cold trap by-pass circuits for oxide removal, and a new pumped circuit had to be installed to effect the initial clean-up before the originally installed traps could be brought into operation. Later, when running at high coolant velocities, it was found that bubbles of the nitrogen cover gas were entrained in the liquid metal coolant, causing undesirable reactivity changes within the core. The cause for this has been found and the necessary modifications to eliminate this fault were nearly complete at the end of the period under review.

98. The fuel element used in the present charge is of annular cross-section and consists of an enriched uranium alloy in a niobium outer can and a vanadium inner can. Investigations have continued into the problems of corrosion of the niobium and vanadium in the liquid metal coolant. It has been necessary to keep the oxide and hydride content of the liquid metal down to low limits by the use of a two-stage clean-up system to prevent corrosion and embrittlement. The improvement of this fuel element to obtain better performance is under investigation.

99. The D.F.R. chemical reprocessing plant has been commissioned by reprocessing the first charge of fuel elements used for the low power experiments.

100. The next stage in fast reactor development is intended to be a plant from which commercial fast reactors will be designed. Work on this over the past year has been concerned mainly with reactor physics, with the engineering design study and with the development of the fuel element. These studies, which have been aided by parametric surveys using the electronic computers at Risley, have examined the effect of variations in design factors (e.g., coolant flow rate, coolant channel diameter, fuel rod diameter, core length/diameter ratio, breeder thickness), on the cost of power produced. This work has helped to define the important variables.

101. Investigations into the interactions of high-energy neutrons with fast reactor materials have been carried out using particle accelerating machines at Harwell. The zero energy breeder reactor assembly (ZEBRA), designed to

study the reactor physics of large size fast assemblies, is now under construction at Winfrith. Studies of reactor kinetics and investigations into stability and control of fast reactors are being carried out on the D.F.R.

102. Work on the fabrication and irradiation testing of possible fast reactor fuel materials has started. At first the irradiation testing will be done in D.M.T.R., DIDO and PLUTO in close association with development work on fuel fabrication and canning materials being carried out at Dounreay. Later, this irradiation work will also be carried out in D.F.R.

103. The use of certain fuels in the plant mentioned in paragraph 100 would require the introduction of new chemical reprocessing techniques. In addition, because of the high investment of plutonium in a fast reactor, the hold-up of fuel in the reprocessing cycle must be kept to a minimum; thus the reprocessing plant must be able to accept fuel in which the radioactivity has been allowed to decay for a comparatively short period.

High Temperature Gas-Cooled Reactors

104. As described in the Sixth Annual Report, paragraph 93, the H.T.G.C. reactor represents a further development of the gas-cooled, graphite-moderated reactor system and requires a far-reaching extension of the technology. By using helium as coolant and dispensing with metals in the core, gas outlet temperatures can be taken much higher than in the A.G.R. This results in a higher thermodynamic efficiency in converting heat to power and also, a more compact reactor system. The primary fuel would be highly enriched uranium-235. Dispersion of the uranium-235 in graphite and its continuous replacement by uranium-233 generated from thorium is expected to give a very long life to the fuel. Together with the high fuel ratings, this would indicate that low fuel costs should result.

105. The major part of the Authority effort in support of the H.T.G.C. concept has been directed towards the 20 MW(H) Dragon reactor experiment now under construction at Winfrith under the auspices of the Organisation for European Economic Co-operation. Over the five year life of the Dragon project the Authority are likely to contribute almost 60 per cent. of the total financial budget. They are providing, on payment, about the same proportion of the staff engaged on the project, as well as site services. In addition, supporting research work is being carried out by the Authority under contract to the Dragon project. Full details of the progress on the Dragon reactor are contained in the annual report published by O.E.E.C., but progress on the research work carried out by the Authority under contract is given below.

106. The zero-energy reactor ZENITH has been used in support of Dragon. The experiments relating to the effectiveness of the Dragon control rods which were recorded in the Sixth Annual Report, paragraph 99, were completed early in the year. Since June, 1960, experiments with a second core loading have covered a range of core and reflector temperatures up to 630°C and have included measurements of temperature coefficients of reactivity, of power distribution in the core and of conversion factor.

107. A neutron "chopper" has been installed on ZENITH for measurements of neutron energy spectrum. The chopper is essentially a rotating disc which allows burst of neutrons from the reactor to pass down an evacuated flight tube to instruments which measure their time of flight and therefore their

energy. With this apparatus, determination of the distribution of energy among the neutrons is possible, and this, in turn, enables the prediction of nuclear reaction rates for the materials in the reactor, of reactivity and of temperature coefficients of reactivity.

108. Because the fuel elements to be used in the Dragon reactor will be in a graphite container, it is important to understand the mechanism by which fission products may pass through graphite and be taken up by the helium coolant. A study is therefore being made of the way in which both gaseous and non-gaseous fission products diffuse out of graphite crystals and also through the pores of a polycrystalline mass of graphite. The chemical interactions of fission products with graphite are also being studied. Because of the leakage of fission products from the fuel through the graphite container, the helium coolant in the Dragon reactor will be contaminated with volatile fission products and equipment will be required for their continuous removal. A combination of low temperature (-196°C) condensation and adsorption equipment has been recommended and design information has been provided to the Dragon project.

109. At the high operating pressures and temperatures of the coolant in the Dragon reactor, the large gas blower presents special problems of materials of construction, gas bearings and gas seals. A great deal of design and operating information on gas bearings and seals has been accumulated by the Authority, and this information has been made available, under a commercial access agreement, to the suppliers of the main gas circulators for the Dragon reactor.

110. In addition to their work in support of the Dragon project, the Authority are investigating the possible applications of the high temperature gas-cooled reactor systems to both marine propulsion units and to large, land-based power stations. Particular attention will be paid to the fuel cycle. Whereas the fuel cycle proposed for the Dragon reactor starts with uranium-235 and thorium and, in a large reactor, would be theoretically almost self-maintaining through the production of uranium-233 from the thorium, the Authority are extending the investigations to the plutonium/thorium/uranium-233 cycle.

Steam Generating Heavy Water Reactor

111. The Sixth Annual Report, paragraph 102, referred to the review of the status of the S.G.H.W. to be carried out during 1960-61. This assessment was completed on the basis of a detailed design study. The Authority are now engaged on solving some of the key problems. Some of these problems apply equally to other heavy-water-moderated reactors using pressure tube construction. Accordingly a development programme was formulated which will be carried out in collaboration with Atomic Energy of Canada Limited. The Authority have not yet taken a decision whether or not to construct a reactor experiment.

112. As part of the preliminary studies on the S.G.H.W. system, a series of reactor physics experiments was performed in the DIMPLE and LIDO research reactors. These experiments were designed to investigate problems posed by the use of fuel elements consisting of large numbers of thin uranium dioxide rods, and by the presence of two moderating materials (the light water coolant and the heavy water moderator). The effects of a mixture of steam and water in the boiling zone of the reactor were simulated by the use of a mixture of light and heavy water in proportions which gave equivalent nuclear properties.

These experiments confirmed theoretical predictions; more refined calculations of the power which can be extracted from the system are now being developed. Parallel theoretical work on instability arising from reactivity feed-back from the steam voids indicated that stability problems should not limit the power available from the reactor.

113. A series of sub-critical experiments has been planned to obtain further information on reactor physics aspects of the S.G.H.W. power reactor design. In particular, the question of thermal flux peaking will be studied more closely; the variation of neutron spectrum across a lattice cell will be measured to provide a sound basis for the calculation of these flux distributions. The design of one exponential and one sub-critical assembly was started in January, 1961, as part of the development programme.

114. A major mechanical problem in the design of the S.G.H.W. reactor is the jointing of the zirconium pressure tubes which carry the coolant through the core to the stainless steel header. The difficulty arises because zirconium and stainless steel have different coefficients of thermal expansion and yet the joint must maintain its integrity under pressure when it is thermally cycled between room and reactor operating temperature. Joints up to 6-in. in diameter have been developed which retain a low leakage rate when temperature cycled between 15° and 350°C under an internal pressure of 600 p.s.i. More severe conditions of service have been simulated by subjecting the joints to alternate bending moments while undergoing temperature cycling.

Marine Reactors

Submarine

115. The Authority continued to assist the Admiralty on safety aspects of their nuclear submarine projects and to advise on the supporting facilities necessary for operation and maintenance. Arrangements have been made to supply fuel material for future reactor cores, including that for the second nuclear submarine which has now been ordered.

Merchant Ships

116. During the year the Authority concluded their economic studies of reactor systems which are currently being developed and which might be suitable for marine application. These systems include the pressurised water reactor (P.W.R.), boiling water reactor (B.W.R.), and the organic-moderated reactor (O.M.R.) and also the more advanced steam-cooled, heavy-water reactor (S.C.H.W.) and the steam-generating, heavy-water reactor (S.G.H.W.) systems. Findings of these investigations have been reported to the Committee on the Application of Nuclear Power to Marine Purposes. On behalf of this committee, the Authority have also assisted in the examination and assessment of the nuclear designs put forward in the five tender proposals made by industry and submitted to the Ministry of Transport.

117. The work has again emphasised the difficulties of designing and building small power reactors which would be economically competitive with conventional marine power plants. The power of the majority of marine propulsion plants, covering a wide field of merchant ships, lies in the region of 15–30 MW(H). The largest tankers of about 65,000 tons d.w.t., of which several are now coming into operation, use conventional power units up to 65 MW(H).

118. It is apparent that considerable progress in both reactor and fuel element technologies will be required before nuclear power can compete in this field. The reduction in capital cost necessary is considerably greater than can reasonably be envisaged through normal development of any of the existing reactor systems. Further work will be concentrated on more advanced systems which may show a better economic potential such as the high temperature gas-cooled systems.

119. In all this work the Authority have maintained close collaboration with the several marine interests. The Authority have also given assistance to Lloyds Register of Shipping in the formulation of their Provisional Rules for the Classification of Nuclear Ships.

CHAPTER V

GENERAL RESEARCH AND DEVELOPMENT

Introduction

120. The preceding chapter describes progress with the Authority's reactor programme, including the research and development undertaken on problems connected with specific reactor systems. In the present chapter an account is given of some of the research and development carried out by the Authority with somewhat wider objectives. This work falls roughly into three classes. First, there is a broad attack on the scientific problems arising from nuclear power, and especially on those concerned with materials. These problems include, for example, the effects of radiation on materials, the nuclear properties of materials and their effect on reactor performance, the chemical behaviour of materials in a reactor, and engineering problems such as heat transfer.

121. The second class of work fuses into the first and is one stage further removed from application to a particular reactor or plant. It covers fundamental research in those many branches of science of importance to the Authority. Most of this work is carried out in the Research Group, particularly at Harwell, and engages people of the highest academic standards, either as members of the Authority's staff or as visitors from the universities and overseas.

122. The third class of work is concerned with research on isotopes or large sources of radiation. This work is now centred on Wantage but use is made of several of the Authority's reactors, especially those at Harwell.

123. Basic and applied research conducted in support of one industry has value in other industries; new scientific work is always of great interest to the universities. The policy of the Authority is therefore to publish the results of their research, subject only to such limitations as are necessarily imposed by security considerations.

124. It would not be possible, or appropriate, to attempt to describe in the annual report all the research being conducted by the Authority; previous reports have each selected a few items for discussion according to the interest at the time. A similar pattern is followed in this and in the following chapter. A wider appreciation of the research work in progress can be obtained from the Authority's scientific reports and publications. During the past year the

Authority have made publicly available 517 technical reports, and 335 research articles by Authority staff have been published in the scientific journals. The titles of these reports and publications can be found in the monthly lists issued on behalf of the Authority by the Atomic Energy Research Establishment Library. These lists are available on request.

Radiation Damage

125. The study of radiation damage is important in the development of fuel elements, solid moderator materials, and structural components for reactor cores. There are two main ways in which radiation damage in reactor materials is brought about. Firstly, the atoms composing the materials may be displaced from their normal positions by collision with high energy particles. For example, fast neutrons cause damage in structural or moderator materials and the fission fragments, generated in nuclear fission, cause damage in nuclear fuels. The displaced atoms and vacant atomic positions created by irradiation are mobile, and clusters of both types of defect can develop; these defects cause changes in mechanical properties and, in some instances, changes in dimensions (see paragraph 130). Secondly, neutron irradiation causes nuclear reactions in irradiated materials. The most important consequences of these reactions arise from the accumulation of fission product gases in irradiated fuel or of helium in irradiated beryllium; in both cases the inert gas formed causes the material to swell at elevated temperatures or to become brittle at lower temperatures. Some examples of work on irradiation damage are given in the following paragraphs.

126. Recent investigations at Harwell have shown the existence of two types of defect in irradiated copper. In this work, extremely thin films of metal (10^{-5} cm., or less, in thickness) were examined under the electron microscope. This led to the observation of dislocation loops having a diameter of about 10^{-6} cm.; and of what are thought to be clusters of vacant atomic positions about one-quarter of the size of the dislocation loops. This work is being continued in the hope that it will help to reveal the mechanism of irradiation growth in uranium; parallel studies have shown, for the first time, the presence of dislocation loops in irradiated uranium.

127. Studies of the effects of irradiation on graphite have continued using the high flux research reactors DIDO and PLUTO. The results, following the pattern of earlier work on graphite, show an extremely complex behaviour and suggest that the changes produced by irradiation are essentially due to groups of interstitial atoms which congregate if the graphite is heated during or after irradiation. Direct evidence in support of this theory has recently been obtained by using the electron microscope. Thin sections of irradiated graphite crystals have been examined and clusters of what are thought to be groups of interstitial atoms have been observed. These grow when the graphite is heated and they sometimes form regular patterns. A full explanation of these phenomena must await further experiment. A long term objective of these and other related studies is to relate the changes produced in irradiated graphite crystals to the complex phenomena observed in reactor grade graphite.

128. The mechanism of atomic displacements has been studied by observing the paths of atoms ejected from the surfaces of irradiated metallic single crystals. The directions of ejection are found to be parallel with the simple crystal

directions (i.e., those directions within the crystal along which the atoms are most closely packed). This suggests that ejection is brought about by a sequence of atomic collisions passing down a row of closely packed atoms in the crystal. The detailed study of these processes can provide information about the initial configuration of defects and about the forces operating between individual atoms. The intense bombardment required in this and similar work is provided by an ion accelerator which delivers a 100 micro-ampère beam of inert-gas ions at an energy of 0.1 MeV.

129. Growth under irradiation, previously demonstrated in alpha uranium, has now been induced in other anisotropic metals (i.e., metals having different properties in different directions) by irradiation with fission fragments. These new results have assisted theoretical understanding of growth processes. The growth of six metals has been investigated at liquid nitrogen temperature (-196°C) and at 75°C . Magnesium and beryllium showed no growth at either temperature, while growth was observed at both temperatures in zirconium and titanium. The remaining two metals, cadmium and zinc, exhibited growth at the lower temperature only. When growth was observed it was always found to take place in the direction of lowest thermal expansion. This indicated that the local anisotropic expansion in the region of disorder created by the stopping of a fission fragment (the so-called fission spike) may play an important part in the growth process. This view is supported by the observed behaviour of magnesium which is isotropic in its thermal expansion and showed no growth under fission fragment bombardment. Beryllium is thought to have shown no growth because the fission spike formed in the metal under irradiation with fission fragments is small. Other experiments, in which uranium was irradiated with 3 MeV protons at 80°C , also indicate that no growth occurs if the displacement spikes are small. The same techniques are now being used to study the detailed geometry of growth in uranium.

130. The volume increase, or "swelling", of irradiated uranium is due mainly to the gaseous fission products, krypton and xenon. For typical irradiations and temperatures, the volume of these gases at atmospheric pressure might be several times that of the original uranium. It has been shown by electron microscopy that minimum swelling is associated with a very fine dispersion of small bubbles of gas, typically about 0.1 microns in diameter, at a fairly regular spacing of about 0.5 microns. In these circumstances the gas pressure, of the order 1 ton per square inch, is fully restrained by surface tension forces. If the bubbles are more coarsely distributed they may grow, presumably because they can collect gas atoms and vacancies from a larger volume. A point is ultimately reached when surface tension becomes relatively unimportant and the bubbles expand against the creep strength of the metal. Even when the bubble distribution is fine, however, metallographic examination of irradiated material has shown that significant contributions to swelling can result from cracks and ragged holes at grain boundaries which are on a much larger scale than the fine bubbles. Several mechanisms for the initiation of such cracks and holes are being investigated; these include the sweeping-up of bubbles by grain boundary movements and inter-crystalline stresses arising from thermal cycling.

131. The effect of neutron irradiation on the physical and mechanical properties of beryllium, to which reference was made in paragraph 90, is being studied using electron microscope "thin film" techniques. At Harwell the

beryllium is electrolytically thinned; at Windscale cleavage flakes for examination have been produced by fracturing. By these methods bubbles smaller than 10^{-6} cm. have been seen in beryllium irradiated to very high neutron doses. The presence and size of these bubbles depend both on dose and temperature; they are believed to be the main cause of the changes in mechanical properties. For example, the bubbles are thought to be responsible for the decrease in the ductility of beryllium which takes place at high neutron doses. On present evidence, however, neither bubble formation nor loss of ductility appear likely to be substantial in the dose and temperature ranges of current interest in reactors.

Research on Ceramic Fuels

132. In recent years the Authority have become increasingly interested in the use of ceramic fuels in power reactor systems. Most research has so far been done on uranium oxide systems although uranium carbide, mixed uranium and plutonium oxides, and dispersions of mixed oxides in steel (cermets) are also of interest. The first step in the examination of the properties of ceramics and cermets is to establish the conditions required to obtain homogeneous bodies of low porosity. Successful techniques of preparation have been devised by paying close attention to the mechanism of sintering and to the behaviour of the materials concerned over a wide range of experimental conditions. Thus, a novel technique has been developed at Harwell for the preparation of uranium carbide, with low open-pore space, by the "reaction sintering" of uranium and carbon powders; this is based on the retention of liquid uranium for a closely-controlled and limited time. This method is of considerable potential interest since it would replace expensive arc-melting and casting methods. Detailed studies of the effect of the sintering atmosphere and temperature on composition, and on inter-diffusion processes, have permitted the successful preparation of homogeneous and stoichiometric uranium/plutonium dioxide solid solutions of low porosity from the mixed oxide powders; this process is much more convenient than co-precipitation from solutions.

133. Uranium oxide has a low thermal conductivity and, when irradiated in a reactor, steep temperature gradients are set up and cracking takes place. Steeper temperature gradients will cause growth of the oxide grains and, at the extreme, centre melting will occur. At lower temperatures the release of fission product gases from the oxide is controlled by the rate of diffusion through the oxide; if the irradiation conditions are such that grain growth, together with migration of pores, takes place then a much higher fraction of the fission product gases is released. Novel experimental techniques have been devised, in which oxide samples can be subject to large and controlled temperature gradients, to study these structural changes in unirradiated material.

134. An understanding of the properties of single crystals is essential if the behaviour of polycrystalline ceramics is to be understood. A recent achievement has been the production of single crystals of pure uranium dioxide by electrolytic deposition from a solution of uranyl chloride in fused alkali metal chlorides. The physical properties of these crystals, for example their plasticity and structure, are now being studied. Neutron diffraction techniques have been devised to study the positions of the uranium and oxygen atoms in single crystals over a range of oxygen contents and temperatures.

135. Polycrystalline ceramic materials are brittle and so have a poor resistance to thermal shock; the mechanisms which give rise to this undesirable property have been studied. The first experiments have been made on magnesium oxide, a typical brittle ceramic which can readily be prepared in the single crystal form; the experiments will later be extended to uranium compounds. It has been shown that the brittleness of magnesia is due to the presence of surface cracks, less than one thousandth of an inch in length, which grow during deformation and lead to fracture. A typical crystal, if quenched from about 200°C into cold water, will disintegrate. But, if the microcracks are removed by chemical polishing, a crystal can be quenched from 1000°C without even cracking. The next step is to study bi-crystals since the grain boundaries in the polycrystal are sources of weakness. It should eventually be possible to decide whether or not it is practicable to make a more ductile ceramic.

136. Studies of plutonium and uranium oxide systems are also being made at Harwell from the chemical point of view. Both uranium and plutonium dioxide can exist with oxygen contents which differ from the content indicated by the chemical formula (two atoms of oxygen per metal atom) and the precise oxygen content affects many of their physical properties (e.g., ease of sintering, thermal conductivity, ability to retain fission products). Recent work has established the oxygen content of uranium dioxide as a function of oxygen pressure and temperature. A special technique (the measurement of electromotive force at high temperatures) has also been developed to characterise and investigate an oxygen composition range which covers the probable oxygen composition of the uranium dioxide in A.G.R. fuel elements. High temperature X-ray diffraction measurements on plutonium oxide systems have identified two intermediate oxides of plutonium between PuO_2 and Pu_2O_3 . Chemical studies are also being carried out on the behaviour of uranium dioxide under irradiation. These include investigations of crystal lattice deformations using X-ray diffraction, of the chemical changes which take place when uranium oxide is irradiated in a carbon dioxide atmosphere, and of the factors which govern the retention of fission product atoms within the uranium oxide lattice.

Research on Fluidised Beds

137. Fluidisation is a technique of increasing importance in the chemical industry and it is used, for example, in several stages of the process used by the Authority in manufacturing uranium from ore concentrates. The technique involves passing a fluid, either gas or liquid, upwards through a bed of particles. Under these conditions, there is a threshold fluid flow above which the bed lifts and is supported by the fluid. At higher fluid flows the bed itself behaves as a fluid. These so-called fluidised beds provide very good contact between the solid particles and the fluid, have a fairly uniform temperature distribution and have extremely good heat transfer conditions. Although there have been many successful applications of the fluidised bed technique, the underlying theory is ill-defined and successful design is essentially empirical. Investigations at Harwell, which are aimed at establishing the basic theory on a firm basis, have principally been directed towards studying the gas and solid flow patterns in fluidised beds. A variety of experimental techniques, including the use of radioactive tracers, has been employed. One typical investigation was designed to relate the formation and behaviour of bubbles in the fluidised beds to the movements of the gas and solids. These experiments have shown that the roof

of a bubble is robust and that a pocket of gas does not rise through a rain of solid particles, as had been thought in the past. It has also been shown that streams of gas adjacent to bubbles enter through the sides and bottom of the bubbles and mix inside them. This work suggests that bubbles, which have often been thought a disadvantage and a sign of gas channelling, may help to promote gas mixing. Although the stability of bubbles once formed has been demonstrated, a good deal more work remains to be done before the conditions for the formation of bubbles can be defined. The problem of gas distribution in a fluidised bed is one of the most important factors in the design of a successful plant.

138. Fluidised beds can be used to carry out single-stage chemical operations. Many chemical reactions, however, have to be carried out under counter-current conditions which can at present only be achieved with fluidised beds by operating several in cascade. A number of advantages could be gained if a single fluidised bed could be operated to provide the required conditions. It is now known that tapered beds, that is, beds in which the cross-sectional area of the bed increases with height, can provide these conditions. Experimental work is therefore being undertaken to determine the effects of bed height, angle of taper and other factors in relation to the other bed variables (e.g., solid characteristics, gas flow). Among the more important conclusions reached is that there is a minimum bed height below which the advantages of counter-current flow may not be obtained.

Manufacture of Pure Uranium

139. Although the Springfields uranium plant produces material of high quality, the progress of development has created a requirement for uranium of very high purity for research and development work. Electrolytic refining has been used at the Culcheth laboratories for the small-scale production of pure uranium metal. About 200 kilograms of high purity natural uranium have been produced in billet form in addition to enriched material for irradiation testing.

Chemical Processing

140. The chemical processing stages in the preparation of materials for reactors and in the reprocessing of irradiated fuels for the recovery of their fissile content represents a substantial item in fuel costs. Basic research at Harwell in this field has been directed both towards understanding the chemistry involved in the relevant industrial processes and towards developing improvements which may result in future economies. For example, if the beryllium ore, beryl, is roasted with fluorosilicates, beryllium is liberated in a form which can be leached out in water. The processes involved are being given detailed study. In common with many other materials, the physical properties of beryllium are affected by traces of contaminants; the technique of fractional sublimation is therefore being studied as a possible method which might be used to free beryllium from traces of such contaminants. Other processes which are being studied on a laboratory scale include the conversion of solutions of uranyl nitrate to oxides of uranium and, in particular, to uranium dioxide. Uranium dioxide is of interest, both as the raw material for ceramic fuels and as an intermediate in the manufacture of uranium metal or uranium hexafluoride.

141. The conversion of uranium dioxide into uranium tetrafluoride is an important step in the production of uranium metal or hexafluoride. The

chemical reactivity of uranium dioxide particles has been shown to depend critically on the size and geometrical arrangement of the small crystallites forming the oxide. Methods of controlling these factors have been developed which depend upon reacting uranium trioxide with water (to form hydrates) before conversion to uranium dioxide.

142. Investigations of fuel reprocessing are mainly confined to the study of nitric acid solutions of irradiated fuel and solvent extraction separation procedures. Certain radioactive fission products tend to accompany uranium and plutonium in separation processes. Of these ruthenium is of particular importance since it occurs in forms which are difficult to separate from uranium or plutonium. It is also desirable to eliminate ruthenium from the active waste arising from fuel reprocessing, since one of its isotopes, ruthenium-106, has a half-life of one year. Basic research on ruthenium chemistry has led to the identification of the chemical species which are responsible for the similarity in behaviour between ruthenium and uranium. Micro-methods have been evolved to estimate the amounts of these compounds in the highly radioactive solutions derived from irradiated fuels. In conjunction with these studies chemical processes to deal with the difficulties introduced by ruthenium have been developed on the laboratory scale in a form which will enable them to be applied industrially.

Treatment and Disposal of Radioactive Wastes

143. Research at Harwell on radioactive wastes has been directed towards developing methods for separating radioactive constituents from waste solutions and for converting them into a form which can be stored cheaply and safely until the natural process of radioactive decay reduces their activity to harmless levels. The most highly active wastes, such as those deriving from fuel element treatment plants, are evaporated to small volume for storage in stainless steel tanks. Laboratory work over the last few years has shown that it may be possible to store these materials more conveniently by incorporating them into insoluble glass-like solids. The method used was to convert nitric acid solutions of fission products into glass by heating the solution, as a slurry, with silica and borax. More recent experimental work has demonstrated that this method will produce satisfactory glass-like materials on the scale which would be required in an operating plant. A pilot plant study (1,000 curies per batch) is now being carried out to obtain data on which the design of a full-scale plant could be based.

144. The evaporation method of reducing the bulk of material to be stored is so expensive that it is only used for very highly active wastes; chemical precipitation methods, or methods involving the use of ion-exchange, are much cheaper for medium and low-level wastes. Ion-exchange methods have been studied for some years at Harwell; their use avoids the production of chemical sludges and gives a final concentrate of small volume for storage or disposal. A development programme, carried out with the assistance of industry, has shown sufficient promise to justify continuing the development to the plant stage. However, the ion-exchange method cannot be used on a fully continuous basis since the ion-exchange material has to be chemically regenerated from time to time. Laboratory studies of the related technique of electro-deionisation (in which ion-exchange materials are incorporated into an electrolytic cell) have shown that higher concentration factors may be achieved using this method.

Electro-deionisation also offers the possibility of continuous operation, since the ion-exchange material can be continuously regenerated, without adding chemicals, by passing an electric current at right-angles to the solution flow. A small pilot scale cell has been successfully operated at solution flows of 50 gallons per hour. This has shown that electro-deionisation is particularly suitable for treating solutions which have low salt contents. The work is being continued using cells capable of dealing with solution flows of up to 500 gallons per hour.

Analytical Research

145. New materials and alloys, or even new uses for older materials, often give rise to formidable new problems in analytical chemistry. For example, beryllium is a toxic material and, when it is used in laboratories and workshops, the amount in the air must be carefully controlled. A new method of automatic monitoring for beryllium has been developed at Woolwich in which a stream of the air to be examined is passed between platinum metal electrodes. A spark discharge passed between the electrodes excites the emission of light with wavelengths characteristic of any materials suspended in the air. The light characteristic of beryllium can then be isolated and detected photo-electrically to give a reliable analysis of the beryllium content within a minute.

146. Mass spectrometry techniques for the precise measurement of the relative abundance of uranium isotopes in uranium have been developed in the Capenhurst laboratories and used to measure the uranium-235 concentration in uranium ores of interest to the Authority. The results have confirmed that there is no detectable variation in isotopic abundance between the different ores. The observed uranium-235 concentration is in all cases within 0.05 per cent. of the mean value. The concentration of uranium-235 in any enriched sample is frequently expressed in terms of the concentration of uranium-235 in naturally occurring uranium; for accounting and specification purposes it is essential to know the concentration in natural uranium to a higher accuracy than is necessary for day-to-day measurements. The same mass spectrometry techniques have therefore been used to establish the absolute value of the uranium-235 concentration in natural uranium by comparing it with the uranium-235 concentration in a carefully prepared blend made from virtually pure uranium-235 and uranium-238. The concentration of uranium-235 in naturally occurring uranium was found to be 0.7196 ± 0.0007 per cent. molar concentration, in agreement with the value used in the United States.

147. The isotope dilution method has been applied at Harwell to make high-precision measurement of uranium-235 contents. In this method, a mass spectrometer is used to measure the change in the isotopic abundance (i.e., relative concentration of isotopic species in an element) when a standard sample (containing an element with known isotopic abundance) is mixed with the sample being analysed (containing the same element but having a different isotopic abundance). This change provided the required analysis.

Heat Transfer Studies

148. Improved techniques for removing heat are of great potential importance in reactor or chemical plant design. A promising technique is being investigated at Harwell in which wet steam (i.e., steam containing a proportion

of liquid water) is used as the coolant. If the water in the steam is present as a film or spray very high heat removal efficiencies can be obtained, but the efficiency falls if the steam becomes too dry. Heat transfer experiments at relatively low pressures have been in progress for some time to try to correlate the steam conditions (such as the degree of dryness) with the heat removal characteristics and to determine the limiting conditions. These experiments have shown promise and are being extended to higher pressures. Parallel experiments on the behaviour and stability of films of water have been carried out using air and water under conditions of flow which simulate the steam-water system.

Criticality

149. Research on the physics of criticality problems of importance in plant design, and in the transport and storage of fissile materials, has continued at the Atomic Weapons Research Establishment at Aldermaston and at Dounreay; work has also continued at Harwell on the chemical engineering application of this physics information to plant design. For example, two experimental programmes are in progress at Aldermaston in support of criticality safety assessment. In the first programme, the variation of critical mass is being studied under conditions where knowledge is still imperfect; compacts of enriched uranium dioxide and wax are used to provide varying density and moderator conditions. In the second programme, the way in which arrays of near-critical assemblies interact with each other is being investigated.

Nuclear Physics Research

150. The Sixth Annual Report, paragraphs 113-129, described the general lines of fundamental nuclear physics work at Harwell and at Aldermaston in some detail. These experimental and theoretical studies have continued during the past year.

151. One of the most interesting results obtained during the year was the discovery, at Aldermaston, of a new isotope of carbon, namely, carbon-16. The isotope was formed in the bombardment of a carbon-14 target with a beam of tritium ions (hydrogen nuclei having a mass of three units). The mass of the isotope formed was measured indirectly from measurements of the energies of the protons emitted in the reaction. On experimental and theoretical grounds, it is thought that carbon-16 decays by forming nitrogen-16 which then decays by the emission of a neutron.

Solid State Physics

152. Over the last 30 years, understanding of the nature of the solid state has increased very greatly. For example, the way in which crystals deform under stress is now understood in terms of dislocation processes taking place among the atoms composing the crystals. This discovery has led to a much improved understanding of the mechanical properties of metals and alloys and has changed the way in which these materials are regarded by the engineer and by the metallurgist. The discovery of transistors, and other applications of semi-conducting materials, has had a similarly great influence. A Solid State Physics Division was formed at Harwell in September, 1960, to study the basic physics of materials, particularly transition metals, their alloys and compounds, in a programme designed to make the best possible use of the Harwell research

reactors. The work being done divides into two main categories; firstly, experiments involving the use of neutron diffraction as a tool, and secondly, experiments concerned with the measurement of the general physical properties of the solids.

153. Neutron diffraction can be valuable in studying materials which have strong magnetic properties, e.g., recent experiments at Harwell have demonstrated that metallic iron in the ferromagnetic state can support spin waves with properties closely similar to those which had been predicted for electrons described by a Heitler-London model. This result suggests that the conventional band model of electrons in transition metals is not wholly adequate, at least for iron. Corresponding work on nickel is now in progress and promises to show some distinction between these two ferromagnetic metals. Complicated magnetic structures have been observed in many materials, even, for example, in the pure metal chromium, thus demonstrating that current ideas on electrons in solids, even in simple solids, need some attention.

154. The studies of neutron diffraction properties are supported by several investigations using techniques which allow the magnetic moments of individual atoms in solids to be determined. These techniques include nuclear magnetic resonance measurements and Mössbauer resonant gamma-ray absorptions. Recent experiments have shown that the behaviour of alloys of ferromagnetic elements is far more complex than might be thought from an examination of the macroscopic magnetic properties alone. Further studies have been carried out on weakly magnetic materials, such as the vanadium-based alloys, which have shown that the electronic structure of the light transition elements is far from the simple idealised model usually employed to discuss them.

DAPHNE Reactor

155. The reactors DIDO and PLUTO are expensive pieces of equipment and it is important to make the best possible use of available experimental time and space in them. However, it is difficult to calculate the effects of loading different kinds of experimental equipment into the reactors, and at present these effects often have to be determined by preliminary experiments during which the reactor concerned must be operated at low power. In order to avoid this loss of high power operating time, a zero energy reactor DAPHNE is being designed and built at Harwell having a core which simulates the DIDO/PLUTO core and using enriched uranium fuel and heavy water moderator. DAPHNE will be used, for example, to measure the effect on reactivity of particular experiments, the interaction of one experiment with another and the effect of fuel disposition and burn-up.

HERALD Reactor

156. A new research reactor, HERALD, was commissioned at Aldermaston during 1960. This reactor was operated continuously at a power of 1 MW(H) during the year for research with neutrons and for the production of special isotopes. In addition, HERALD was used to measure neutron data of importance in the design of civil reactors. HERALD uses enriched uranium as fuel and ordinary water as both coolant and moderator. A zero-energy version, named HORACE, has been used throughout the year to provide experimental data on the nuclear characteristics of HERALD fuel arrangements.

VERA Reactor

157. A new low power reactor VERA became critical at Aldermaston on 22nd February, 1961. It is being used in reactor physics experiments to improve nuclear data and methods of calculation for fast critical assemblies. More information on these systems is required for many problems relating to the safety of storage and processing of fissile materials, and for the fast reactor development programme.

Radio and Nuclear Chemistry

158. The theory of nuclear fission is still far from complete and further progress in understanding the details of the process depends mainly upon the accumulation of more experimental information. The fission process is being studied in detail at Harwell in a programme of work which was started a few years ago. For example, the way in which different fission fragments penetrate aluminium foils have been studied. This work has shown that if a nucleus undergoes nuclear fission then more kinetic energy is released when the fragments are of unequal size than when they are equal. Another experiment has been carried out to test a theory which suggests that the ratio of the yield of symmetrical to asymmetrical fragments in the fission reaction depends in a special way upon the type of interaction between the fissioning nucleus and the incident neutron. The ratio has been studied for incident neutrons with energies in the range 60–600 KeV; the results show that the yield ratio does change but not in the way predicted. Radiochemical studies of the nuclear fission process have been started at Aldermaston. Novel apparatus has been built to permit rapid chemical separations and purifications to be carried out according to a pre-set programme. The times for separation and purification vary between 10 seconds and a minute. These chemical techniques are now being applied to study the fission process.

Reactor Physics Research

159. Reactor physics research is aimed at understanding the basic mechanisms of the neutron chain reaction. The problems are to establish the conditions under which a reactor will operate, to find out how much heat will be generated in each part of an operating reactor, to discover how to control it and to determine the character and intensity of the radiations emitted from the reactor core. The data required are obtained by making direct measurements on "models" of the cores of possible reactors. These models may be made just large enough to sustain a nuclear chain reaction (critical assembly) or they may be smaller than this so that an external source of neutrons is needed to drive them (sub-critical assembly).

160. In addition to the work of this kind reported in the previous chapter (paragraphs 66–67, 83–86, 101 and 106) experiments have been carried out at Winfrith on the characteristics of plutonium/water and uranium oxide/organic liquid systems using two sub-critical assemblies (HELEN I and HELEN II).

161. A nuclear reactor operating at a very low power level is sensitive to slight changes in operating conditions and accurate reactor core data can be obtained by oscillating samples of material through the core. This oscillator technique has been used at Winfrith to obtain information on the way in which

the Doppler temperature coefficient of uranium and thorium varies with the temperature and geometry of the fuel elements. This information is of considerable value in reactor safety and control assessments. The reactor NERO, which was transferred from Harwell to Winfrith during the year, has now been fitted with oscillator equipment; the reactor went critical at Winfrith in November, 1960. A new oscillator reactor, called HECTOR, is under construction at Winfrith. In this reactor, the samples will be studied under conditions which are closely similar to those expected in a power reactor.

162. An important problem, common to all reactors, is that of knowing the precise speed distribution among the neutrons in a reactor (the neutron spectrum). In a thermal reactor, the nature of the spectrum depends critically on the way in which energy is exchanged between the neutrons and the moderator atoms. Methods for obtaining this information have been developed at Harwell but larger neutron fluxes are required than are available from the DIDO and PLUTO reactors. Accordingly, experiments are being carried out, in co-operation with Atomic Energy of Canada Limited and the United States Atomic Energy Commission, in the NRU reactor at the Chalk River laboratories. Graphite, ordinary water, and heavy water moderators have been investigated so far and, in some cases, measurements have been made at several temperatures. In a supplementary study, the interaction between neutrons and various crystal lattices and liquid systems is being studied. At the same time, direct measurements of neutron spectra are being made on sub-critical assemblies at Harwell and Winfrith. The arrays studied so far include hot and cold graphite/natural uranium lattices, water/natural uranium lattices and plutonium/graphite lattices. The NESTOR neutron-source reactor, which came into operation at Winfrith on the 13th March, 1961, will permit an increase in the scope of the Winfrith work in this field.

163. Data required for the design of radiation shields is obtained by making direct measurements on models of parts of reactor shields. Radiation characteristic of typical reactor cores is injected into the models from the LIDO reactor at Harwell. Measurements made under operating conditions on the shields of the Calder reactors have confirmed that the effectiveness of bulk concrete shields can now be predicted with satisfactory accuracy. Further work on the problem of radiation streaming through cooling gas ducts and fuel charge tubes is being done using LIDO, one of the Calder reactors and one of the Chapelcross reactors. Some progress has been made towards predicting the intensity and spectrum of the relatively fast neutrons which cause radiation damage, for example, in the pressure vessel.

164. The characteristics of any reactor system can, in principle, be predicted if the required basic nuclear data (e.g., neutron cross-sections) are known with sufficient accuracy over a wide range of neutron speeds and if large computing machines are available for carrying out the highly complex calculations required. Some success has been achieved in predicting reactor characteristics in this way and this approach is expected to assume increasing importance in future. Continued improvements have been made in the precision and reliability of neutron cross-section measurements. Fast neutron data, of particular importance to radiation damage studies, are being obtained from work with the Van de Graaff and tandem accelerators at Harwell and at Aldermaston.

Radioisotope Applications

165. A special proportional counter, with a very thin window, has been developed at the Wantage Research Laboratory for the measurement of characteristic X-rays emitted by elements in the range aluminium to iron. This instrument has been used successfully to measure one-micron anodic films on aluminium, thin pressure-sensitive coatings on special paper backings and the percentage of sulphur in gas containing up to 5 per cent. of sulphur dioxide. The characteristic X-rays were excited by using a tritium-titanium source.

166. The Isotope Advisory Service at Wantage has continued to assist firms to solve industrial problems with the aid of radioisotope techniques. Using standard equipment to detect characteristic X-radiation, it has proved feasible to measure the thickness of gold paint on titanium, the thickness of zinc plating on steel and the thickness of silver plating on copper wire. For example, the thickness of gold paint could be measured to an accuracy of about 2 per cent., in about 10 seconds, for thicknesses in the range 0-50 millionths of an inch. The methods employed are being further developed for routine application.

Applications of Large Radiation Sources

167. Commissioning of the Wantage Research Laboratory pilot plant for irradiating packages of materials with gamma rays was completed in December, 1960, by which time several thousand cubic feet of material had been processed. Contracts for the use of the plant have been let to a number of firms; the bulk of the material being processed is disposable medical equipment. The radiation source has recently been increased from 130,000 curies of cobalt-60 to 270,000 curies. The shielding provided will accommodate 500,000 curies thus giving room for further expansion of capacity.

168. Medical support for radiation sterilisation has increased during the year and the use of gamma-radiation sterilisation for disposable medical equipment, such as hypodermic needles and plastic syringes, is expanding rapidly. The number of gamma-radiation sterilised lines that are commercially available in quantity has increased from two or three to more than a dozen during the year. In common with other sterilisation processes, gamma irradiation does not impart immunity from further infection and, to obtain maximum advantage, the items must be individually packaged. Industrial firms have mastered the consequent packaging problems for a wide range of products. Extended trials on the sterilisation of dressings are going forward successfully.

169. The use of radiation to eliminate salmonella food poisoning organisms from various food products is being investigated. A high degree of inactivation of salmonella in frozen whole egg and desiccated coconut can be achieved using relatively low radiation doses. Extensive tests are being carried out on the quality of the treated product at Wantage, by the British Baking Industries' Research Association, and by various industrial users. Most results indicate no quality change but there are indications of flavour changes which require further investigation.

Electronics Research

170. A good deal of the Authority's research depends on the detection, identification and measurement of the various types of radiation involved in nuclear energy work. The techniques of electronics are essential for these

purposes. Much basic research at Harwell is therefore directed towards improving existing electronic techniques or developing new ones. For example, the electrical and optical effects produced by individual nuclear particles as they pass through matter are being studied, paying special attention to the possibility of exploiting these effects. Similarly, means for the measurement of time intervals between one thousandth and less than one thousandth of a millionth part of a second are being investigated. In nuclear physics work one of the major problems is the sorting and classification of the electrical pulses generated in measurements of nuclear disintegrations produced by particles from accelerators. Two typical current examples are the development of a barrier-grid tube system, used as an intermediate store, for studying many neutron energies simultaneously in a single burst of neutrons passing down a time-of-flight spectrometer, and the work on scintillation track imaging employing filamentary scintillators and image intensifiers.

171. Work has continued at Winfrith on the development of improved automatic control systems for reactors and on improved reactor instrumentation techniques. For example, faster and more reliable switching devices for reactor control and safety circuits have been studied. These use transistor and magnetic cores in place of thermionic valves and electromagnetic relays. Several types of instrument are in service and an automatic control system, using transistors and magnetic cores, has operated successfully in the laboratory.

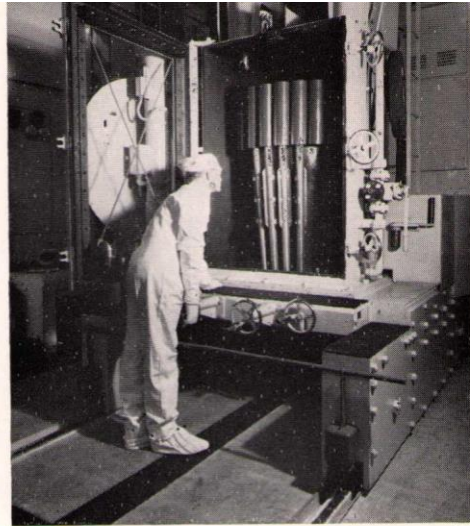
CHAPTER VI

CONTROLLED THERMONUCLEAR RESEARCH

General Prospects

172. The prospects of eventually achieving magnetic containment of plasma for thermonuclear power generation remain difficult to assess because the conditions for obtaining stable confinement are insufficiently understood. Experimental results suggest that the guiding concepts of hydromagnetic theory give too limited criteria by which to obtain understanding of the phenomena observed. Theoretically stable configurations, such as the stellarator and hard-core geometries, have exhibited unexpected fluctuations, whereas spectacularly good containment has been obtained in mirror geometry at the University of California Livermore Laboratories, indicating a stability or quasi-stability which was not predicted by simple hydromagnetic theory. Observations on the containment of plasma in ZETA emphasise the importance of particle density, not specifically included in hydromagnetic stability theory. The main purpose of the present work of the Authority is to clarify understanding of stability phenomena. Although many problems in fusion research can be studied by small or medium-sized experiments, it seems unlikely that a full understanding will be achieved without further large scale experiments. Such assemblies will no doubt be tried in various parts of the world. They must be regarded as experiments and not as prototype reactors of the kind made familiar by contemporary fission reactor development.

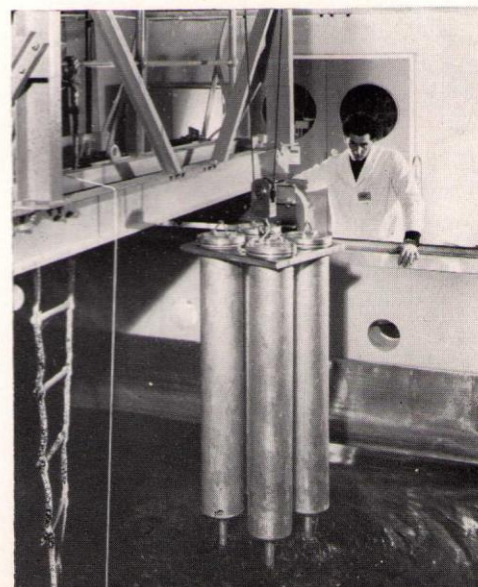
CHAPELCROSS. A fuel-element basket on the charge-discharge floor of No. 4 reactor at Chapelcross plutonium and nuclear power producing station. The Authority's eight reactors (at Calder Hall and Chapelcross) supply more than 2,000 million units of electricity annually to the national grid. The new fuel element factory at Springfields was brought into full-scale production during 1960-61.

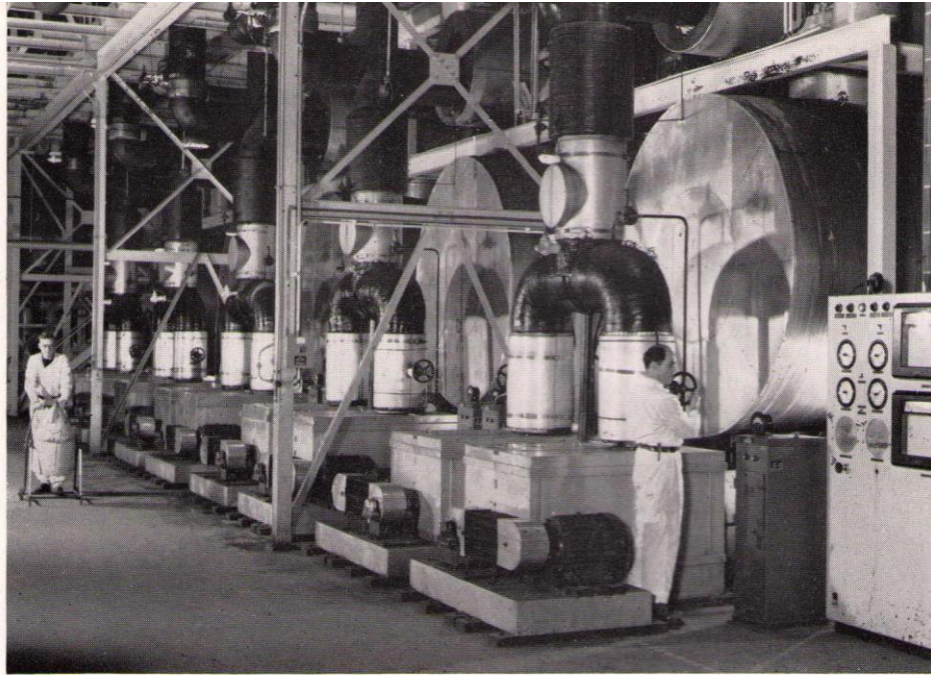


SEISMIC TESTS. The Weapons Group has been studying problems raised by the Geneva Conference of Experts in their examination of methods of detecting violations of a possible agreement on the suspension of nuclear tests. The photograph shows the setting up of a measuring instrument in a Cornish tin-mine, to record the seismic waves resulting from the detonation of depth charges (of conventional explosive) in the English Channel.



IRRADIATION. Irradiation can be used to sterilise disposable medical equipment such as hypodermic needles and plastic syringes. Research or pilot scale trials of this technique are carried out in a fuel element cooling pond at Harwell. The photograph shows water-tight cylinders containing samples to be irradiated.

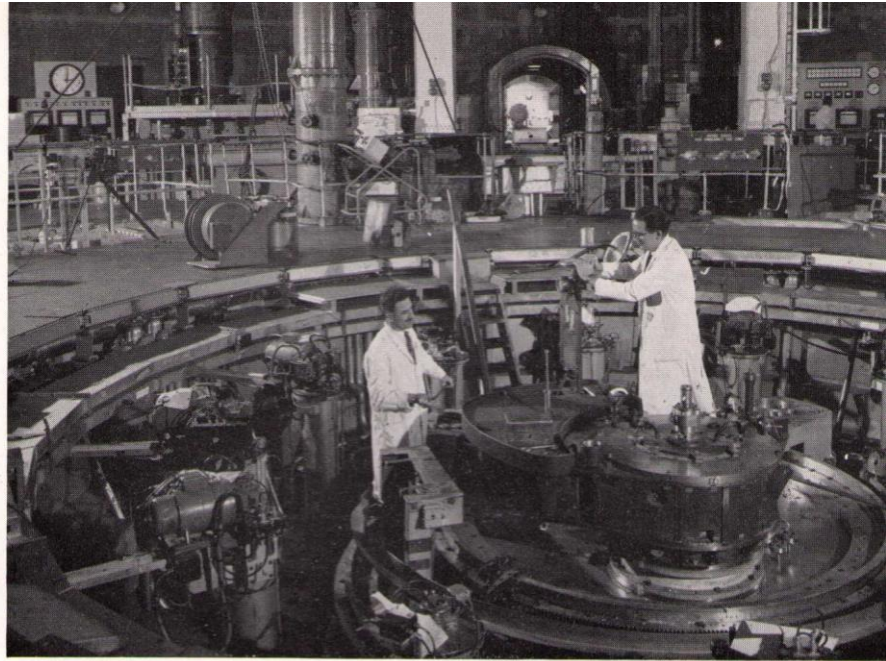




CAPENHURST. The gaseous diffusion plant at Capenhurst is one of the largest single-roof factories in Europe. Here uranium-235 (in the form of hexafluoride) is concentrated from natural uranium so that enriched fuel can be formed, e.g. for the fuel elements of fast reactors and for test reactors such as DIDO and PLUTO.

ADVANCED GAS-COOLED REACTOR. A general view (February, 1961) of the experimental A.G.R., now nearing completion at Windscale. It is planned to begin operation towards the end of 1961. The main objective of the A.G.R. is to reduce the capital cost of the reactor installation.



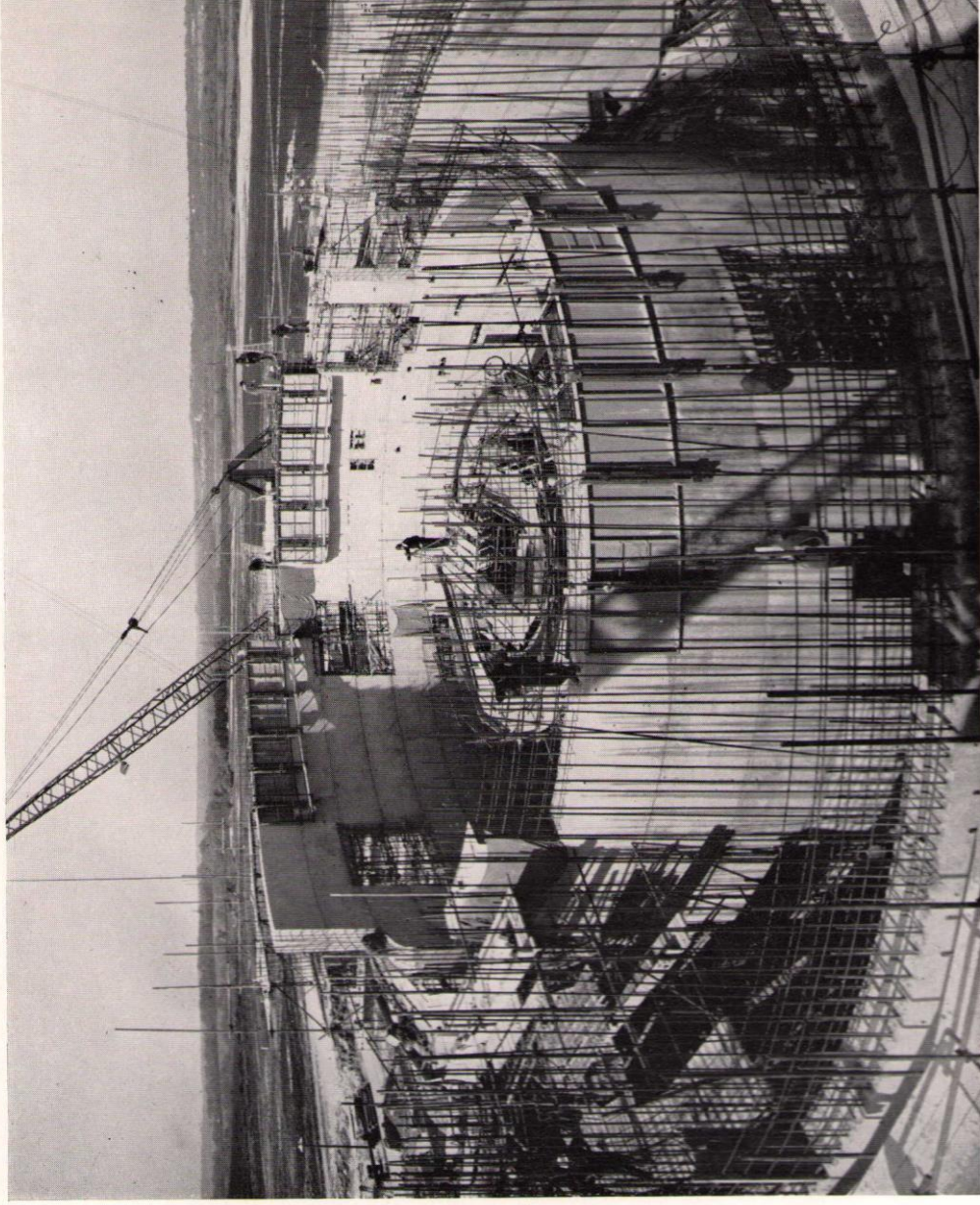


DOUNREAY. A view of the top of the fast reactor at Dounreay while modification were in progress to eliminate problems of gas entrainment in the liquid metal coolant. The fast reactor system is one on which the Authority are working with a view to commercial application in the 1970's.

HARWELL. Among distinguished visitors to Authority establishments during 1960-61 was Her Majesty the Queen of the Hellenes seen here at Harwell with Sir William Penney and Dr. E. B. Paul, of Nuclear Physics Division. Sir William is now Deputy Chairman of the Authority.



DRAGON. The Dragon reactor under construction (April, 1961) at Winfrith. This experimental high temperature gas-cooled reactor is being designed by an international team under the auspices of O.E.E.C.



Containment Studies

173. The configuration of the containing magnetic field is an important variable at the command of the experimenter. Only elementary shapes have so far been considered of which the principal ones are (a) stabilised pinch, (b) hard-core geometry, (c) stellarator geometry, (d) mirror geometry and (e) cusped geometry. All of these, with the exception of (c), are under active study by the Authority. All are theoretically stable under certain conditions but only the mirror geometry (in experiments conducted at Livermore) has yielded observations consistent with stability.

Stabilised Pinch

174. Work has continued on the containment properties of the toroidal pinched discharge in ZETA, the ring-shaped apparatus in which deuterium gas is heated to high temperatures by an electric discharge. Improvements mentioned in the Sixth Annual Report, paragraph 185, have been used to study energy losses and other phenomena over a wide range of plasma densities. Spectroscopic measurements, supported by detailed analysis of the energy balance of the plasma, have enabled the average time the ions are contained in the discharge to be measured and it has been shown that, at low plasma densities, the loss of particles to the walls accounts for most of the loss of energy from the discharge. As the discharge proceeds there is a net decrease in the number of particles in the plasma and the discharge terminates abruptly when the number of particles falls to about 6×10^{16} per cm length of discharge. At this density the remaining energy in the plasma appears to be carried to the walls by fast electrons. At higher plasma densities the containment time of the particles is longer and most of the energy put into the discharge is lost by radiation from impurity ions in the plasma so that the electron temperature remains low. It is possible that the enhanced containment time may not be maintained if this temperature is raised.

175. An important condition for hydromagnetic stability is that the current should flow in a thin skin on the surface of the column of plasma. At low pressures, such as those used in early work on ZETA, this skin current could not be obtained. Measurements of the magnetic fields have now been made at higher pressures and good skin currents have been found. These skin currents often disappear more rapidly than expected, particularly at high discharge powers.

176. Experiments are proceeding at Harwell on straight tubes incorporating fast-rising pinch discharges with trapped axial magnetic fields. A new apparatus has been brought into operation, which is longer than any used hitherto, as part of a further assessment of the effects of electrodes on phenomena occurring in the tubes. The small-scale instabilities observed appear to be independent of any phenomena occurring at the electrodes of the tube.

177. The Intermediate Current Stability Experiment (described in the Sixth Annual Report, paragraphs 187–188) designed to investigate the stability of an improved pinch configuration, has not been continued because design studies showed that it would take more effort and resources than were justified for a single experiment in the present state of knowledge of plasma physics.

Hard-core Geometry

178. In this cylindrical geometry, the hot plasma is confined between an external magnetic field and an azimuthal field generated by a current flowing

through a central conductor and returning through the plasma. FIG. I shows a diagrammatic representation of a hard-core apparatus at Harwell. The configuration is theoretically stable. Nevertheless, fluctuations have been detected which are smaller than those observed in the theoretically unstable linear pinch but which are apparently of the same type. The cause of the fluctuations has not been identified and further experiments are being devised. A toroidal version of the hard-core geometry is being built, under an Authority contract, at the research laboratories of Associated Electrical Industries Limited at Aldermaston.

Mirror Geometry

179. The containment in this geometry is not complete because plasma leaks out at the ends of the "magnetic bottle". It does so relatively slowly because the magnetic fields are enhanced there to form so-called magnetic mirrors which reflect particles moving in most but not all directions. The problems associated with injecting the plasma into such a machine are being investigated. Experiments have begun at Harwell on a method of achieving long path lengths in mirror machines by space modulation of the magnetic field. Particles are injected axially at such a velocity that they experience radial acceleration, at their own cyclotron frequency, due to the modulations. The principle of this method, first demonstrated by Russian workers, has been tested with an electron beam model. An experiment using ions is under construction.

180. The Phoenix programme at the Atomic Weapons Research Establishment also aims to build up a clean, dense plasma with high ion temperature, in a mirror machine by high energy injection. In this case, the externally injected particles are neutral atoms and are trapped within the mirror machine by being ionised there. FIG. II shows the principal characteristics of this machine. In the latest Phoenix proposal, a low density electron stream, or alternatively the residual gas, will be used to ionise the atoms.

181. Accurate information on the various interactions that occur between beams of fast particles and the common gases has been sought as a necessary step in understanding and improving mirror devices and a group at A.W.R.E., Aldermaston, has been investigating these: also, particular attention has been paid to the dissociation of molecular and atomic ions by electric fields.

Cusped Geometry

182. Theoretically this configuration is much less liable to instability than the pinch geometry, although containment is not complete because the lines of force are not closed within the container and plasma tends to leak out of the cusp apices. An apparatus for studying containment in cusp geometry has been built and brought into operation. FIG. III illustrates the method of operation. Plasma, obtained by shock pre-heating and pre-ionisation, is compressed by fast-rising cusped-shaped fields. Measurements on the stability and leakage properties have just begun.

Radio frequency confinement

183. Studies of plasma containment by magnetic fields oscillating at radio frequencies have been made at Harwell. Preliminary studies at the Services Electronics Research Laboratory, under an A.W.R.E. contract, have shown R.F. cavity resonators to be efficient in ionising a gas, but have given no evidence of containment.

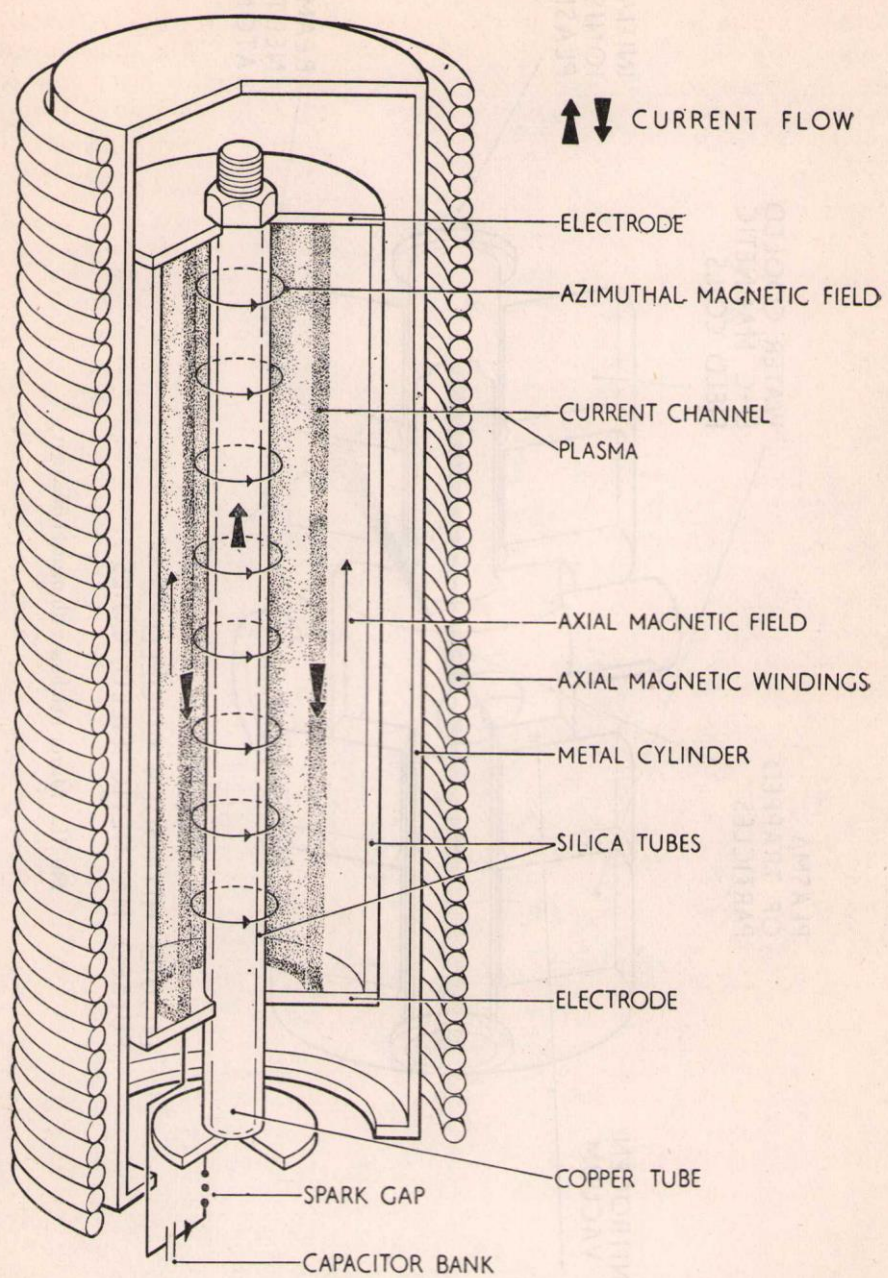


FIG. I. Hard-core geometry

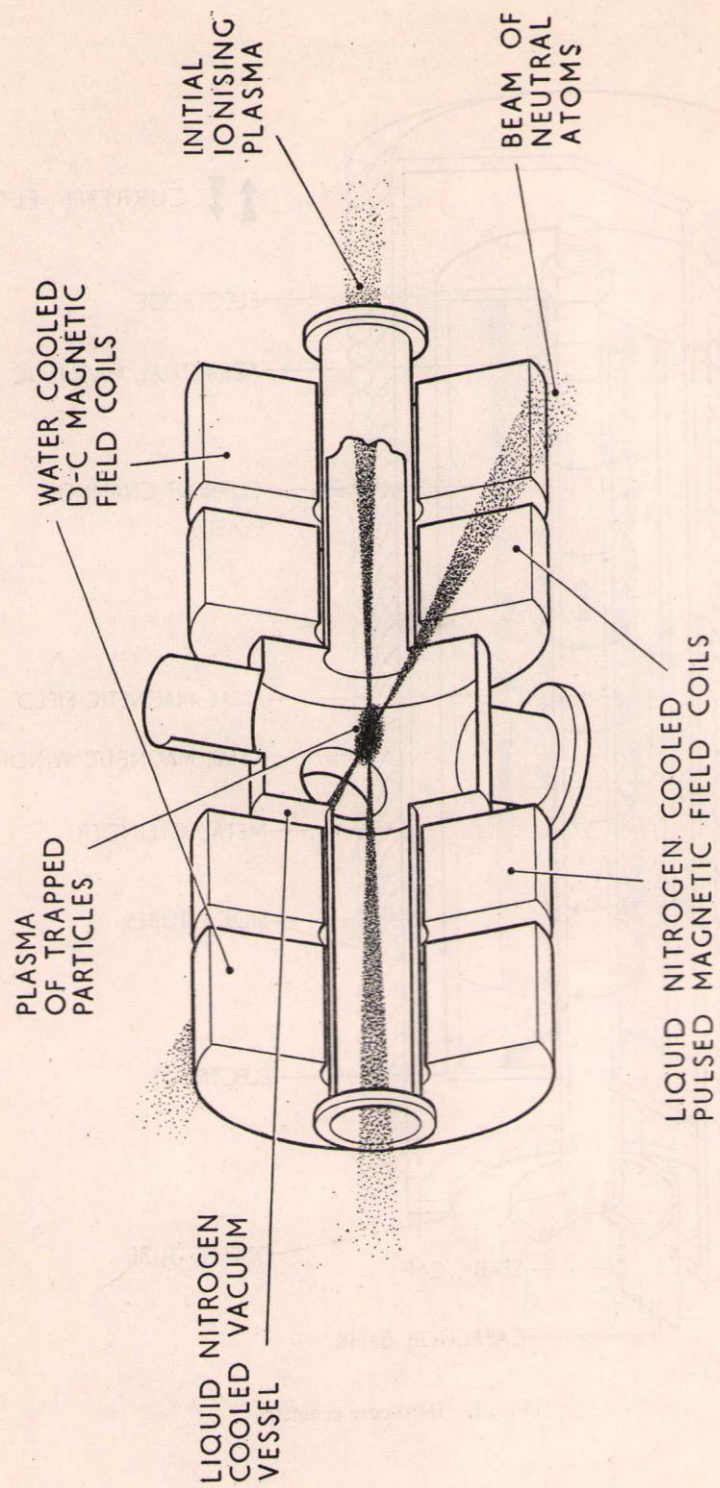
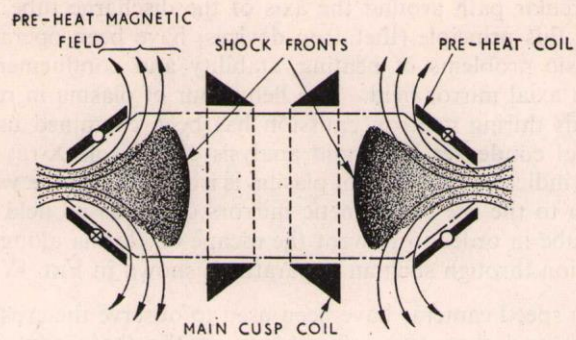
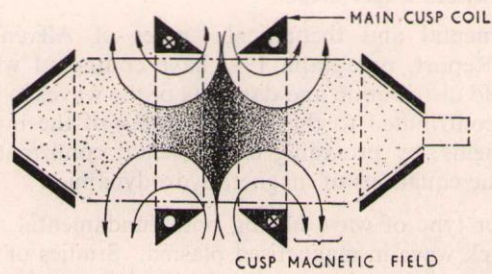


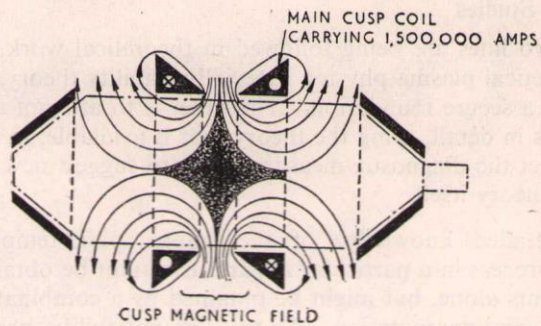
FIG. II. Mirror machine with neutral injection



Stage 1. Pre-heating by shock waves



Stage 2. Collision of shock waves and beginning of main compression



Stage 3. Final compression of plasma

FIG. III. Cusped geometry containment

Theta pinch

184. The Sixth Annual Report, paragraphs 199–201, described results obtained at A.W.R.E. on the study of theta-mode discharges in which current flows in a circular path around the axis of the discharge tube. A number of devices using this principle (thetatron devices) have been operated in order to study the basic problems of heating, stability and confinement of a plasma trapped in an axial mirror field. The behaviour of plasma in reversed trapped magnetic fields during neutron emission has been examined using a new and more powerful condenser bank and analysis of the soft X-ray emission from the discharge indicates that the hot plasma is isolated from the walls. Attention is being given to the use of magnetic mirrors of increased field strength at the ends of the tube in order to prevent the escape of plasma along the axis of the tube. A section through such an apparatus is shown in FIG. IV.

185. High speed cameras have been used to observe the cross-sectional area of the plasma and thus give information on the theta containment. These observations have shown that a high degree of containment can be achieved over a narrow range of pressures.

Other Plasma Physics Experiments

186. Experimental and theoretical studies of Alfvén wave propagation (Sixth Annual Report, paragraph 191) have continued with investigations of propagation, field distribution and damping of the waves in a long, straight tube. The work has contributed to the understanding of the interaction of plasmas and magnetic fields, by providing experimental confirmation of some of the predictions of the equations of magnetohydrodynamics.

187. Another type of wave having both fundamental and practical importance is the shock wave in magnetised plasma. Studies of shock wave heating and shock phenomena have been made with straight and toroidal pinch discharge apparatus. Further experiments are being designed to elucidate the interactions within the shock front in the magnetised plasma.

Theoretical Studies

188. Two lines are being followed in theoretical work. One is to develop basic theoretical plasma physics, especially stability theory, in order to give the predictions a secure foundation. The other is to attempt to analyse individual experiments in detail, using the theory that is available, in order to supplement and interpret the diagnostic measurements, to suggest new experiments, and to check the theory itself.

189. Detailed knowledge of the whole spatio-temporal course of the discharge process in a particular apparatus cannot be obtained from diagnostic measurements alone, but might be obtained by a combination of measurement with theory and computation. To test this possibility, programmes have been written for the I.B.M. 7090 computer at A.W.R.E. which analyse the pinch discharge in cylindrical geometry, by solving the full magnetohydrodynamic equations for either a fully or partially ionised gas. The result of such a computation is a detailed theoretical history of the discharge. This can be compared, quantitatively, with experiment. The programme for the fully ionised gas has been used to analyse a fast cylindrical pinch experiment at the Atomic Energy

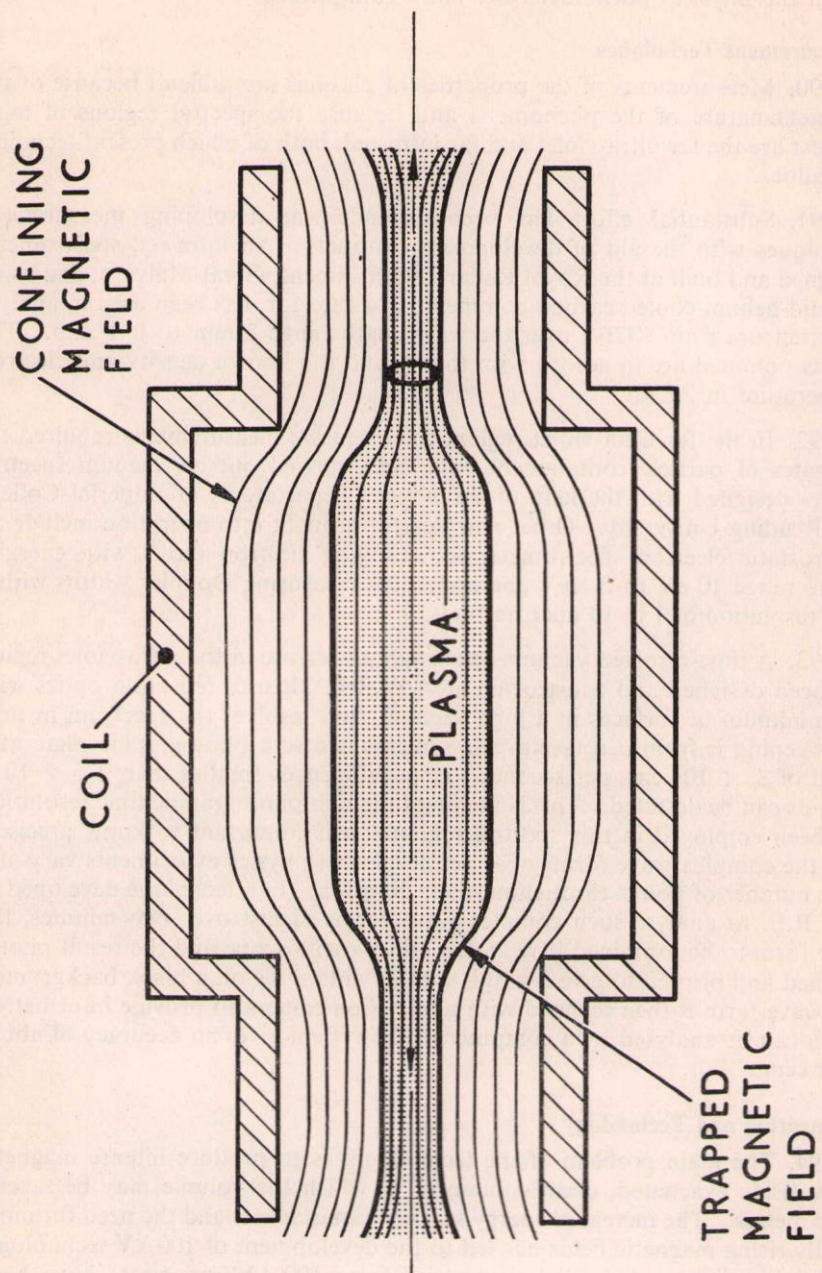


Fig. IV. Section of mirror thetaatron

Research Establishment and broad agreement has been obtained. More powerful computers will shortly be available and these should make it possible to undertake a theoretical analysis of toroidal experiments, such as ZETA, in which the physical phenomena are more complicated.

Measurement Techniques

190. Measurements of the properties of plasmas are difficult because of the transient nature of the phenomena and because the spectral regions of most interest are the far ultra-violet and far infra-red, both of which present technical difficulties.

191. Substantial effort has been expended in developing measurement techniques with the aid of development contracts. An infra-red spectrometer designed and built at the Royal Radar Establishment, Great Malvern, and using a liquid-helium-cooled carbon bolometer as a detector, has been used to analyse the spectrum from ZETA over the wavelength range 2 mm to 0.1 mm. The results obtained are in accord with theory and the known density and electron temperature in ZETA.

192. In the far ultra-violet region, the extensive measurements required for estimates of particle containment have been carried out on vacuum spectrometers designed with the help of the physics departments of Imperial College and Reading University. Other new devices brought into operation include an electrostatic electron spectrometer for studying electron fluxes with energies in the range 10 eV to 5 KeV and apparatus measuring Doppler widths with a time resolution of 1 to 10 microseconds.

193. A time-resolved vacuum spectrograph for use in the ultra-violet region has been designed and constructed at A.W.R.E. It uses reflection optics with the minimum of surfaces in a high vacuum, and resolves the spectrum in time by sweeping it from a rotating plane mirror across a photographic plate at a speed of 3×10^5 cms per second. Time differences smaller than 2.5×10^{-8} seconds can be detected. This is the first time that photographic time resolution has been employed in this spectral region. It is important to know precisely how the complex wave forms observed in plasma physics experiments vary at a large number of points throughout their duration. In a technique developed at A.W.R.E. to analyse such complex wave forms in just over two minutes, the wave form to be examined is recorded on an oscilloscope and the result photographed and printed to give a graph with a white trace on a black background. The wave form is then scanned with a television camera to provide information which can be analysed by a computer. The system gives an accuracy of about 2 per cent.

Engineering and Technology

194. The main problem of the technologist is to produce intense magnetic fields inside evacuated, clean containers of which the volume may be several cubic metres. The increased energy storage requirements and the need for more rapidly rising magnetic fields has led to the development of 100 kV technology. In collaboration with various industrial firms 100 kV capacitors have been designed, developed and tested, and tests are being carried out on spark gaps for switch duty at 100 kV and 100 kA. A promising solution to the problem of the so-called "clamp" switch, which has to hold off 100 kV and then pass many

tens of kiloamps with very small voltage drop, is also under test. The problems of constructing suitable vessels for plasma physics experiments are being intensively studied, with help from industry, and significant advances have been made in the understanding of thermal shock processes. The cracking of ceramic surfaces has been measured as a function of pulsed thermal loading and has been found to be in agreement with theory.

195. Much of the development work which was begun in connection with the I.C.S.E. experiment is continuing because the technology is needed for other existing experiments as well as for future pinch experiments.

Culham Laboratory

196. It was stated in the Sixth Annual Report (paragraph 204, *et seq.*) that approval had been obtained to develop the new site at Culham, near Oxford, as a laboratory of the Research Group. Construction on the site is proceeding in three phases, the first of which is expected to be completed early in 1962. Experimental work now in progress at A.E.R.E., Harwell, and at A.W.R.E., Aldermaston, will be steadily transferred to the Culham Laboratory over the next three years. The Authority are advised on their programme of controlled thermonuclear research by a Controlled Thermonuclear Research Advisory Committee, whose chairman is Sir William Penney.

CHAPTER VII

NUCLEAR WEAPONS

197. Although, for security reasons, no details can be given, a substantial proportion of the Authority's effort, both in the fissile material production plants and in the Weapons Group, continues to be devoted to the nuclear weapons programme as approved by the Ministry of Defence. This programme includes active and successful collaboration with the United States of America in accordance with the Mutual Defence Agreement of July, 1958 (Cmnd. 537).

198. In the Sixth Annual Report, paragraph 209, mention was made of a study by the Weapons Group of the technical problems which were raised by the Geneva Conference of Experts in their examination of the methods of detecting violations of a possible agreement on the suspension of nuclear tests. The programme of underground chemical explosions at Callington in Cornwall and elsewhere in the United Kingdom, also referred to in paragraph 211 of the above report, has been completed during the year, and the results of some 50 shots showed that a considerable reduction in seismic effect can be obtained by firing in a large natural or man-made cavern as compared with the effect when the charge is tamped into a small hole. These experiments contributed to an assessment of the problems involved in the detection of violations of any agreement to suspend nuclear tests and in the establishment of the most effective control system.

199. A new programme of seismic work has now been set in hand, with the objective of improving ability to discriminate between the signals from underground explosions and those from earthquakes. The programme includes a basic study of the mechanisms controlling the transfer of explosive energy into

seismic signals and of the mechanism of propagation of these signals through the earth, the design of improved types of seismometer and a study of the characteristics of the signals from earthquakes and explosions. Methods for improving the signal to noise ratio are also under investigation and work has been started on the use of large arrays of seismometers and of deep bore holes for this purpose. The first phase of the programme, known as "Operation Seagull", was carried out in March, 1961. In collaboration with the Admiralty, a series of depth charges were detonated in the English Channel and the resulting seismic waves recorded by the various instruments so far developed, which were situated in different types of surface media at various locations in the south of England and in Wales.

200. Work at the Atomic Weapons Research Establishment is also proceeding on earth-based methods of detecting explosions in space. The majority of these methods exploit either the ionic or optical changes which occur in the upper atmosphere due to incident weapon radiations.

201. Both the gamma and X-radiation from the weapon produce a change in the ionic density in the atmosphere, whilst electrons arising from the beta decay of the radioactive debris from a nuclear explosion may be trapped in the earth's magnetic field and appear as a variation of charge density. It is therefore possible to adapt existing methods for observing the ionosphere to the detection of explosions in space, and the work already done on the various possible methods indicates that detection of a one kiloton explosion should be possible at distances in excess of 10^5 kilometres.

202. It has been shown that a strong near ultra-violet luminescence results from the X-radiation from a nuclear explosion and by observing this with specially designed instruments it should, under appropriate atmospheric conditions, be possible to detect explosions at distances in excess of a million kilometres. A problem here is to distinguish between this luminescence and lightning effects. Theoretical and laboratory investigations have shown that there should be an intense infra-red emission from the upper atmosphere also induced by X-radiation and this gives promise of detection at even greater ranges.

203. Two further methods for detecting such explosions are being considered—the direct light output from the explosion and the coherent electromagnetic signals produced by a Compton electron avalanche. Instruments are being designed which are capable of detection using these principles.

204. In all these methods of detection, apart from the study of the physics involved and the development of the necessary instrumentation, work is proceeding on the methods of data recording and analysis appropriate to each system. This is necessitated by two factors. The first is the influence of natural backgrounds which produce large numbers of signals similar to those from nuclear explosions, and which will therefore over-burden the detection system with false alarms unless they can be positively recognised and automatically rejected. It is an essential part of this programme, therefore, to accumulate data on these background signals and to examine criteria by which they can be recognised. The second factor is the large amount of data which is produced and which has to be sifted and analysed. To do this it is essential to use automatic data processing machinery and to ensure that the method of recording is compatible with the data processing equipment. Since the latter is likely to

be specialised and costly, the recording methods used in all the systems must be rationalised so that the number of different types of instrument installed at a detection station can be kept to a minimum.

205. Although the voluntary suspension of nuclear weapon tests continues, the development of nuclear weapons for service use necessarily requires a considerable supporting programme of fundamental research and development. This is in addition to the work on nuclear and plasma physics which is described elsewhere in this report. In fact, despite the restrictions imposed by security, about 150 papers by the staff of the Weapons Group have, during the year, been approved for publication either in the open literature or at scientific conferences.

CHAPTER VIII

RAW MATERIALS

Uranium

206. Uranium supply and demand became even more out of balance during the year under review. Schemes to restrict current output have been put into operation in most producing countries; but these only reflect a deferment of deliveries under existing contracts.

207. The Authority's commitments continue to be considerably in excess of their current requirements, and the burden was further increased by the rephasing of the nuclear power programme announced in June, 1960. The effect of this on the Authority's prospective stocks was offset by the stretch-out agreements reached, after a year of negotiation, between the South African Atomic Energy Board, the United States Atomic Energy Commission and the Authority in January, 1961. Under these agreements the total quantities of material to be bought separately by the Authority and by the Commission remain unchanged. Deliveries to the Commission will still be completed by the end of 1966, but those to the Authority up to that date will be reduced by 6,000 tons, this quantity being delivered between 1967 and 1970. These agreements will not only defer expenditure but will to some extent reduce it; as several relatively high cost mines will cease to produce and others will have smaller contracts, the industry is now able to sell at a price which will be somewhat lower than the average payable under the former Combined Development Agency contracts.

208. The uncertainty of outlook, even for established producers, called for a review of the guarantees given by the Authority to take up new production from the Federation of Rhodesia and Nyasaland and from a number of colonial and dependent territories. These guarantees had been issued at the time when there was an urgent need to increase world production. They had not led by 1960 to the proving of any major deposits, and the undertaking to offer "prices which were reasonable in the circumstances of the time" ceased to have any meaning when there were no longer buyers at any price for substantial quantities of uranium. After discussion, therefore, with the governments concerned, and with their agreement, the guarantees were withdrawn.

209. Contact between the United Kingdom Government and Union Minière du Haut-Katanga concerning possible uranium supplies goes back to April, 1939, when the possibility of an atomic weapon was first being canvassed.

The first large supply of uranium was made when Union Minière's stock in the United States was handed over to the Manhattan District in September, 1942. The Shinkolobwe mine in the Congo was reopened in that year and continued in operation till it was closed on exhaustion in 1960. Under the formal contract with the Combined Development Trust signed in 1944, and its many extensions, Union Minière, with the co-operation of the Belgian Government, provided the bulk of the uranium supporting the Allied wartime atomic energy effort, the immediate post-war defence programme and the U.K. atomic energy project up to 1953. During the year the final deliveries were made under the contract between the Agency and Union Minière for uranium from Shinkolobwe. Thus ended a connection which went back to the very earliest days of the atomic project and which made a notable contribution to its development.

210. The only remaining C.D.A. contracts are those with Portugal and Australia, the last of which will have expired by early 1963. Supplies continued under the Authority's direct uranium contracts. Arrangements were made, following the Combined Development Agency's agreements in South Africa, for deliveries by the Harmony Gold Mining Company, under the separate contract with the Authority, to be extended to 1970. Deliveries from Canada were less than three-quarters of those in the previous year as a result of the 1959 stretch-out agreement and further subsequent adjustments.

211. Discussions have continued between the Authority and Eldorado Mining and Refining Limited, about supplies of uranium from Canada following the expiry of the current contracts for 10,500 tons of uranium. In 1957 the Authority exchanged letters with Eldorado arranging for the supply of a further 12,000 tons during the period 1963-66. Shortly after the exchange, the Authority's requirements declined rapidly and soon reached the point when none of the 12,000 tons was needed. Eldorado therefore was asked in early 1958 to re-negotiate the arrangement but no agreement was reached. Further discussions took place at intervals up to November, 1960; at the end of the year a resumption of negotiations was pending.

Technical Services

212. Agreement was reached with the Department of Scientific and Industrial Research on a progressive reduction of the programme of work to be carried out for the Authority by the National Chemical Laboratory, the Geological Survey of Great Britain and the Warren Spring Laboratory. Investigation of certain uranium occurrences in the Buller Gorge area of the South Island of New Zealand was brought to a close with negative results. The assessment of the potential beryl resources of Southern Rhodesia continued; a similar assessment in Uganda ended in January, 1961. Potential sources of helium, a possible reactor coolant, have been kept under review.

CHAPTER IX

COMMERCIAL OPERATIONS

213. As last year, the Authority's main commercial sales have been of fuel elements, radioisotopes, graphite and electricity. Total value of these sales during the year was nearly £21 million, about half of which arose from the sale

of fuel elements. Of the total, £6½ million was received by way of advance payment from the Central Electricity Generating Board during the year 1959-60. In addition to these sales, the Authority obtain a revenue from the fees charged under licence agreements and for consultancy services. These represent a sale of technical knowledge and experience and the Authority are thus able to recover part of the expenditure on research and development originally carried out at the taxpayer's expense.

Sale of Radioisotopes

214. The Radiochemical Centre at Amersham is responsible for the sales of radioisotopes, labelled compounds and radiation sources. Demand for these products continues to increase steadily and the total value of sales rose by about 10 per cent. during the year to over £1,300,000. In the face of expanding overseas production, the proportion exported was maintained at about 60 per cent., and the Centre had dealings with some 60 countries, the principal buyers being Federal Germany, the United States, France, Canada and Japan. The number of consignments despatched from Amersham and from Harwell was about 40,000, varying in size from a few millionths of a curie to 150,000 curies. The new laboratory at Amersham for handling alpha-emitting isotopes is now in full use.

215. To meet requirements for isotopes such as iodine-131, phosphorous-32 and gold-198 which are well established in clinical practice, certain improvements have been made in production plants and methods. Hitherto the supply of these isotopes has been entirely dependent upon the use of BEPO, and there have been occasional difficulties when that reactor has been shut down for maintenance. To improve the reliability of the service, arrangements are being made to use other research reactors for this purpose, and during the year production of iodine-131 was transferred to PLUTO. New equipment designed for this purpose now makes it possible to discharge the product while the reactor is operating at full power.

216. An encouraging feature was the growth of interest in several of the minor isotopes, made either in reactors or in cyclotrons, such as beryllium-7, cobalt-57 or -58, iron-59 and calcium-47. A regular supply of iodine-132 is now available for clinical use as an alternative to iodine-131 in cases where the shorter half-life is an advantage, and small quantities of two other isotopes of iodine, iodine-124 and iodine-125, are being made from time to time in the Hammersmith cyclotron in collaboration with the Medical Research Council Radiotherapeutic Research Unit. Thus there are now four distinct isotopes of iodine available for medical and research use. Altogether some 90 different isotopes are handled by the centre in the course of a year.

217. To meet the expected demand for large quantities of cobalt-60 for industrial irradiation processes, the Authority have built up a stock of about 2,000,000 curies of this isotope. During 1960-61 some 500,000 curies were processed and delivered to industrial and experimental installations. The nuclear power stations of the C.E.G.B. will have the capacity to make very large quantities of cobalt-60 in the future; the use of these reactors for this purpose was authorised by Parliament under the Electricity (Amendment) Act, 1961. The Authority and the C.E.G.B. are making arrangements to produce radioactive material in the Board's reactors in due course. The Authority will be responsible for the processing, distribution and sale of this material.

218. The use of isotopically labelled compounds as tracers in pure and applied research, particularly in biology and biochemistry, continues to grow. Carbon-14 remains pre-eminent and the demand for its compounds increased by about 30 per cent. during the year. The centre's list of carbon-14 compounds now includes 230 items and on average over 90 per cent. of these were immediately available on demand throughout the year. Among those added to the list during 1960 were stearic and palmitic acids which have been isolated from *Chlorella* grown upon carbon-14. These are of interest in the study of fat metabolism. Work is proceeding to isolate other compounds of vital interest from this source. The labelling of certain insecticides with carbon-14 at high specific activity is greatly assisting the study of the biochemical mechanisms of insect resistance to them. The production of carbon-14 itself has substantially increased and is now sufficient to allow its more liberal use in large-scale tracer experiments.

219. Interest in labelled compounds of isotopes other than carbon-14 is growing rapidly. In particular tritium is being used to supplement it as a tracer in biochemical research, and among the technical advances with this isotope has been the production at Amersham of labelled thymidine (used by cytologists in the study of the chemistry of genetics) at the highest specific activity so far available. Altogether some 150 different compounds containing 65 different isotopes were synthesized during the year, indicating a growing awareness that in the testing of detergents, drugs, antibiotics, insecticides, weedkillers and other technical chemicals, the tracer method has become exceedingly important. Indeed, examination of the corresponding labelled compound may now be said to be an essential preliminary to the general use of new chemicals of this kind.

220. Notwithstanding the abundance of radioisotopes from artificial sources, the demand for naturally occurring radioelements is still substantial. Radium appliances are still used extensively in radiotherapy, and nearly 3,000 radium appliances were manufactured during the year. There was also an increasing interest in neutron sources based on radium, polonium or radiothorium, which are needed for use in nuclear reactors.

221. Charges for the irradiation service in the research reactors at Harwell were increased on 1st January, 1961, and so were those for the radon service. Otherwise the prices of the centre's products remained substantially unchanged during the year and there was a small trading profit on its operations as a whole.

Sale of Fuel Elements

(i) Power Reactors

222. The nuclear power stations under construction for the C.E.G.B. at Berkeley and at Bradwell are due to be commissioned in 1961. During the year under review the Authority delivered the complete first charge of fuel for one of the two reactors at Berkeley, and part of the first charge for the other reactor. Delivery of the first charge for one of the Bradwell reactors is due to be completed in early April. The quantity of fuel delivered was approximately 600 tonnes and comprised some 80,000 fuel elements.

223. During the year the C.E.G.B. announced their intention to place contracts for the building of nuclear power stations at Dungeness, Kent, and at Sizewell, Suffolk. Preparations are in hand for the supply by the Authority of

magnox-clad natural uranium fuel elements for these stations and for the stations already under construction for the C.E.G.B. at Hinkley Point and Trawsfynydd and for the South of Scotland Electricity Board at Hunterston. A substantial and increasing revenue is therefore to be expected.

224. The commercial basis for the supply of fuel elements to the C.E.G.B. was negotiated during the year.

(ii) *Research Reactors*

225. In addition to supplying enriched uranium fuel for their own materials testing and research reactors, the Authority continued to sell fuel to the Australian Atomic Energy Commission for the Hifar materials testing reactor, and to the Danish Atomic Energy Commission for use in their DR.3 materials testing reactor at Risø. The Authority have also undertaken to carry out the reprocessing of irradiated fuel from these reactors. A quantity of fuel was supplied by the Authority to the Land Nordrhein-Westfalen for use in the Merlin type reactor at Jülich, Germany, and negotiations are proceeding with this organisation for the supply of fuel for the DIDO type reactor which they are building.

226. Natural uranium fuel was provided to Imperial College and Queen Mary College, London, to the Royal Naval College, Greenwich, and to the universities of Birmingham, Manchester and Southampton for use in sub-critical assemblies.

Other Sales

227. The Authority's nuclear power plants at Calder Hall and at Chapelcross continued to export by-product electricity to the C.E.G.B. and to the S.S.E.B. respectively. Revenue to the Authority from this source amounted to approximately £5,000,000.

228. Over 12,000 tons of nuclear quality graphite for the civil power stations in the United Kingdom were delivered during the year. Deliveries to Berkeley, Bradwell, Hunterston and Hinkley Point were completed, and those for Trawsfynydd started. Quantities of graphite for small reactors and for research purposes were also supplied during the year.

229. Miscellaneous sales included the fabrication and hire of special uranium elements to the consortia and other companies for experimental purposes, and also non-fissile materials such as beryllium, zirconium and certain magnox alloys. In addition, services, such as the hiring of computer time and irradiation testing facilities, were provided.

Collaboration with Industry

230. The Authority's close association with the consortia of firms constructing the nuclear power stations for the electricity boards has continued. As a result of mergers that took place during the year the number of consortia was reduced to three. The consortia are licensed to use the information resulting from the Authority's extensive design work and research and development in the field of gas-cooled, graphite-moderated reactors. They are also kept generally informed of the Authority's work on other reactor systems and take part with the Authority in examining their technical and economic potentialities.

In addition to the arrangements under licence, the consortia take part in a direct collaborative research programme the results of which are pooled. Revised arrangements for allocating the cost of this collaborative research were agreed during the year.

Patents and Licensing

231. The Authority continued to protect inventions, resulting from their research and development work, by patents both in the U.K. and overseas. Licences and sub-licences granted under these patents, which cover a wide field, have resulted in an income during the year of nearly £90,000.

232. Negotiations continued with foreign organisations regarding the possible grant of licences by the Authority for the manufacture overseas of natural uranium fuel elements using the methods and processes developed at Springfields.

Access Agreements

233. There is a continued demand by companies for access to the Authority's information and experience in particular fields for various purposes. A significant feature this year was the preparation by certain companies of tenders to the Ministry of Transport for a nuclear propelled merchant ship. Various reactor systems were investigated for the purpose by the companies, several of which entered into access agreements with the Authority.

Consultancy

234. The Authority act as consultants to the C.E.G.B. on the nuclear portions of their generating stations. Similar consultancy has been provided to the S.S.E.B. for Hunterston, to Agip Nucleare for Latina, and to the Japan Atomic Power Company for the station at Tokai Mura. Income from this service was over £300,000 in the year.

Attachment Agreements

235. Paragraphs 284-290 give details of the training in reactor operation and in the nature and uses of radioisotopes which the Authority provide at the Reactor Operations School at Calder, at the Reactor School at Harwell and at the Isotope School at Wantage.

236. The Authority charge for this training, which is provided both to U.K. and to foreign students, and the total receipts from this source amounted to £64,000 during the year. Of this total, £35,000 came from the Harwell Reactor School, £18,000 from Calder, and the balance from the Isotope School at Wantage.

237. Staff from industry and from the electricity generating boards continue to be attached to the Authority's design offices and laboratories. In some cases the attachments are part of general arrangements made with the boards or with industry which help to foster co-operation in areas where the commercial exploitation stage has not yet been reached. A direct charge is not usually made where the Authority are also obtaining benefit from such an attachment.

CHAPTER X

HEALTH AND SAFETY

238. The United Kingdom has played a prominent part from the outset in the development of international health and safety standards for atomic energy work and in insisting on the application of the required elaborate precautions. The Authority have made a major contribution to this work. They will continue to keep the public fully informed on their safety experience. As their own knowledge develops they expect to be able to relax some of the more rigorous requirements and are confident that strengthening public confidence will permit the full development of the benefits to be derived from atomic energy.

The Principles of Radiological Protection

239. In December, 1960, the committee appointed, under the chairmanship of Sir Harold Himsworth, by the Medical Research Council, published their second report on "The Hazards to Man of Nuclear and Allied Radiations". The Authority have given careful consideration to this report, which provides a detailed summary of the biological effects of radiation and assesses existing and foreseeable levels of exposure to radiation of the population in the U.K.

240. The report endorsed, in general, the recommendations of the International Commission on Radiological Protection, which have been adopted by the Authority, and where the committee recommended changes from the I.C.R.P. recommendations, the Authority have applied these changes. The committee drew attention to the fact that the maximum permissible levels of exposure are derived on the basis of a balance of possible risks against the undoubted benefits derived from the use of radiation. The committee repeated a recommendation from their 1956 report, namely, that adequate justification should be required for the employment of ionising radiations on however small a scale.

241. This, together with the recommendations of I.C.R.P. to keep all exposures as low as practicable, forms the fundamental basis of Authority policy, not only as regards the exposure of their employees, but also in operations such as the disposal of radioactive waste.

242. The committee also commented on the contribution to the total population dose from the occupational exposure of workers to radiation. They reported that this dose, at present, is the equivalent of 15 millirads per generation, which is some 60 times lower than the allowance suggested for this purpose by I.C.R.P. The committee commented that they considered this state of affairs to be most satisfactory.

Protection of the Public

243. The Radioactive Substances Act, 1960, will make permanent and extend to all users of radioactive materials the requirement for the authorisation by Ministers of all discharges of radioactive waste and for the inspection of premises and records. The Authority's requests for authorisations will be governed, as in the past, by the principles set out in paragraph 117 of the White Paper "The Control of Radioactive Wastes" (Cmnd. 884, November, 1959).

244. The Authority assisted in the preparation of the International Atomic Energy Agency regulations for the safe transport of radioactive materials by all forms of transport (Sixth Annual Report, paragraph 235). These are intended to provide agreed standards for international traffic and to form a basis for national legislation. The Authority are also assisting in preparing regulations governing the transport of radioactive materials in the U.K. and have established machinery for approving and standardising designs of containers to meet these regulations.

Protection of Staff

245. Owing to the expansion of the work of the Authority there has been an increase in the number of employees classed as radiation workers, who now total nearly 18,000. The maximum permissible whole body dose (three rems* in 13 weeks) was exceeded by a small margin on 9 occasions in 1960. This compares with 14 occasions in 1959 and 25 in 1958. In every case arrangements were made to reduce subsequent exposure and to ensure that long-term dose limits were not exceeded.

246. In addition to radioactive materials, a wide range of non-radioactive toxic materials is handled in the Authority's establishments. Many of these, such as solvents, are in wide industrial use and protection procedures are well established. Others, such as beryllium, are not so familiar in the general industrial field and special attention has been paid to the design and operation of the handling facilities. Close supervision is maintained of the working environment and careful attention given to the medical surveillance of employees.

247. Continued co-operation has been maintained with the Factory Inspectorate of the Ministry of Labour, and information on safety techniques and training methods is freely exchanged through the medium of local industrial safety organisations and the Royal Society for the Prevention of Accidents. A central system of recording lost-time accidents was introduced during the year. The accident frequency rate (i.e., the number of lost-time accidents per 100,000 man-hours worked) was 0.84 and the mean duration was 173.1 hours.

248. The Authority regret to report the death of one of their industrial workers following an accident involving hydrofluoric acid at Springfields on 23rd August, 1960.

Training in Health and Safety

249. The Report to the Authority of the committee under the chairmanship of Sir Douglas Veale was published on 29th April, 1960.

250. It was recommended that the Authority should not be required to undertake an extensive part in a national training scheme but that their main contribution should be the provision of specialised courses, colloquia and conferences. The specialised courses in radiation protection were continued during the year.

251. Recommendations affecting the form and content of courses, and the financing of students attending them, were brought to the attention of the government departments and public bodies concerned. The Authority, together with representatives of other interested bodies, are taking a leading part in developing plans to give effect to these recommendations.

* A rem is a unit of radiation dose which takes account of the relative biological effectiveness of the different types of radiation.

252. The proposal in the Veale Report to establish a National Radiological Advisory Service would relieve the Authority of many tasks which they undertake at present but which it is not their proper function to fulfil. The Authority are collaborating with other interested bodies in discussions to determine the form which the service might take. Legislation would be necessary before such a body could be established.

253. Recommendations concerning the production of books, films and radio and television programmes were addressed by the committee to the Authority. These are being studied with due regard to the fact that, in these fields, collaboration with other interested bodies is generally to be preferred to unilateral action by the Authority.

Co-operation with the Ministry of Power

254. The Nuclear Installations (Licensing and Insurance) Act, 1959, was brought into force by Order in Council on 1st April, 1960, and from that date the functions of assessing and evaluating the safety of reactors and nuclear plant, other than those of the Authority, were formally assumed by the Chief Inspector of Nuclear Installations of the Ministry of Power. The Safeguards Division of the Authority Health and Safety Branch is continuing, as the agent of the Chief Inspector, to carry out certain parts of this work. The staff of the division have contributed to the work involved in the licensing of reactors for the Central Electricity Generating Board and the South of Scotland Electricity Board; and also for universities, research institutions and government departments.

255. The Authority are exempt from the principal provisions of the act. But, in pursuance of an undertaking given in Parliament, the Minister for Science, after consulting the Authority, issued a direction to the Authority on 1st April, 1960, requiring them to keep the Minister of Power and the Secretary of State for Scotland fully informed of any substantial developments relating to the safety and safe operation of their own nuclear plant and installations; and, so far as practicable, to have regard in the operation of their own plant and installations to any current safety requirements imposed by the Minister of Power and the Secretary of State for Scotland.

256. This direction is being implemented by the transmission of copies of relevant safety assessments of the Authority's own installations; by the operation throughout the Authority of a system of central reporting and analysis of occurrences of safety importance; and through regular discussions between representatives of the Authority and of the Ministry of Power.

257. The Authority are represented by three members of their staff on the Nuclear Safety Advisory Committee, under the chairmanship of Lord Fleck, which has been set up to advise the Minister of Power. Sir John Cockcroft, a part-time Member of the Authority, is also a member of the committee in an independent capacity.

Nuclear Ships and Submarines

258. Members of the Authority's staff have participated in the study of the development of safety principles and practice connected with nuclear ships and submarines. The Authority have advised the Admiralty and the Ministry of Transport on the evaluation of a number of ports and harbours in the U.K. for the reception of nuclear ships and submarines, and a paper on the principles

governing this work was presented to the I.A.E.A. Symposium on Nuclear Ships, which was held at Taormina, Sicily, in November, 1960. The Authority participated in the Conference on the Safety of Life at Sea held in London in May and June, 1960, under the auspices of the Intergovernmental Maritime Consultative Organisation. Among the results of this conference were a new chapter in the International Convention on the Safety of Life at Sea dealing with the regulation of nuclear merchant ships, and a series of recommendations to member governments on principles to govern their design and construction.

Research and Investigations

259. A major part of the Authority's effort in the reactor and plant safety field has been devoted to investigations, particularly of the operation of their plants and, in relation to the nuclear power programme, of the reactors at Calder Hall and Chapelcross. In addition, a considerable number of specific projects of safety interest have been pursued.

260. A substantial programme of theoretical work on criticality problems has been undertaken. This has been related to problems of plant design and the storage and transport of fissile material as well as the experimental work on this subject referred to in paragraph 149. Effort has also been devoted to the development, in collaboration with industry, of the application of improved instrumentation such as solid state devices. Studies have been made of the effects of temperature and irradiation on materials used in reactor construction, with special attention to the requirements of the steels used in nuclear technology, including ductile/brittle transition temperature (see paragraphs 78 and 79); creep; and the effect of strain cycling.

261. Mention was made in the Fifth Annual Report, paragraph 191, of work at Foulness using scale models to confirm the safe design of reactor systems. This work is continuing and the studies have included, for example, the mechanical consequences of ruptures in the pipe work of cooling systems and the development and containment of flying debris. The experience gained in experiments on blast wave loading and on the ultimate strength of concrete structures, undertaken initially for Civil Defence purposes, has been most useful in this work. In assessing the possible effects of reactor incidents on the structural components of the reactor, such as the concrete biological shield, it is important to know the rate of build-up of the energy release and to learn the effect of this variation on the structural components. For this purpose alternative energy sources are being developed, such as burning propellants and electrical discharges.

262. A number of research projects and investigations in the field of radiological protection have been continued and some of the more important are summarised below:

- (a) The behaviour of radioiodine at very low concentrations in air has been studied by controlled releases into the containment buildings of reactors. The radioiodine, which is an important fission product, was rapidly absorbed on to surfaces and atmospheric condensation nuclei. Laboratory studies on the efficiency of glass filter papers impregnated with carbon for the collection of radioiodine have shown a high efficiency in a wide variety of physical conditions. Investigations on this are continuing.

- (b) The Authority were represented in the team provided by the I.A.E.A. for studying the radiation doses received during the accident to a reactor at Vinca, Yugoslavia, in 1959. The team simulated the circumstances of the accident under controlled conditions. Supporting laboratory work included methods of measurement of neutron dose at various depths in tissue.
- (c) The development of an improved film badge for personnel monitoring was undertaken in conjunction with the Radiological Protection Service of the Ministry of Health and the Medical Research Council. The number of monitoring installations for measuring the radioactivity of the whole body is being increased by the introduction of equipment at Windscale, Dounreay and Winfrith, in addition to that which has been in operation for some years at Harwell. These installations can be used for routine monitoring as well as for research studies on the behaviour of radioactive materials in the human body.
- (d) Improved treatment processes have been investigated for both liquid and solid wastes and extensive work has continued on the uptake of radioactive materials by fresh and seawater biological organisms. To improve knowledge of the dispersal of low-level radioactive waste discharged to sea, the research programme has included study of the effects of tides, currents and wind on the movement of the waters of the Solway Firth.

International Co-operation

263. The Authority continued throughout the year to devote their main international effort in the health and safety field to participation in the work in this field of the I.A.E.A. In addition, fruitful bilateral exchanges have continued, particularly with the United States, Canada and France.

Sir Ernest Rock Carling

264. Sir Ernest Rock Carling died on 15th July, 1960. He had been an honorary consultant to the Atomic Energy Research Establishment at Harwell from 1946 and had played a valuable part in the establishment of the Radiochemical Centre at Amersham. From 1954 until his death he was radiological consultant to the Authority.

265. He was the doyen of British medical radiologists, and was widely experienced in many kindred fields. He was no less prominent in the international sphere, having been chairman of the International Commission on Radiological Protection.

266. The Authority record with gratitude Sir Ernest Rock Carling's distinguished service to the British atomic energy project over many years.

CHAPTER XI

INFORMATION SERVICES

267. The demand for information on atomic energy, from both home and overseas enquirers, has continued to grow, but the pattern of enquiries is changing. There are fewer requests for general background information, and more detailed questions on specific points.

Press

268. A two-day course to assist journalists in writing about radioisotopes—their production, distribution and application—was held in April, 1960, at the Authority's Isotope School at the Wantage Research Laboratory. The course was well attended, not only by correspondents of the national press but by technical journalists representing trade journals of industries which benefit from the use of radioisotopes.

269. In the following month, journalists visited first the Radiochemical Centre at Amersham to see the production of isotopes and to inspect the new organic and alpha laboratories, and later the Wantage Research Laboratory where they were shown the development of new isotope applications. The press was also invited to the opening in June, by the Chairman of the Authority, of the Isotope Information Bureau at the London Office of the Authority.

270. Almost 100 journalists, including representatives from Europe, Canada, the United States of America and the Union of Soviet Socialist Republics, attended a press visit to Windscale in May, to see progress in the construction of the advanced gas-cooled reactor. A press visit to the Atomic Energy Establishment at Winfrith in September was attended by over 90 journalists from 13 countries. With the co-operation of the Dragon authorities, the press was also able to see the progress of this project.

271. The press also attended a ceremony to mark the start of the construction of the Dragon reactor in April; underground test firings in Cornwall in the spring and autumn of 1960 and "Operation Seagull" in March, 1961 (in connection with the Authority's seismic research programme); and the opening of the new Harwell library in September.

Exhibitions

272. The travelling exhibition "Atoms at Work", was shown in Edinburgh (October), Cardiff (November) and Brighton (February, 1961). Lectures and film shows were arranged at each location. The total attendance of over 30,000 included 8,000 pupils of schools and colleges in conducted parties.

273. The Authority took part in, or contributed to, 12 other exhibitions in the United Kingdom. In April-May, 1960, they staged an exhibit at the Fuel Efficiency Exhibition. In May the Radiochemical Centre, Amersham, exhibited at the Instruments, Electronics and Automation Exhibition. In the same month an exhibition was mounted at Windscale in support of the A.G.R. press visit and the Authority also provided an exhibit for the "Safety at Sea" conference in London. The Atomic Weapons Research Establishment, Aldermaston, showed recent examples of their research at the International Medical Electronics Exhibition in July and at the Corrosion Exhibition in November. An exhibit illustrating the solvent extraction of plutonium was provided by the Atomic Energy Research Establishment, Harwell, and the northern groups for the Royal Society Tercentenary Exhibition at Burlington House in July. An exhibition was arranged in connection with the press visit to Winfrith in September. In October a two-day exhibition was staged at the headquarters of the Trades Union Congress in conjunction with a conference on "Radiations in Industry". A display of Authority photographs and models was held from December to February in the Oxford Street showrooms of Ilford Limited.

Seven thousand people attended an "Atomic Power" exhibition in the City Museum, Coventry, in November-December. In January, 1961, the Authority participated in the annual exhibition of the Physical Society. Exhibits and photographs were provided for the Royal Society of Health permanent exhibition which opened in March, 1961.

274. The Authority exhibited at the Golden Jubilee Celebration of the University of Natal in June. In September they took a major part in the Fifth International Instruments and Measurements Conference and Exhibition at Stockholm. On this occasion the Authority arranged a scientific exhibit at the conference and co-operated with the Nuclear Energy Trade Associations' Conference to organise the U.K. section of a commercial exhibition. Models and display material were provided to the Board of Trade for the New York Fair in June and to the British Chamber of Commerce for the Izmir (Turkey) International Fair in July-August. An exhibition was held under the auspices of the Royal Dublin Society in March, 1961.

275. In addition to exhibiting on their own account, the Authority loaned models and other display materials to educational and other organisations at home and overseas. In particular they co-operated with the British Association for the Advancement of Science in devising visual aids for lectures.

Films

276. Four new films were completed during the year: "R. & D." (Research and Development in the Development and Engineering Group); "Steel and Nuclear Power"; "Commissioning of the Dounreay Fast Reactor"; and "The Dounreay Symposium". An earlier film, "Nuclear Power in Britain", was brought up to date under the title "Britain's Atomic Power Stations (1960)"; a shortened version of "Radioisotopes in Industry" was retitled "Industrial Uses of Radioisotopes".

277. There is a continuing home demand for Authority films from schools, technical colleges, universities, research and other organisations, industrial firms and H.M. Forces. Authority films, many of them in foreign language versions, were shown in 45 countries, in some cases by the Authority, but chiefly by the Central Office of Information and by the British Council.

Publications

278. New publications included "Atom 1960", an illustrated summary of the Authority's Sixth Annual Report, and "Careers in the United Kingdom Atomic Energy Authority". Further additions were made to the series of "Technical Information Sheets"; a Swedish version of these has been adopted by the Swedish atomic energy organisation for distribution to universities and technical colleges. The circulation of the Authority's monthly bulletin, "Atom", rose from 13,300 to 15,500 copies, over 3,000 of which go overseas.

Isotope Information Bureau

279. The scope of the public information room at Charles II Street was widened during the year to include an Isotope Information Bureau. The bureau opened in June to provide a convenient point of enquiry in London for those seeking information on the production, sale and uses of radioisotopes.

Its facilities include a reference library, exhibition and film-viewer. About 70 isotope enquiries a week were received during the year, between 15 and 20 of which were from industry. The information room dealt with over 2,000 enquiries on subjects other than isotopes.

Dounreay Gazebo

280. A former airfield control tower at the Dounreay establishment was opened in June as a public exhibition-room and gazebo (it commands an excellent view of the site). In four months there were 8,000 visitors. It will reopen on 1st May, 1961.

Photographs

281. Over 700 new negatives were added to the Photographic Library during the year in addition to 250 prints from outside sources.

Libraries

282. The Authority's libraries, besides serving the Authority's own staff, continued to lend material to, and to answer questions from, external organisations. During the year over 10,000 items were lent, and over 500 external enquiries answered, principally from British industrial firms and universities.

283. A new library building was opened at the Atomic Energy Research Establishment, Harwell, on 7th September, 1960, by Sir Lindor Brown, C.B.E., F.R.C.P., Sec. R.S., Chairman of the Department of Scientific and Industrial Research Consultative Committee for the National Lending Library for Science and Technology. On the following day a meeting was held between representatives of the Authority's libraries and of the British libraries which maintain deposit collections of the Authority's unclassified reports. Nineteen external libraries were represented.

The Authority's Schools

Harwell Reactor School

284. Two standard, two senior technical executive and three control and instrumentation courses were held during the year and in July there was an additional course specially for 25 senior technical executives from the Organisation for European Economic Co-operation countries. The Colleges of Advanced Technology at Birmingham, Bradford and Salford continued to co-operate in running the standard course, the final three weeks of which are held at Warmwell, near Winfrith.

285. Two more courses on the principles of radiation protection were held, following last year's inauguration of this type of course.

286. Two hundred and fifty-eight British and 80 foreign students attended the Reactor School during the year. Since the school began there have been 1,773 British and 608 foreign students.

Calder Operation School

287. The number of students who have passed through the school now exceeds 500. During the past year seven courses for professional engineers and physicists were held and 137 students attended; 32 were from overseas countries.

288. The training of staff for nuclear power stations being constructed overseas by British consortia has been an important part of the school's activities. Thirty-three members of the operations staff for the Italian Latina station and seven members of the operations staff for the Japanese Tokai Mura station attended during the year and special courses were organised at technician level.

Isotope School

289. The successful introduction of radioisotope methods into industrial practice depends very largely upon the development of an informed opinion about their value throughout industry. Over the last few years the Isotope School at Wantage has arranged several successful courses for members of the Institute of Directors to assist in creating an informed opinion. As a natural development of this series of courses, a four-day course for trades union officials was held in September, 1960, after discussion with the Trades Union Congress. The course programme was designed to give an objective account of the use of radioisotopes in industry and special attention was paid to the health and safety aspects. The course included lectures by senior staff of the Authority and by experts from elsewhere in addition to visits, demonstrations and a small amount of practical work. Forty trade union officials attended the course.

290. A total of 292 students, of whom 142 were from overseas, attended the school during the year. Of these, 110 attended general courses and the remainder attended special courses under the following headings: advanced chemistry; medical; advanced radiography; special chemistry; advanced biochemistry; radiological protection; trades unions.

CHAPTER XII

INTERNATIONAL RELATIONS

291. The international standing of the Authority as a pioneer in civil nuclear research with a large continuing programme leads to many calls by international organisations and overseas countries for advice and assistance on a wide range of topics. Preparation for and participation in the growing number of international meetings and discussions, of both bilateral and multi-lateral character, which are held in the course of a year is costly in time, particularly the time of senior staff. Nevertheless, the Authority welcome the opportunities provided to further the development of the peaceful uses of atomic energy for the general benefit of all countries, and they devote a considerable effort to this end.

292. Collaboration in controlled thermonuclear research is a good example of the benefits which can, in suitable cases, be derived from international co-operation. During the year "Nuclear Fusion" appeared, the first issue of the International Atomic Energy Agency's journal of plasma physics and thermonuclear fusion, in which two of the five main papers were contributed by Authority staff. Authority and United States Atomic Energy Commission laboratories have continued to co-operate through frequent consultation in the planning and working of experiments. Co-operation with European laboratories working on fusion has continued through the regular meetings of the

European Fusion Study Group. The group has no formal joint programme of work but each laboratory pursues its own special lines of research and shares the results. Staff exchanges are being arranged with the Max Planck Institute for Physics and Astrophysics at Munich, which has collaborated with the Authority in the development of the pinch analysis computer programme.

International Atomic Energy Agency

293. The I.A.E.A. has continued to make considerable use of Authority experts, particularly in the preparation of international health and safety codes of practice, in the drafting of recommendations and manuals regarding the transport of radioactive materials and the consideration of problems of radioactive waste disposal. Authority staff have also attended panels and symposia on the planning and costing of atomic energy programmes, on the operation of research facilities and on the dissemination of scientific and technical information including the planning of a scientific library. Papers by Authority staff were presented at all the major conferences and symposia organised by the Agency during the year. Sir John Cockcroft continued to serve as a member of the Agency's Scientific Advisory Committee.

294. In July, Mr. Sterling Cole, Director General of the I.A.E.A., accompanied by Dr. H. Seligman, Deputy Director General for Isotopes and Research, visited at the Authority's invitation a number of Authority establishments, including the Atomic Energy Research Establishment at Harwell, the Wantage Research Laboratory, the Radiochemical Centre, Calder Hall and Windscale.

295. The Chairman of the Authority led the United Kingdom delegation to the Fourth Annual General Conference of the Agency held in Vienna in September, 1960. In his speech he paid special tribute to the already considerable degree of success which had attended the Agency's efforts to promote the exchange of information and the spread of ideas through its technical publications and its scientific meetings, and to secure common agreement on reasonable standards in such matters as health and safety, the handling and transport of radioactive materials, waste disposal, insurance, and safeguards against the diversion of fissile material to illicit uses. Atomic energy, the Chairman said, had for the time being moved out of a period of spectacular break-throughs, and progress in it, and the contribution which the Agency could make to it, would for some time to come depend upon the type of unsensational achievement characteristic of a period of consolidation. The road to the Agency's objective, namely to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world, appeared now in the light of practical experience to be longer and harder than it did when the Agency's statute was drafted in 1956. But the United Kingdom remained confident that the objective was both good and attainable and that the Agency could and would play its full part in reaching it.

296. During the conference, Authority representatives took part in discussions on nuclear power development and on the disposal of radioactive wastes. The Authority, in conjunction with the Agricultural Research Council and the Ministry of Agriculture, organised a small exhibition on "Isotopes in research relating to crop production".

297. During the year 16 holders of I.A.E.A. Fellowships from 11 countries in Europe, Asia and South America attended Authority schools or were attached

to Authority establishments. The Authority have offered a further six free places for I.A.E.A. Fellows to undertake research projects at the Wantage Research Laboratory.

European Nuclear Energy Agency

298. (i) *Dragon Project.* The Organisation for European Economic Co-operation project (Dragon) has continued to make good progress in the design of the experimental H.T.G.C. reactor and in the associated research and development programme. By 31st March, 1961, the build-up of professional staff was substantially complete at a figure of 156, comprising 85 seconded from the Authority, two from British industry and 69 who had come from overseas. The research and development programme was described in the project's first annual report published in July, 1960. Work is being carried out by the project team and under contracts placed in the signatory countries including the U.K. Work carried out by the Authority under such contracts is described in paragraphs 105-109. Construction of the 20 MW reactor experiment was formally inaugurated on 27th April, 1960, by Dr. S. Eklund of Sweden, then Chairman of the Board of Management. The civil engineering concrete work for the reactor was approximately 40 per cent. complete by 31st March, 1961, and a start had been made on the steel containment building. The auxiliary buildings for control and services were at an advanced stage of construction. Contracts for items of plant such as the pressure vessel, gas circulators, primary and secondary heat exchangers, charge machines, etc., had been let to the various signatory countries, on the basis of competitive tender.

(ii) *Halden Reactor.* An agreement was signed on 14th June, 1960, extending the joint programme of experimental operation of the Norwegian boiling water reactor at Halden by E.N.E.A. member countries from three to four and a half years. The reactor produced its first steam at a power rating of 2 MW(H) in October. Two members of the Authority's staff and a representative of U.K. industry are attached to the project.

(iii) *Convention on Third Party Liability.* The O.E.E.C. Convention on Third Party Liability in the field of Nuclear Energy was signed during the year by the great majority of member countries, including the U.K. The convention is subject to ratification which will in some cases have to await the passing of national legislation to give effect to its provisions. The convention places liability for loss or damage due to a nuclear incident on the operator of the nuclear installation concerned and requires him to obtain insurance or other financial security sufficient to provide a minimum compensation of \$5 million for any one incident. In the case of the U.K., cover for more than this amount is already required by law.

(iv) *Miscellaneous.* The Authority have continued to take part in the work of the European-American Nuclear Data Committee (a field in which demands for greater precision are constantly increasing) and in the E.N.E.A. Health and Safety Sub-Committee. A member of the Research Group staff serves on the Committee on Food Irradiation.

Euratom

299. The second meeting of the U.K.-Euratom Continuing Committee for Co-operation was held in Brussels on 29th November, 1960. The U.K. was represented by Lord Hailsham, Minister for Science, and by the Chairman of

the Authority. The committee reviewed existing collaboration under the U.K.-Euratom Agreement and considered the possibility of further collaboration, particularly in the fields of the development of research and power reactor systems and the pooling of basic data in reactor and engineering physics. They also arranged for discussions to be held on the economics and costing of nuclear power projects.

300. The U.K.-Euratom Joint Working Group met twice during the year, in October, 1960, and in February, 1961. A joint symposium on the advanced gas-cooled reactor, attended by 46 representatives from the Authority and from Euratom member countries, was held at Risley in April, 1960. A group of Euratom Commission staff and experts in the field of nuclear and reactor physics from national atomic energy organisations in Euratom countries visited Harwell and Winfrith in March, 1961. Members of the Authority's Health and Safety staff took part in an international symposium on the legal and administrative problems of radiation protection organised by Euratom in September, 1960. Two Euratom engineers have each spent six months at Harwell working on irradiation loops; three others have been studying heat exchange at Winfrith. It has also been agreed that Authority staff should assist in the commissioning of the BR.2 reactor at Mol in Belgium.

301. Monsieur Spaak, Director General of the Euratom Supply Agency, visited Springfields, Calder, Risley and the London Office of the Authority in January, 1961.

302. The Authority are collaborating with Euratom and the U.S.A.E.C. in TRANSATOM, a new body set up in Brussels to co-ordinate the collection and dissemination of information concerning translations of nuclear literature.

European Organisation for Nuclear Research (CERN)

303. M. de Rose, President of CERN, visited Harwell, Winfrith and the London Office of the Authority in June, 1960. Mr. J. B. Adams of the Research Group, who was appointed interim Director General of CERN after the tragic death of Mr. C. J. Bakker in an air accident, has now taken up his new appointment as Director of the Research Group's Culham Laboratory but is continuing to act as Director General of CERN until 31st July, 1961.

CENTO Institute of Nuclear Science

304. The CENTO Institute of Nuclear Science in Tehran, under the direction of Mr. H. A. C. McKay of the Authority's Research Group, held a general radio-isotope course and a short course for entomological field workers during the year. Research undertaken includes physical testing projects (the study of water flow problems, tritium counting, physical testing of cement, study of archaeological ceramic specimens), chemistry projects (solvent extraction, cholesterol in chick embryo), plant growth projects and entomological projects. A nuclear science symposium attended by experts from the CENTO countries, the U.K., the U.S. and France took place in Hamadan, Iran, in July, 1960.

Co-operation with other International Organisations

305. Sir John Cockcroft has continued to represent the U.K. on the United Nations Scientific Advisory Committee, and Dr. W. G. Marley is the U.K. alternative representative on the U.N. Scientific Committee on the Effects of

Atomic Radiation. Sir William Cook and senior members of the staff of the Development and Engineering and Production Groups attended a sectional meeting of the World Power Conference in Madrid in June, 1960. Authority staff have taken part in the work of the European Atomic Energy Society and have attended specialised meetings of the International Standards Organisation, the World Health Organisation and the Fifth International Conference on Instruments and Measurements. A member of the staff of the Isotope Research Division, Wantage, helped to organise a Radioisotope Training Course for medical and biological scientists nominated by member governments of the Commission for Technical Co-operation in Africa South of the Sahara (C.C.T.A.) held in Leopoldville in May-June, 1960.

The Commonwealth Countries

306. (i) *Canada*. As in previous years, representatives of the Authority and of Atomic Energy of Canada Limited met to review the progress and scope of their collaboration. The Chairman of the Authority presided over this year's meeting, which was held in London in October, 1960. The Canadian team was led by Mr. Lorne Gray, the President of A.E.C.L., and included all the members of the Executive Committee of the Board of Directors and Dr. C. J. MacKenzie, the President of the Canadian Atomic Energy Control Board. In addition to reviewing the pattern of collaboration and considering the possibilities of co-ordinating work on the steam generating heavy water reactor system, views were exchanged on the prospects for the reactor systems which are being developed independently in the two countries.

(ii) *Australia*. Following discussions in London in June and July, 1960, with Mr. McKnight, the Executive Commissioner of the Australian Atomic Energy Commission, proposals were formulated, within the general terms of the agreement between the Authority and the Commission, for extending the exchange of information in fields in which both organisations are working.

(iii) *Pakistan*. Discussions were held with Dr. Usmani, the Chairman of the Pakistan Atomic Energy Commission, in May, 1960, and again in January, 1961, about ways in which the Authority could help the Commission, particularly by the provision of training.

(iv) *India*. The Chairman of the Authority was the official representative of Her Majesty's Government at the inauguration of the Canada-India research reactor at Trombay in January, 1961. He and Sir John Cockcroft subsequently read papers at a symposium at Trombay on aspects of the U.K. nuclear power programme.

(v) In November, 1960, the Indian Government invited tenders for a 300 MW nuclear power station at Tarapur to be constructed as part of their third Five-Year Plan. In December a team from the Tarapur project visited the U.K. and had discussions with the Authority on commercial aspects of possible fuel supply and nuclear consultancy for the station.

United States of America

307. The Chairman of the Authority, at the invitation of the U.S. Atomic Energy Commission, visited the U.S.A. at the end of May, 1960, to see some of their work and to discuss matters of common interest. Sir William Penney and Sir Claude Pelly also visited the U.S.A. during the year.

308. American visitors to the Authority included the Commission's then Chairman, Mr. McCone, who was in London in December, 1960, and members of the Congressional Joint Committee on Atomic Energy, who visited the U.K. at the end of November and discussed matters of common interest with Members of the Authority.

309. The bilateral agreements between the Governments of the U.K. and of the U.S.A. provide the general framework under which exchanges of information and visits between the Authority and the U.S.A.E.C. take place. Subjects covered by team visits during the year included fast reactors, advanced gas-cooled reactor systems, the development of the gas centrifuge process for the separation of uranium-235, health and safety, and the design and equipment of facilities for plutonium fuel manufacture and feed materials technology. There have been many other visits in both directions by individual staff attending specialist discussions and conferences.

Other Countries

310. Overseas interest in British atomic energy activities has been maintained at a high level. There have been many visits and enquiries concerning British type power reactors and their fuel, while interest in possible licensing arrangements for uranium metal production and natural uranium fuel element manufacture led to detailed negotiations with firms in Federal Germany and in Belgium and to discussions with representatives of the official atomic energy organisations in India and in Japan. The creation and development of new research centres overseas and the developing interest, particularly in Europe, in nuclear marine propulsion have been reflected in the nature of individual visits from overseas to Authority establishments.

Denmark

311. An exchange of notes took place on 20th May, 1960, between the Governments of the U.K. and of Denmark formalising arrangements agreed between the Authority and the Danish Atomic Energy Commission covering the British designed research reactor DR.3, to ensure that nuclear materials and reactors supplied from the U.K. to the Commission should be used only for peaceful purposes (Cmnd. 1127). The Chairman of the Authority and Sir William Cook visited Denmark during the year. Arrangements were made for the Authority to use irradiation space in the DR.3 reactor.

France

312. The collaboration between the Authority and the French Commissariat à l'Energie Atomique was reviewed by representatives of the two bodies at a meeting in London in May, 1960. In November the Chairman of the Authority, Sir William Cook and Dr. Vick visited France to see some of the French atomic energy establishments. Many other visits in both directions by staff of the two organisations were made under the agreed programme of collaboration on the peaceful uses of atomic energy.

Netherlands

313. Under the agreement between the Authority and the Netherlands atomic energy organisation, the Reactor Centrum Nederland, arrangements were made for an exchange of staff to work on aqueous slurry loops.

Spain

314. Senor Otero, President of the Spanish Junta de Energía Nuclear, visited the U.K. in the summer of 1960 at the Authority's invitation. Subsequently, Junta and Authority teams exchanged visits to discuss research and development work on the manufacture of natural uranium fuel elements for civil purposes. The Authority also continued to keep in touch with the Spanish consortia interested in the development of nuclear power. The Chairman of the Authority paid a return visit to Spain in March, 1961, at the invitation of the Junta.

Union of Soviet Socialist Republics

315. The possibility of establishing arrangements to facilitate continuing exchanges concerning the peaceful uses of atomic energy, especially through visits between scientists and other experts of the Authority and the U.S.S.R. Council of Ministers State Committee on Atomic Energy, was discussed informally with Russian representatives during the year.

Yugoslavia

316. A Yugoslav team, reviewing the nature of atomic energy programmes in other countries and engaged upon an assessment of reactor systems, spent 10 days in the U.K. in June, 1960, and visited a number of Authority establishments. Sir John Cockcroft was in Yugoslavia in March, 1961, as the guest of the Federal Nuclear Energy Commission and visited their establishments.

Miscellaneous

317. Authority representatives attended and read papers at many conferences and symposia organised by overseas countries, including the Fifth Instruments and Measurements Congress in Stockholm and the Fifth Nuclear Congress in Rome.

318. In addition to those already mentioned distinguished visitors to Authority establishments during the year included Her Majesty the Queen of the Hellenes; Dr. Siegfried Balke, Minister for Nuclear Affairs in the Federal Republic of Germany; Senator the Hon. W. H. Spooner, MM., Australian Minister for National Development; and Rear-Admiral Octacilio Cunha, then President of the Brazilian Commission for Nuclear Energy.

CHAPTER XIII

THE AUTHORITY'S STAFF

319. The Authority wish to congratulate Dr. H. London of the Nuclear Physics Division of the Research Group on his election to fellowship of the Royal Society in March, 1961.

Senior Staff

320. The Boards of Management of the five 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

321. The total number of staff employed by the Authority increased from 38,500 on 1st April, 1960, to 40,840 on 31st March, 1961. The total number of non-industrial staff increased from 18,928 to 20,234 and industrial employees from 19,572 to 20,606. The rate of expansion was slightly less than during the previous year and is likely to fall still more in 1961 as the manning of the Authority's establishments nears completion.

Recruitment

322. The abolition of National Service and an increase in the number of university grants for higher degrees were among the factors which led to some difficulty in recruiting, particularly in some technical disciplines. In general, however, no serious problems arose in the recruitment of non-industrial staff.

323. Difficulty continued to be experienced in recruiting industrial employees in remote areas or where there is strong competition but, in general, it was possible to obtain an adequate supply of industrial recruits.

Staff and Industrial Relations

324. Through the machinery of the Whitley Council a wide range of subjects was discussed, both centrally and locally, between representatives of the Authority and of the non-industrial staff. During the year various adjustments were made in the salaries of non-industrial staff to take account of outside salary increases.

325. In addition to meetings of the full National Joint Industrial Council and its General Purposes Committee there were regular meetings of local joint industrial committees at all the main establishments and factories and new local Joint Industrial Committees were established at Winfrith and at Risley (also covering Culcheth).

326. Agreements were reached on the National Joint Industrial Council for:—

- (a) a reduction in the working week from 44 to 42 hours for industrial employees;
- (b) improved lead rates for craftsmen and general workers;
- (c) an increase in the national minimum wage rates for male juvenile industrial employees.

327. The Benevolent Fund for non-industrial staff, which is administered under the supervision of the Authority Whitley Council, continued to give financial assistance to members of the staff and their dependents who had need of it.

328. Local benevolent funds gave assistance to industrial employees and new funds were set up at two further establishments with initial financial assistance provided by the Authority.

329. The Joint Committee on Health and Safety (which includes representatives of both non-industrial and industrial employees) met regularly during the year and considered a wide range of subjects concerning the health and safety of the Authority's employees. The corresponding local Joint Sub-Committees which have been set up in the larger establishments also continued to function well.

Superannuation

330. In accordance with Section 2 of the Atomic Energy Authority Act, 1959, arrangements were made during the year for the admission of employees of the National Institute for Research in Nuclear Science to membership of the Authority's superannuation schemes. Certain other minor amendments were made to the Authority's scheme with the approval of the Minister for Science.

331. After consultation with representatives of both non-industrial and industrial employees, it was agreed that members of the Authority's pension schemes should, as far as practicable, be contracted out of the graduated State pension scheme established under the National Insurance Act, 1959. The Registrar of Non-Participating Employment has issued the appropriate certificates of non-participation.

Training

332. The Authority continued to encourage their employees, particularly junior grades, to undertake appropriate part-time courses at technical colleges and colleges of further education. They are granted time off, usually one day a week, to attend day classes and are given financial assistance including the payment of course and examination fees.

333. Promising scientific and engineering staff have continued to be selected for Authority awards for full-time university degree courses and sandwich courses leading to the Diploma in Technology or to professional qualifications. The results for the first of the students to complete Diploma in Technology courses with Authority awards became known during the year; two students obtained Diplomas in Technology with first-class honours and three with second-class honours.

334. Internal courses established in previous years to meet the particular training needs of staff at the Authority's establishments were continued and developed and a number of new courses were introduced. Management conferences were held for senior staff and arrangements made for parties of scientists and engineers from all Groups to meet to discuss topics of special interest to the Authority's work.

335. The Authority recruited 23 student apprentices and 192 craft apprentices during the year for training in their various establishments. This reflects the importance which the Authority attach to the recommendations of the National Joint Advisory Council in 1957 (the Carr Committee Report) for the recruitment and training of the larger numbers of young people leaving school.

Housing

336. The number of houses owned by the Authority at 31st March, 1961, was 5,778 with 163 under construction or planned; 2,116 houses have been provided by local authorities for Authority employees coming into their areas and a further 536 are planned.

Hostels and Canteens

337. Additional accommodation completed during the year brought the total number of places available for employees in the Authority's hostels to 2,251. A hostel for apprentices is under construction at Dounreay. Plans have been made to provide a new hostel for Winfrith and hostels elsewhere in the Authority have been, or are being, extended.

338. A new canteen, with 700 places, was opened at Winfrith and another, with 1,250 places, at Windscale.

APPENDIX I

MEMBERSHIP OF ATOMIC ENERGY AUTHORITY AS AT 1st APRIL, 1961

Chairman

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

Deputy Chairman

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

Full-time Members

Sir William Cook, C.B.

(Member for Reactors)

Sir Alan Hitchman, K.C.B.

(Member for Finance and Administration)

Sir Leonard Owen, C.B.E.

(Member for Production and Engineering)

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., F.R.S.

Sir James Chadwick, F.R.S.

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

Mr. S. J. Pears, F.C.A.

Mr. R. M. Geddes, O.B.E.

Secretary

Mr. D. E. H. Peirson

APPENDIX II

ATOMIC ENERGY AUTHORITY SENIOR STAFF AS AT 1st APRIL, 1961

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)

REACTOR GROUP

Headquarters, Risley

R. V. Moore, G.C.	..	..	..	Managing Director
P. T. Fletcher, C.B.E.	..	..	..	Special Adviser to Member for Reactors
Dr. H. Kronberger, O.B.E.	..	..	..	Deputy Managing Director (Development)
A. M. Allen	..	..	..	Director of Personnel and Administration
H. Cartwright, M.B.E.	..	..	..	Director of Industrial Power
S. Fawcett	..	..	..	Director of Reactor Design
F. W. Fenning	..	..	..	Director of Reactor Technology
Dr. H. K. Hardy	..	..	..	Director of Fuel Element Development
D. R. Newman	..	..	..	Director of Finance

Atomic Energy Establishment, Winfrith

D. W. Fry	..	..	..	Director
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Dounreay Experimental Reactor Establishment

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

ENGINEERING GROUP

Headquarters, Risley

J. B. W. Cunningham	..	..	..	Managing Director
H. V. Disney, C.B.E.	..	..	..	Deputy Managing Director
J. D. Glanville, O.B.E.	..	..	..	Director of Supply Services
D. S. Mitchell	..	..	..	Director of Personnel and Administration
J. Tatlock, M.B.E.	..	..	..	Director of Fuel Element Design and Inspection
C. J. Turner, C.B.E.	..	..	..	Director of Plant Design
T. L. Viney	..	..	..	Director of Works and Buildings

Southern Works Organisation, Tadley

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

Headquarters, Risley

J. C. C. Stewart, C.B.E.	..	..	..	Managing Director
Dr. J. M. Hill	..	..	..	Deputy Managing Director
Dr. N. L. Franklin	..	..	..	Technical Director
Dr. A. B. McIntosh	..	..	..	Liaison Director
D. S. Mitchell	..	..	..	Personnel and Administration Director
K. B. Ross, O.B.E.	..	..	..	Operations Director

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

RESEARCH GROUP

Atomic Energy Research Establishment, Harwell

Dr. F. A. Vick, O.B.E. Director, Research Group and A.E.R.E.,
Harwell
Dr. R. Spence, C.B., F.R.S. Deputy Director
L. Grainger Assistant Director
R. F. Jackson Chief Engineer
T. B. Le Cren General Secretary

The Culham Laboratory

J. B. Adams Director

Radiochemical Centre, Amersham

Dr. W. P. Grove Director

WEAPONS GROUP

Atomic Weapons Research Establishment, Aldermaston

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

Foulness Establishment

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

Woolwich Common

G. A. Bailey Superintendent

Orfordness Establishment

H. S. Weeks Group Leader

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. 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
Pensions and Taxation Matters.

APPENDIX III

THE AUTHORITY'S REACTORS AS AT 31st MARCH, 1961

Research and Experimental Reactors

NAME	LOCATION	DATE OF START-UP	PEAK NEUTRON FLUX THERMAL n/cm^2 sec.	MAXIMUM HEAT OUTPUT	MODERATOR	COOLANT	FUEL	PURPOSE
1. GLEEP ..	Harwell	1947	3.7×10^{10}	100 kW	Graphite	Air	Natural uranium	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. LIDO ..	Harwell	1956	10^{12}	100 kW	Light water	Light water	Uranium 235	Thermal reactor studies, including shielding.
4. Dido ..	Harwell	1956	2.2×10^{14}	12.5 MW	Heavy water	Heavy water	Uranium 235	Nuclear reactor material studies; isotope production; neutron physics; radiation chemistry.
5. 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.
6. D.M.T.R. ..	Dounreay	1958	1.2×10^{14}	10 MW	Heavy water	Heavy water	Uranium 235	Studies on nuclear reactor materials.
7. HORACE ..	Aldermaston	1958	about 10^8	10 Watts	Light water	Light water	Uranium 235	To obtain basic nuclear information on HERALD.
8. 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).

9. ZENITH ..	Winfrith Heath	1959	10 ⁸	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 temperature 800°C in core, 400°C in reflector).
10. NERO ..	Winfrith Heath	1960	2 × 10 ⁸	Less than 10 Watts	Graphite	None	Enriched uranium	Investigations for advanced graphite-moderated reactors; pile oscillator studies.
11. HERALD ..	Aldermaston	1960	5 × 10 ¹³	5 MW	Light water	Light water	Uranium 235	Neutron physics; radiochemical and nuclear reactor materials studies.
12. VERA ..	Aldermaston	1961	—	100 Watts	None	None	Highly enriched uranium	Experimental studies of fast reactor systems.
13. NESTOR ..	Winfrith Heath	1961	10 ¹¹	10 kW	Light water	Light water	Enriched uranium—aluminium alloy	Source of neutrons for sub-critical assemblies.

Research and Experimental Reactors under construction

14. AGR ..	Windscale	1961	2.5 × 10 ¹³	100 MW (28 MW(E) Net)	Graphite	Carbon dioxide	Enriched uranium oxide	To study the advanced gas-cooled power reactor system and to test fuel elements for the system.
15. HERO ..	Windscale	1961	—	A few Watts	Graphite	Carbon dioxide used as a heating gas	Enriched uranium oxide	Reactor physics studies for the advanced gas-cooled reactor system.
16. DAPHNE ..	Harwell	1962	2 × 10 ⁹	up to 100 Watts	Heavy water	Heavy water	Uranium 235	To simulate Dido and Pluto, and to provide basic information in support of those reactors.

Research and Experimental Reactors under construction (contd.)

NAME	LOCATION	DATE OF START-UP	PEAK NEUTRON FLUX THERMAL n/cm ² sec.	MAXIMUM HEAT OUTPUT	MODERATOR	COOLANT	FUEL	PURPOSE
17. HECTOR	Winfrith Heath	Mid-1962	3×10^8	up to 100 Watts	Graphite	Carbon dioxide used as a heating gas	Permanent fuel: enriched uranium alloy. Central core: variable	Oscillator reactor — reactivity measurements on materials and fuel elements.
18. ZEBRA	Winfrith Heath	1962	5×10^9 fast flux	100 Watts	None	None	Uranium 235; plutonium	A flexible system intended primarily to investigate the physics of large fast reactors.

Plutonium/Power Producing Reactors (in production)

19-22. Calder (2 stations) ("A" and "B") (4 reactors)	Calderbridge	Station "A" 1956 Station "B" 1958	—	200 MW (nominal) per reactor (37 MW(E) Net)	Graphite	Carbon dioxide	Natural uranium	Plutonium and power production.
23-26. Chapelcross (4 reactors)	Annan	1958 (1st reactor) 1959 (reactors 2, 3 and 4)	—	200 MW (nominal) per reactor (37 MW(E) Net)	Graphite	Carbon dioxide	Natural uranium	Plutonium and power production.

NOTE: ZEUS was dismantled in September, 1957, ZEPHYR in June, 1958, and HAZEL in September, 1958. NERO was dismantled at Harwell and re-erected at Winfrith in 1960. NEPTUNE ceased operation in June, 1959. DIMPLe was dismantled in December, 1960, and is to be re-erected at Winfrith in 1961.

APPENDIX IV

BALANCE SHEET OF THE UNITED KINGDOM ATOMIC ENERGY AUTHORITY AS AT 31st MARCH, 1960

FOREWORD

1. The sixth Balance Sheet of the United Kingdom Atomic Energy Authority, as at 31st March, 1960, 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 31st March, 1960, is withheld from publication in the interests of national security.

2. The Authority are financed by 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 Office of the Minister for Science 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 Production Group operates factories and the whole cost of their operation including expenditure on research, development and design is regarded as recoverable in the prices of its products.
- (b) The Development and Engineering Group undertakes research, development, engineering and consultancy work not only in aid of current projects but also for possible future reactor systems. Expenditure of this Group, including amortisation of fixed assets, less recoveries, is regarded as a charge to be borne by H.M. Exchequer.
- (c) 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.
- (d) The Weapons Group undertakes the production of components for weapons and research work in connection with weapons, both under contract from the Ministry of Aviation. It also undertakes other research and development. The cost of the operation of this Group, less the amounts chargeable to the Ministry of Aviation for production and research, and other income, is regarded as a charge to be borne by H.M. Exchequer.

4. The charge for interest on capital has 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 1959–60 resulted in weighted averages of 5·31 per cent. on fixed capital and 4·17 per cent. on working capital.

29th November, 1960.

UNITED KINGDOM ATOMIC

BALANCE SHEET AS AT

31 March 1959			£	£
£				
363,754,960	I. CAPITAL ACCOUNT			
	Balance at 1 April 1959		432,986,012	
94,531,770	Net advances from Office of the Minister for			
18,510,221	Science		85,455,971	
	Interest on capital		21,614,138	
476,796,951			540,056,121	
	Deduct—			
43,810,939	Net Cost of Operations for the year		58,602,608	
432,986,012	Capital Account at 31 March 1960			481,453,513
	II. RESERVE FOR LOSSES (in lieu of insurance) (see Note 3)			
	Balance at 1 April 1959		4,550,568	
	Add—			
	Amount charged to operating costs in the year ..		2,300,000	
			6,850,568	
	Deduct—			
	Charged in the year		210,521	
4,550,568				6,640,047
10,436,243	III. CURRENT LIABILITIES AND PROVISIONS			
340,728	Trade creditors and accrued liabilities		16,413,210	
	Payments in advance		6,586,906	
845,675	Provisions for superannuation and special main- tenance		949,808	
				23,949,924
449,159,226				512,043,484
10,615,336	IV. PRINCIPAL NON-INDUSTRIAL SUPERANNUATION SCHEME			
	Balance at 31 March 1960			13,583,910
2,370,202	V. PROTECTED PERSONS SUPERANNUATION SCHEME			
	Balance at 31 March 1960			2,610,609
656,307	VI. INDUSTRIAL SUPERANNUATION SCHEME			
	Balance at 31 March 1960			1,225,136
	Notes forming part of this Balance Sheet are appended (see page 80).			
£462,801,071				£529,463,139

ENERGY AUTHORITY

31 MARCH 1960

31 March 1959 £		As valued at 1 August 1954 plus additions at cost £	Depre- ciation £	£
	I. FIXED ASSETS, at cost or estimated cost less depreciation			
559,463	Freehold land	592,911	—	592,911
95,205,855	Buildings, ancillary installations, housing and hostels	123,642,407	18,862,819	104,779,588
111,210,674	Plant and machinery, motor vehicles, loose apparatus, tools and equipment	168,212,382	37,757,711	130,454,671
3,176,638	Furniture, fittings and office machinery	4,221,967	881,091	3,340,876
222,007	Capital assistance—assets with assisted contractors	519,006	272,776	246,230
210,374,637		£297,188,673	57,774,397	239,414,276
40,072,191	Assets in course of construction			30,308,918
250,446,828				269,723,194
	II. SPECIAL DEVELOPMENT AND DEFERRED REVENUE EXPENDITURE LESS AMOUNTS WRITTEN OFF			
910,609	Initial production expenses		498,285	
2,685,577	Research and development expenditure in aid of design		1,065,027	1,563,312
	III. LOANS, ADVANCES AND INVESTMENTS			
21,353,465	Loans and advances for the production of uranium, including accrued interest		17,680,482	
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 £12,229)		14,871	17,695,353
	IV. CURRENT ASSETS			
50,981,790	Stocks of raw materials and stores (see Note 4)		79,622,816	
113,612,697	Work in progress (see Note 4)		131,932,565	
6,983,777	Debtors, deposits and payments in advance		9,914,978	
2,169,612	Balances with Paymaster-General, with bankers and cash in hand		1,591,266	223,061,625
449,159,226				512,043,484
	V. PRINCIPAL NON-INDUSTRIAL SUPERANNUATION SCHEME FUND			
10,573,845	Amount due from H.M. Exchequer (see Note 5)		13,542,562	
41,491	Insurance policies		41,348	13,583,910
	VI. PROTECTED PERSONS SUPERANNUATION SCHEME FUND			
2,370,202	Amount due from H.M. Exchequer (see Note 6)			2,610,609
	VII. INDUSTRIAL SUPERANNUATION SCHEME FUND			
656,307	Amount due from H.M. Exchequer (see Note 7)		1,225,101	
—	Insurance policies		35	1,225,136
£462,801,071				£529,463,139

Roger Makins, Chairman.

E. A. Hitchman, Member.

NOTES

These notes form part of the Balance Sheet as at 31 March 1960.

1. Capital expenditure authorised but not provided for in these Accounts amounted to £56m. of which £23m. had been committed contractually.
2. The Authority have extensive commitments for the purchase under contract of uranium concentrates and graphite.
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. Stocks and work in progress are valued at the lower of cost or realisable value.
5. 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 1960	9,115,526
Interest on funds treated as deposited with H.M. Exchequer	1,233,940
	<u>£13,542,562</u>

The first actuarial valuation of the Scheme is being undertaken as at 31 March 1960, but the outcome is not yet known.

6. 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 industrial civil servants transferred to the Authority	1,094,511
Excess of contributions and other receipts over benefits and other outgoings for the period 1 August 1954 to 31 March 1960	1,159,446
Interest on funds treated as deposited with H.M. Exchequer	356,652
	<u>£2,610,609</u>

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

7. 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 1960	1,190,067
Interest on funds treated as deposited with H.M. Exchequer	35,034
	<u>£1,225,101</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 1960.

E. G. Compton,
Comptroller and Auditor General.

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