

UNITED KINGDOM
ATOMIC ENERGY
AUTHORITY

FIFTH
ANNUAL REPORT
1958-59



LONDON
HER MAJESTY'S STATIONERY OFFICE
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UNITED KINGDOM
ATOMIC ENERGY AUTHORITY

FIFTH
ANNUAL REPORT

For the Period
1st April, 1958—31st March, 1959

*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
21st July 1959*

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UNITED KINGDOM
ATOMIC ENERGY AUTHORITY

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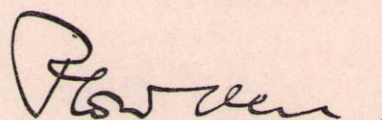
11th June, 1959

FIFTH
ANNUAL REPORT

SIR,

I have the honour to submit, in accordance with Section 3 (5) of the Atomic Energy Authority Act, 1954, the Fifth Annual Report of the United Kingdom Atomic Energy Authority. This Report covers the period from 1st April, 1958, to 31st March, 1959.

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



Chairman.

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

CONTENTS

	<i>Page</i>
CHAPTER I. Introduction, Membership, Finance and Accounts ...	1
Introduction	1
Board Membership	2
Finance	3
Accounts	3
 CHAPTER II. Five Years of Progress on Fission, Fusion and Radio-isotopes ...	 4
Fission	4
Controlled Fusion	5
Radioisotopes	5
 CHAPTER III. Raw Materials ...	 6
Uranium	6
Combined Development Agency	7
Combined Development Agency Contracts	7
United Kingdom Contracts	7
Australia	7
Canada	7
Central African Federation	7
South Africa	7
Prospecting	8
Beryllium and Helium	8
Technical Services	8
 CHAPTER IV. Production Plants ...	 8
Springfields	8
Windscale and Calder	9
Chemical Plants	9
Calder Reactors	9
Chapelcross	10
Capenhurst	10
 CHAPTER V. The Reactor Development Programme ...	 10
 Part I	
GENERAL	
Reactors for Power Generation—Objectives	10
Marine Propulsion	11
Submarine Propulsion	11
Surface Propulsion	11

	<i>Page</i>
Part II	
REACTORS UNDER CONSTRUCTION	
Work for United Kingdom Electricity Boards' Reactors	12
Fast Reactor	12
Advanced Gas-Cooled Reactor	13
Part III	
MAJOR REACTOR INVESTIGATIONS	
Water Moderated Reactors for Power Generation	13
High Temperature Gas-Cooled Reactor	14
Part IV	
OTHER REACTOR STUDIES	
Organic-Liquid-Moderated Reactors	15
General Technological Work	15
Research Reactors	16
CHAPTER VI. Controlled Thermonuclear Reactions	16
Work at Harwell and in Industry	16
ZETA I and Sceptre III and IV	17
Small Scale Apparatus	18
Technological Development	19
Work at the Atomic Weapons Research Establishment	20
C.T.R. Advisory Committee	21
CHAPTER VII. Other Research and Development	22
Part I	
RESEARCH GROUP	
Metallurgical Research	22
Physics of the Solid State	24
Graphite	24
Metals and Alloys	25
Diffusion in Solids	25
Work on Particle Accelerators	25
Part II	
INDUSTRIAL GROUP	
General	27
Calder Type Reactors	28
Fuel Elements	28
Moderator	29
Steel	29
Reactor Physics	30

	<i>Page</i>
Advanced Gas-Cooled Reactor	30
Fuel Elements	30
Moderator	31
Reactor Physics	32
Safety	32
Processing	33
Springfields	33
Windscale	33
Capenhurst	33
 Part III WEAPONS GROUP 	
General	34
High Energy Machines	34
Safety	34
Applied Chemistry	35
Chelate Derivatives	35
Particle Size Measurements	35
Decontamination	36
Data Processing	36
CHAPTER VIII. Isotopes and Irradiation Programmes	36
Sales	36
Reorganisation of Marketing and Production	36
Production	37
Isotope Applications	37
Large Scale Irradiation Work	37
Exhibitions	38
Isotope School	38
CHAPTER IX. The Weapons Programme	38
CHAPTER X. Health and Safety	39
Review of Health and Safety Organisation	39
The Shortage of Specialist Health and Safety Staff	40
Protection of the Staff	40
Non-radioactive Hazards	41
Research into Health and Safety Problems	42
Fallout from Nuclear Tests	42
Whole Body Monitor	42
Waste Disposal	42
Co-operation with Government Departments	43
International Co-operation	44

	<i>Page</i>
CHAPTER XI. Public Relations	44
Exhibitions	44
Films	45
Publications	46
Photographs	46
Public Information Room	46
CHAPTER XII. Commercial Relations	47
Relations with Industry... ..	47
Harwell Reactor School	48
Calder Operations School	48
Attachments of Staff from Industry	48
Sales of Technical Information	48
Sale of Goods	49
Fuel Elements	49
Other Products	49
CHAPTER XIII. International Relations	50
International Organisations	50
Bagdad Pact Nuclear Centre	50
Euratom	50
European Nuclear Energy Agency	51
Boiling Water Reactor	51
High Temperature Gas-Cooled Reactor	51
International Atomic Energy Agency	52
United Nations	52
U.N. Scientific Committee on the Effects of Radiation, Report	52
Co-operation with Other International Organisations... ..	52
Commonwealth Countries	52
Commonwealth Conference and Tour	52
Canada	52
Australia and New Zealand	53
India	53
United States of America	53
Japan	54
Other Countries	54
CHAPTER XIV. The Authority's Staff	55
Senior Staff	55
Strength	55
Recruitment	55
Staff and Industrial Relations	56

UNITED KINGDOM ATOMIC ENERGY AUTHORITY

FIFTH ANNUAL REPORT

1958—1959

CHAPTER I

Introduction, Membership, Finance and Accounts

Introduction

1. The year 1958-59 saw steady progress in both civil and defence applications of atomic energy in the United Kingdom.

2. On the civil side, work started during the year on construction at Windscale of the advanced gas-cooled reactor prototype. A zero energy reactor to be known as HERO is to be built to complement the work of the A.G.R. prototype.

3. An agreement with the United States for exchange of a wide range of nuclear defence information was concluded on 3rd July, 1958. This agreement, which also permitted purchase from the United States of machinery and fuel for a nuclear submarine prototype, makes possible close collaboration between the two countries on weapon development.

4. The last of the four Calder Hall reactors became critical on 8th December, 1958, and the first reactor at Chapelcross came into use for electricity generation on 25th February, 1959.

5. The millionth uranium fuel rod was produced at Springfields in January, 1959, and the thousandth student was enrolled at the Authority's Isotope School in November, 1958. During the year the Authority's staff increased from 30,341 to 35,260.

6. Construction work on the site being developed on Winfrith Heath in Dorset for the Atomic Energy Establishment, Winfrith, has continued satisfactorily. A general services building and the first zero energy reactor building were occupied during March, 1959, and installation of the ZENITH zero energy experiment was proceeding. Scientific and engineering design work in connection with reactor research had started, and by March, 1959, the Research Group staff at Winfrith totalled 750. The on-site section of the effluent pipeline to the sea was completed during the year, and preparations for continuing it out to sea were in hand. An apprentices' school and hostel were opened in September, 1958, and 60 boys commenced their training.

7. In September, 1958, the Authority announced that they proposed during the period 1960 to 1963 to move from Harwell to Winfrith Heath the whole of the controlled thermonuclear project. The Authority later decided that this question should be further examined, and a final decision had not been reached at the end of the financial year.

8. The Final Report of the Committee appointed by the Prime Minister to make a technical evaluation of the information relating to the design and operation of the Windscale piles, and to review the factors involved in the controlled release of Wigner energy, was presented to Parliament in July, 1958. The Authority subsequently decided to close the piles down and seal them, in view of the expense which would have been involved in rehabilitating No. 1 pile and in altering No. 2 pile to conform with the recommendations made by the Committee, and also because both piles were approaching obsolescence.

9. The total number of visitors to the Authority's establishments during the year was 60,889.

10. Internationally, the most important event of the year was the second Geneva Conference on the Peaceful Uses of Atomic Energy, held in September, 1958.

11. After the Geneva Conference, representatives of the Commonwealth countries made a tour of some of the Authority's establishments.

12. An agreement for co-operation between the United Kingdom and Euratom was signed at the Foreign Office on 4th February, 1959. Collaboration between twelve European countries in the development at the Atomic Energy Establishment, Winfrith Heath, of the high temperature gas-cooled reactor experiment (Dragon) was provided for in an agreement signed in Paris on 23rd March, 1959, under the auspices of the European Nuclear Energy Agency. During the year, bilateral agreements were concluded also with Japan and Portugal.

13. The terms of the first contract for the supply of fuel for a nuclear power station overseas—the Latina station of Agip Nucleare—were negotiated during the year.

14. The sudden death of Sir Claude Gibb, Chairman of the Nuclear Power Plant Company Limited, on 15th January, 1959, robbed the British nuclear energy industry of one of its most energetic and farsighted leaders.

Board Membership

15. The membership of the Authority as at 31st March, 1959, is set out at Appendix I.

16. During the year a number of changes were effected or announced in the full-time membership of the Authority. Mr. W. Strath relinquished his appointment as Member for External Relations and Commercial Policy on becoming Permanent Secretary to the Ministry of Supply, and was succeeded on 1st April, 1959, by Sir Alan Hitchman. Sir John Cockcroft, who has been appointed Master of Churchill College, Cambridge, will be succeeded as Member for Scientific Research by Sir William Penney on 1st July, 1959. Sir John will remain on the Board of the Authority as a part-time Member, and will continue to represent the Authority on a number of international organisations.

17. Two further changes were announced on 20th March, 1959. First, the Authority decided to divide the Industrial Group into two. The two Groups are to be entitled respectively "Development and Engineering" and "Production". Sir William Cook will be the Member for Development

and Engineering ; Sir Leonard Owen will be the Member (Designate) for Production. The Authority consider that this division of responsibility will make for better management, having regard to the size and diversity of activities of the Industrial Group.

18. Second, the Authority decided to restore to their technical Members executive as well as functional responsibility. Experience has shown that the separation of functional from executive responsibility described in paragraph 23 of the Fourth Annual Report does not suit the particular circumstances of the Authority as well as the previous arrangement, which will accordingly be restored from 1st July, 1959. Sir William Penney will then have executive responsibility for the Research Group as well as functional responsibility for scientific research throughout the Authority. Sir William Cook will have executive responsibility for the Development and Engineering Group as well as functional responsibility for these subjects throughout the Authority. Sir Leonard Owen will have executive responsibility for the Production Group, and a new Member for Weapons Research and Development, when appointed, will have executive responsibility for the Weapons Group.

Finance

19. The Authority's Estimates for 1958-59 were presented to Parliament on 17th February, 1958, as part of the Atomic Energy Vote (Civil Estimates, Class IX, 7), and were approved for the net sum of £105,744,010.

20. A Supplementary Estimate of £80,010 was approved by Parliament on 8th July, 1958. This was to sanction contributions towards international atomic energy projects in which the Authority are associated with other member countries of the European Nuclear Energy Agency. The projects include research and development and the construction and operation of experimental reactors. The contributions consisted of £80,000 towards the cost of the boiling water reactor experiment in Norway, and a token sum of £10 for reactor experiments in the United Kingdom.

21. The Authority's Estimates for 1959-60 were presented to Parliament on 10th February, 1959, as a net total of £92,433,010, a decrease of £13,391,010 compared with the 1958-59 Estimates. Increased expenditure on salaries and wages, other current expenditure and grants to the National Institute for Research in Nuclear Science, are more than offset by increased receipts under appropriations-in-aid and reduced expenditure on works services, plant and machinery.

22. On 21st January, 1959, a sub-committee of the Select Committee on Estimates of the House of Commons started an examination of the Authority's Estimates so far as they relate to the Industrial Group.

Accounts

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

24. The Balance Sheet as at 31st March, 1958, was submitted to the Comptroller and Auditor-General on 27th November, 1958, and will in due course be presented to Parliament.* (The Operating Account is withheld from publication in the interests of national security.)

CHAPTER II

FIVE YEARS OF PROGRESS ON FISSION, FUSION AND RADIOISOTOPES

25. The Fifth Annual Report of the Atomic Energy Authority is an occasion for reviewing the progress which has been made during the last five years in the applications of nuclear energy.

26. Up to 1955 much of the research and development work in atomic energy was carried on, if not in secret, at least without attracting any large degree of attention except among the technologists directly concerned. 1955 was the first year of great publicity: it saw the publication of the British "Programme of Nuclear Power" and the first United Nations Conference on the Peaceful Uses of Atomic Energy. The many spectacular achievements which were announced then and have been announced since were the fruit of ten years' work which till then had been largely unnoticed. The rate of advance continues to be rapid; but further progress can only come from research that is increasingly complex and expensive both in money and in men, and it takes time.

27. The opening of Calder Hall in 1956 and its successful operation since then have demonstrated conclusively that electricity can be produced from nuclear power on an industrial scale. We are now in a period of consolidation. The next step is to improve the economics of nuclear power, and intensive work is being carried on to this end. At the same time, the Authority continue to devote substantial effort to research and development on controlled fusion reactions and on the production and application of radioisotopes.

Fission

28. During this period the first five large scale nuclear power stations have come into operation; Calder Hall and Chapelcross, the United States' 60 MW pressurised water reactor power station at Shippingport, the French 30 MW gas-cooled, graphite-moderated reactor power station at Marcoule and the Union of Socialist Soviet Republics' 100 MW graphite-moderated, water-cooled reactor power station in Siberia.

29. Most of these are dual purpose stations and none of them was designed to be economic as an electricity producer. They are being followed by the construction of larger output nuclear power stations designed specifically for the production of electricity. The United Kingdom electricity boards are building stations at Berkeley, Bradwell, Hinkley Point and

* Ordered by the House of Commons to be printed on 14th May, 1959, and now on sale at Her Majesty's Stationery Office (price 6d). The Balance Sheet, together with the Authority's foreword, is reproduced at Appendix III.

Hunterston with a total output of about 1,400 MW. The U.S. are building ten water-moderated reactor power stations with a total output of about 800 MW and a fast reactor station with an output of 100 MW. The U.S.S.R. is building three large power stations with a total output of 1,400 MW including the 500 MW Siberian station. The electricity authorities of France are building two stations of 250 MW total output and Italy is building two stations with a total output of 350 MW.

30. Nuclear propulsion for military vessels is now well established. The United States have three nuclear submarines in commission, others building, and three nuclear warships under construction. The first two civil nuclear propelled ships are being built. The U.S.S.R. icebreaker LENIN, propelled by 44,000 s.h.p. turbines deriving heat from two of its three pressurised water reactors, will come into commission in 1959. The United States SAVANNAH, a combined passenger cargo ship of 21,800 tons displacement, propelled by a 22,000 s.h.p. unit also powered by a pressurised water reactor, will come into commission in 1960. The SAVANNAH is not intended to be competitive with conventional ships.

31. In the United Kingdom gas-cooled, graphite-moderated reactors are developing towards higher temperatures of operation, first to exit gas temperatures of 550°C and later to 750°C. This leads to higher efficiency and gives scope for higher ratings. For water-moderated systems heavy water may be used as a variant to light water to achieve lower fuel costs, and designs may incorporate superheating steam in the reactors to improve overall efficiencies. Later in the development time scale is the fast reactor to be fuelled with plutonium produced in the first generation of civil power stations. The high temperature, gas-cooled reactor aims at operating on the thorium cycle with a high conversion ratio of thorium to uranium-233. In the course of these developments metallic fuel will generally give way to ceramic fuels, which seem likely to achieve much higher burnups.

32. Capital costs of nuclear power stations are predicted to fall by about 30 per cent below present levels as the development potential of the present main types is realised. Further falls should be possible as advanced types, such as the fast and high temperature gas-cooled reactors, come into operation.

Controlled Fusion

33. Work proceeding in the U.K., U.S., U.S.S.R., and Western Europe on controlled fusion reactors was described at the 1958 Geneva Conference.

34. In all projects the hot plasma (ionised gas) is confined by magnetic fields, the so-called magnetic bottle, with the aim of keeping the plasma away from the walls of the containing vessel and thereby preventing loss of energy by conduction. The main difficulty at the moment is to prevent instabilities of the plasma from causing excessive losses of energy.

35. The rate of energy loss will need to be greatly reduced, and temperatures increased tenfold, before a practical fusion reactor can be contemplated.

Radioisotopes

36. The application of radioactive isotopes continues steadily to grow both in range and importance to science and industry. The carbon-14

labelled compounds have proved to be of great importance in studying metabolic processes such as the synthesis of proteins from nucleic acid. The tritium labelled compounds are now beginning to have a similar importance since the short range of the electron emitted from tritium allows a very precise localisation of the tritium in tissue. Thus the process by which thymidine is incorporated into D.N.A. molecules (deoxyribose nucleic acid) and thence into chromosomes has enabled the biologist to follow the phenomenon of chromosome division and duplication.

37. In industry the use of control instruments based on radioactive isotopes, such as thickness gauges, continues to grow. Gamma radiography is now a standard tool in industry. Oil well logging and oil well stimulation are aided by radioisotopes.

38. Tens of thousands of curies of radio-cobalt are now becoming available as by-products from reactor operation. In the future the annual production of radio-cobalt may reach millions of curies. Several commercial applications to sterilisation have already been found and applications to industrial chemistry are being pursued. Radio-caesium is being extracted from radioactive waste in the United States at the rate of 200,000 curies per annum and plans for its extraction are being considered in the United Kingdom. The potential output of radio-caesium amounts to tens of millions of curies per annum.

CHAPTER III

RAW MATERIALS

Uranium

39. Developments during the past year have confirmed that there is now an over-supply of uranium which is likely to persist at least until the late 1960's. The uranium requirements of the free world's current military and civil programmes can now be met by mines already in production. In fact adequate orders may not be available to keep all existing producers in operation throughout this period. With this change to a buyer's market, and the consequent competition to secure the limited orders likely to be available, it is clear that the forward price for additional supplies of uranium will fall. It now seems likely that the forward price may fall even lower than \$8 per lb. which was, until recently, the price guaranteed by the United States Atomic Energy Commission to all United States domestic producers, but which is now restricted to production from reserves established by November, 1958. This changed situation is well known to all the major mining companies, and the position is gradually becoming more widely known among private prospectors.

40. In these circumstances the Authority consider that the attention of all concerned should be drawn to the need, before becoming involved in any expenditure, to weigh what chances there are that a new uranium mine could be brought into production assuming a selling price, including amortisation, probably even lower than \$8 per lb.

41. During the year deliveries to this country began of material purchased under major United Kingdom contracts with Eldorado Mining and Refining Limited of Canada and with Mary Kathleen Uranium Limited

of Queensland, Australia. The major part of the Authority's uranium supplies during 1958-59, however, came from Combined Development Agency sources under continuing contracts of many years' standing.

Combined Development Agency

42. The Combined Development Agency consists of six members: three from the United States, two from the United Kingdom, and one from Canada. The present members are:

U.S. Members

General A. R. Leudecke, General Manager, U.S.A.E.C. (Chairman of CDA).

Mr. Jesse C. Johnson, Director, Division of Raw Materials, U.S.A.E.C.

Mr. John A. Hall, Assistant General Manager for International Activities, U.S.A.E.C.

U.K. Members

Sir Alan Hitchman, Member for External Relations and Commercial Policy, U.K.A.E.A. (Deputy Chairman of CDA).

Mr. E. J. S. Clarke, Principal Metals Officer, U.K.A.E.A.

Canadian Member

Mr. George C. Bateman, until lately a Member of the Atomic Energy Control Board of Canada.

43. The Joint Secretaries are Mr. R. L. Faulkner, U.S.A.E.C., and Mr. H. Hunt, U.K.A.E.A.

Combined Development Agency Contracts

44. The greater part of the Agency's supplies of uranium concentrates during the year were of South African origin. Other supplies came from the Belgian Congo, Australia and Portugal. In May, 1958, an agreement was reached with the South African Atomic Energy Board to restrict deliveries to the Agency. Discussions to limit supplies to the Agency from certain other sources were initiated during the year.

United Kingdom Contracts

45. *Australia.* The Mary Kathleen treatment plant in N.W. Queensland was officially opened by Mr. Menzies, the Australian Prime Minister, in October, 1958. The first shipment under the Authority's contract was made in the same month. In fulfilment of their 1956 undertaking (see Second Annual Report, paragraph 23 (a) (iii)) the Authority have concluded agreements with two companies operating in the South Alligator River area of the Northern Territories for the supply of up to 700 tons of uranium oxide between 1959 and 1966.

46. *Canada.* Deliveries from the Eldorado Mining and Refining Limited commenced in July, 1958.

47. *Central African Federation.* Deliveries from the Rhokana Corporation's plant at Mindola in Northern Rhodesia have continued.

48. *South Africa.* Arrangements were completed with the Harmony Gold Mining Company Limited for the supply of up to 1,500 tons of uranium oxide between 1st July, 1958, and 31st December, 1966.

Prospecting

49. In fulfilment of long standing arrangements, the Authority have sent a geologist to New Zealand to assess the uranium occurrences in the Buller Gorge. An airborne radiometric survey was undertaken over parts of Kenya and Tanganyika. In the U.K. the airborne geophysical survey undertaken last year in south-west Cornwall was extended to east Cornwall and parts of Devonshire and ground investigations were continued. This survey was carried out jointly with the U.K. Geological Survey. In view of the present trend of the uranium market, the Authority do not propose to undertake any further prospecting commitments for uranium.

Beryllium and Helium

50. Purchases of beryl ore were reduced in view of the adequate stock already accumulated. Drilling for helium in Tanganyika was terminated without any economic supplies of gas being found.

Technical Services

51. Technical services continued to be provided by the Radio-Chemical Laboratory of the National Chemical Laboratory at Teddington, the Atomic Energy Division of the Geological Survey of Great Britain, the Mining Division of the Colonial Development Corporation, and the Geological Instrumentation Research Group and the Mineral Dressing Laboratory of the Atomic Energy Research Establishment. Arrangements were completed during the year for handing over the Authority's research work on mineral dressing to the newly established Warren Spring Laboratory of the Department of Scientific and Industrial Research at Stevenage.

CHAPTER IV

PRODUCTION PLANTS

52. Modification of existing plants and commissioning of new plants resulted in an increased output of all materials produced by the Operations Branch of the Industrial Group. In particular, the output of fissile material increased by more than 50 per cent during the year. The total number of staff employed by the Operations Branch increased by 15 per cent. Technical Sections were established at each Works to provide the technical support which the Works Managements require to ensure the safe and efficient operation of the production plants.

Springfields

53. On 7th June, 1958, the second Springfields uranium plant was opened. It is designed to satisfy all the fuel element demands of the first civil power reactors, and to provide uranium and uranium oxide fuel for experimental and prototype reactors.

54. A prototype fluidised bed plant for the production of uranium tetrafluoride from uranyl nitrate was being commissioned, and will continue in use for a further eighteen months to two years, to supplement the production of uranium tetrafluoride from the old plants. It will also enable

operating conditions to be optimised for the full scale fluidised bed plant, which is now being constructed for the manufacture of uranium tetrafluoride on the scale required for the civil programmes. A metallurgical fabrication and fuel element assembly plant was also under construction, which will satisfy all home and export demands for miscellaneous natural and enriched uranium and uranium oxide fuel elements.

55. The uranium ores processed this year included concentrates from South Africa, Australia and Canada. A new ore dissolving plant was commissioned in October and, by the end of the period, was producing all the pure uranyl nitrate the Authority require.

56. A large quantity of uranium was extracted from the residues from processes which are now obsolete. During this processing of residues considerable quantities of protactinium, required for research purposes, was recovered.

57. Owing to improvements in operating techniques, the increased quantities of uranium hexafluoride required by the diffusion plants were supplied without the installation of additional plant.

58. The production of Calder and Chapelcross fuel elements continued throughout the year. The first fuel element assembly line on the second uranium plant was commissioned and used for the production of experimental thermal reactor fuel elements. Fuel elements were supplied for the Harwell reactors and various types of isotope cartridges produced for irradiation in the Calder reactors.

Windscale and Calder

59. *Chemical Plants.* The primary separation plant processed fuel elements from the Calder reactors and the fuel elements discharged from the Windscale piles after the No. 1 pile incident. A weld failure occurred during October, 1958, in one of the highly active dissolver cells, resulting in a leak of radioactive solution, and operations were transferred to a standby unit until the damaged equipment had been decontaminated and repaired. The north side of the uranium purification plant was stripped and decontaminated in order to install modified equipment for a new solvent extraction process, which will extract fission products more efficiently and thus reduce the activity of the liquid effluent from the works. New plants were commissioned for the extraction of isotopes from materials irradiated in the Calder reactors. A pilot plant was used to produce, from stored fission products, ten caesium sources for use in hospitals.

60. All the uranium fuel element and isotope cartridges were discharged from the two Windscale reactors, which at the year's end were being shut down and sealed. The reactor buildings are to be used for fuel element examination facilities in support of the civil reactor programme.

61. *Calder Reactors.* A thermal output of over 200 MW per reactor was consistently obtained with electrical generation of 44.5 MW (gross) and some excess steam production. A considerable amount of experimental work to assist the nuclear power programme was carried out in the reactors. The excess reactivity was used to manufacture isotopes and enabled an experimental programme to be carried out to determine the effects of radiations on reactor materials.

62. Commissioning of the third reactor started at the beginning of 1958. The commissioning programme included a test run of the special equipment for carrying out a Wigner energy anneal of the graphite, if this is ever required. During routine commissioning of this reactor the runaway stop valve and control valve of one turbo-alternator jammed due to foreign material between valve stems and glands. This led to the destruction of the turbo-generator, and, as a consequence, electricity was not generated by this reactor until 6th January, 1959, although the reactor was restored to service almost immediately.

63. The fourth reactor attained criticality during the year.

Chapelcross

64. The first reactor was commissioned and a thermal output of over 200 MW, with an electrical generation of 44.5 MW (gross), obtained.

Capenhurst

65. The diffusion plant at Capenhurst, which produces uranium hexafluoride highly enriched in the uranium-235 isotope, was extended by the addition of units of large size. The performance of the new units was improved during the year by minor modifications and optimisation of the operating conditions. The large masses of uranium hexafluoride in the lower sections, and increased uranium-235 concentrations in the higher sections of the plant, have introduced new criticality problems requiring the re-design or modification of certain sections of the plant. The plant extensions and modifications were carried out without interrupting production, which steadily increased during the year.

66. The plants for the conversion of enriched uranium hexafluoride to uranium tetrafluoride and for the treatment of residues operated satisfactorily. The plants for the production of light metal isotopes operated with increased efficiency and output. New analytical techniques for determining impurities in uranium hexafluoride during plant operation were developed and brought into use on the diffusion plants.

CHAPTER V

THE REACTOR DEVELOPMENT PROGRAMME

Part I

GENERAL

Reactors for Power Generation—Objectives

67. The first aim of the Authority's work on reactor development has continued to be that of ensuring the successful construction and operation of the first nuclear power stations now under construction for the electricity boards in this country. Apart from this immediate task the Authority are devoting extensive resources to the development of more advanced types of reactor, the aim of which is to provide progressively cheaper sources of nuclear power.

68. Because of their low fuel costs, nuclear power stations will be operated at the highest load factors possible in the generating system. The effect of the high capital costs of the early stations will thus be minimised by the fact that they will be operated on the base load. Reductions in capital cost will be essential if nuclear stations are to be competitive at the lower load factors that will eventually obtain when the amount of nuclear capacity installed exceeds the base load on the electricity generating system. Hence the achievement of lower capital costs is a major objective of the Authority's programme of reactor development. Although experience in designing and constructing stations using magnox canned natural uranium fuel elements is reducing the capital cost per kW of this type of station, further major reductions will depend on the development of the more advanced reactors.

69. To these considerations must be added the need to base plans as far as possible on the use of materials readily and cheaply available. Production of uranium enriched in the 235 isotope is expensive in the United Kingdom. Therefore, the enrichment of fuel, where essential, must be kept low and efforts are being made to develop ways of using as fuel the plutonium that will gradually become available from the burning of uranium in the early stations.

70. Beyond the natural uranium reactors, two stages of development are envisaged. The first is represented by systems attaining lower capital cost by the use of slightly enriched fuel. These are the advanced gas-cooled reactor and the water-moderated reactors discussed in paragraphs 82 to 84. The second aim is to introduce reactors which, besides having low capital costs, have negligible net fissile fuel consumption, i.e. reactors in which the production of fissile materials approaches or exceeds its consumption, and the fuel costs of which are low. The high temperature gas-cooled reactor and the fast breeder reactor are in this category.

71. Plans for reactor development must also be related to the possibilities of the export market. The present type of gas-cooled, graphite-moderated reactor may command a market overseas where large stations are required. Nuclear technology will, however, have to advance considerably before smaller reactors (e.g. 20-100 MW) become competitive in normal circumstances. Much of the Authority's work on the larger systems will have application to small reactors and will thus in the long run contribute to the possible development of the latter for export.

Marine Propulsion

Submarine Propulsion

72. Under the 1958 Defence Agreement with the United States a "Skipjack" pressurised water reactor and its fuel are to be supplied for installation in a British hull, and Rolls Royce Limited are to receive information under licence from the Westinghouse Electric Corporation (U.S.A.). The Authority will advise on safety problems associated with the "Skipjack" reactor.

Surface Propulsion

73. During the year, the Authority's collaboration arrangements with industry were strengthened by the institution of quarterly meetings at which

progress in the investigation of reactor systems for their suitability for marine propulsion has been reported and discussed. At the invitation of the Admiralty Committee on the Application of Nuclear Power to Marine Purposes, which was established to study these matters and on which the Authority have two representatives, the Authority conducted detailed studies of the advanced gas-cooled reactor system as applied to surface propulsion. A general appraisal of these and other studies was nearing completion at the end of the year.

Part II

REACTORS UNDER CONSTRUCTION

Work for U.K. Electricity Boards' Reactors

74. During the year a number of Authority staff continued to be engaged on improvements in the design of gas-cooled, graphite-moderated, natural uranium reactors. The consortia of firms engaged in constructing power reactors joined in this work as part of the programme of collaboration between them and the Authority. In particular, the design of the first civil reactors was modified to improve the control system and to raise the temperature of the coolest part of the moderator high enough to prevent any significant accumulation of stored Wigner energy. (Studies of graphite problems are reported in paragraphs 133, 134 and 135 in Part I of Chapter VII, and also in paragraphs 159, 160, 161, 174, 175 and 176 in Part II of the same chapter.) Experience with the Calder Hall reactors (see paragraphs 156-158 in Chapter VII) and work in the Authority's materials testing reactor played an important part in an intensive programme to ensure that the fuel in the civil stations attains an average life of at least 3,000 megawatt days per tonne.

75. A programme of metallurgical research in connection with these reactors was undertaken; some of the work is reported in paragraphs 122-131 in Chapter VII.

76. A collaborative programme, staffed jointly by the Authority, the consortia and the Central Electricity Generating Board, is in progress at Harwell to investigate the reactor physics of graphite-moderated reactors. The object of this programme, known as BICEP*, is a detailed study of the characteristics of natural and slightly enriched uranium, graphite-moderated assemblies and the development of more accurate methods for calculating the physics of the systems. A comprehensive revision of the correlation of experimental data was completed.

Fast Reactor

77. The Authority's major effort in the fast reactor field is the construction and operation of the fast reactor at Dounreay. During the year it was possible to increase the effort on this and the construction was completed. The reactor was handed over to the operating group in December, 1958. Commissioning was proceeding at the end of the period with electrical and mechanical testing of controls and instrumentation. Charging of the liquid metal circuits with sodium potassium alloy was almost complete and the breeder blanket fuel elements had been loaded. This work will be

* British Industries Collaborative Exponential Programme.

followed by loading with core elements and then by approach to criticality. The reactor should begin a period of low power testing during the summer of 1959.

78. Programmes of work on fuel development and general technology for fast reactors were also expanded. The collaboration arrangements with the U.S.A. proved fruitful and there were frequent exchange visits of staff with the Argonne National Laboratory, who operate the American Experimental Breeder Reactor No. 1, and with Atomic Power Development Associates Inc. who are responsible for the design of the Enrico Fermi fast breeder power reactor.

79. At Harwell the zero energy fast reactor ZEPHYR, which was fuelled with plutonium, was dismantled after the completion of some measurements on fast systems with coupled moderating reflectors.

Advanced Gas-Cooled Reactor

80. Preliminary work on the prototype advanced gas-cooled reactor (A.G.R.), described in paragraphs 79 to 86 of the Fourth Annual Report, began on the Windscale site on 1st October, 1958, to the north-west of the existing piles and chemical plant and within the existing security fence. The main civil contractor started work on 1st November, 1958. The 34 ft. deep excavation, the main foundation raft and the floor plates beneath the main biological shield have been completed. Site concrete, following excavation, was completed for the turbine hall and administration building. Underground services were laid and the roads practically finished.

81. A supporting programme of irradiation experiments has been started, which will begin to yield information from the autumn of 1959 onwards, particularly upon the behaviour of beryllium-canned uranium oxide fuel and upon measures to minimise the loss of moderator graphite by the conversion to CO in the CO₂-graphite reaction. The results of this work will be available in time for any necessary modifications to be incorporated in the prototype and its fuel.

Part III

MAJOR REACTOR INVESTIGATIONS

Water Moderated Reactors for Power Generation

82. Progress with the study of the gas-cooled, heavy water-moderated reactor system, described in paragraph 107 of the Fourth Annual Report, has shown that the use of steam as the coolant in a pressure-tube design would enable evaporators to be used in place of heat exchangers three times as large. Moreover, because of the superior thermal transfer properties of steam compared with CO₂, the amount of pipework, and hence the capital cost of the steam-cooled, heavy water reactor should be lower than that of the gas-cooled, heavy water-moderated reactor. Further development potential of the system appears to be considerable.

83. The Authority have therefore begun to study the design of an experimental plant, which could be modified in due course for electricity

generation, in which a 100 MW(H) experimental S.C.H.W. reactor could be operating by the end of 1962. This plant would contain common services for a second reactor, and if the Authority decided to do so, a boiling light water reactor (B.W.R.) could be added in due course.

84. Because of its simplicity and its use of light water as a moderator, the potentialities of the B.W.R. have attracted attention in a number of countries, particularly the U.S.A. where enriched uranium can be produced more cheaply than in this country. For use in the U.K., however, the chief disadvantage of the B.W.R. is that, even with zirconium fuel cans, enrichment to about 1½ per cent is necessary, and a large programme of B.W.R.'s would, therefore, require supplies of fissile material in substantially greater quantities and at lower cost than are at present available in the U.K.

High Temperature Gas-Cooled Reactor

85. Steady progress has been made with the research and development programme for the high temperature gas-cooled reactor (H.T.G.C.). The agreement to develop this reactor as a joint project with other member countries of the European Nuclear Energy Agency is reported in paragraph 282 (ii). The immediate emphasis of the present work is on the development of a reactor based on graphite as the moderator and container for the fissile material. Considerable advances have been made in the production of new types of graphite, both in the experimental plant at Harwell which has produced samples of high density graphite, and by outside contract, where methods of rendering the graphite impervious to gases and fission products have shown considerable promise. An intensive programme was put in hand to determine the resistance of these new graphites to radiation, and small sample fuel elements using these materials were undergoing tests in the research reactors at the end of the year.

86. The study of the reactor experiment meanwhile continued. Detailed calculations were made of the kinetics and stability characteristics of this high temperature reactor, which introduces some novel problems due to high temperature gradients with effect on neutron spectra. The design of the reactor experiment incorporates a gas stream for sweeping fission products away from the surface of the fuel in order to enable tests of various types of fuel element to be carried out in the reactor experiment.

87. It was decided to construct a comprehensive out-of-pile loop for study of the reactions of gases with graphite at the high temperature occurring in these reactors. The design of the loop was completed and construction by a contractor begun. The loop will be installed at Winfrith Heath. Construction of the large in-pile loop for PLUTO is nearing completion and commissioning trials are expected to begin about the end of 1959.

88. A series of exponential experiments to measure certain basic physics constants of the system was in progress at Winfrith Heath. Construction of the high temperature, zero energy experiment ZENITH at Winfrith Heath was almost complete. Physics experiments, initially directed towards elucidating conditions for the reactor experiment, will begin later in the year.

Part IV

OTHER REACTOR STUDIES

Organic-Liquid-Moderated Reactors

89. The organic-liquid-moderated system has possibilities, especially for small reactors. Basic work in this field has been particularly concerned with the study of the stability to radiation of materials likely to be useful as organic coolants and moderators. Irradiations of such materials continued using fast electrons from an electrostatic generator, and pile irradiation using neutrons from BEPO. Tests were made in out-of-pile loops to determine the limiting rates of heat transfer with these organic materials.

General Technological Work

90. Reactor physics studies continued in several zero energy reactors. In particular, the NERO system was used to examine neutron behaviour in order to improve theoretical methods for designing graphite systems. Zoned cores having varying degrees of enrichment in the fuel were studied. NERO assembly was also used to investigate the characteristics of a reactor designed for oscillator measurements of neutron cross-sections and capable of operating at a high temperature. Oscillator measurements to obtain basic nuclear information on fissile isotopes were made in DIMPLE, the heavy water-moderated, zero energy reactor.

91. Particularly with marine applications in mind, the physics of light water-moderated systems has been investigated by a joint Authority and Admiralty team, using the zero energy reactor NEPTUNE, which was originally constructed to provide design information for the power plant of the nuclear submarine "Dreadnought". Another joint team has completed detailed shielding studies with the pool-reactor LIDO.

92. The study of plutonium utilisation in reactors continued. In addition to the long term objective of using plutonium as the initial fuel for the fast reactor, a more immediate study aimed at completing understanding of how the generation of plutonium by irradiation of uranium in existing thermal reactors affects their performance. This will be followed also by an appraisal of the various possibilities of using plutonium for enrichment (as an alternative to Uranium-235) in later thermal reactors.

93. In reactor design studies a large amount of computation is necessary, much of it on a scale that would have been thought impossible only a few years ago. Wide use has been made of high speed digital computers to perform these calculations. These computations have been made on machines in the three groups of the Authority. Standard programmes have been written to perform all the standard calculations of reactor theory so that, for example, large fields can now be surveyed in a design study with speed and with relatively little effort. Much exploratory calculation is now done as routine on the neutron economy and criticality conditions for any proposed critical assembly or reactor design. At present a large scale programme of computations is being carried out for study of the control of civil reactors. Other general work is described in Chapter VII.

Research Reactors

94. During the year the new high flux reactor PLUTO at Harwell came into operation and was brought up in stages to a power of 10 MW(H). Experiments were made to determine the possibility of increasing the power to 15 MW(H). Mock-ups of various experimental loops were put in the reactor at low power, and measurements made of the neutron flux depression caused by these loops. Measurements using samples in the loops also allowed estimates to be made of the nuclear heating which would be produced. Fast neutron fluxes were measured in PLUTO and have been related to irradiation effects produced in graphite.

95. The other high flux reactor DIDO continued to run at 10 MW(H). New hollow fuel elements were developed for use in both DIDO and PLUTO. These elements were successfully used at high power in DIDO and provide a large fast neutron flux for irradiation experiments.

96. The materials testing reactor at Dounreay (DMTR) was commissioned and became critical in May, 1958. The programme of bringing the reactor up to its full power of 10 MW(H) was successfully completed, and the first experimental rigs installed.

97. With the reduction of work on homogeneous aqueous reactors, the programme intended for the zero energy reactor HAZEL at Harwell was curtailed. Some measurements with uranium-233 solution were completed after initial tests with uranium-235. The equipment has now been dismantled and is being transferred to Dounreay for general studies of criticality problems in chemical plants.

98. At the Atomic Weapons Research Establishment, the light water-moderated research reactor HERALD, which will be used for neutron physics and radiochemical studies, was in an advanced stage of construction at the end of the year. Throughout the year the zero energy light water reactor HORACE was the main preoccupation of the reactor team at Aldermaston. This work has proved of value in the basic study of HERALD characteristics. One of the primary objects is to shorten the time taken to run HERALD up to full power. At Harwell a light water-moderated system called EUREKA, for approach-to-critical experiments, is nearly complete. This will be a flexible assembly in which the ratios of moderator to fuel and of cladding material to fissile material can be altered over a wide range. In addition, it will be possible to raise the water temperature to 80°C, in order to measure temperature coefficients. This assembly will be used to study the physics of light water-moderated systems.

CHAPTER VI

CONTROLLED THERMONUCLEAR REACTIONS

Work at Harwell and in Industry

99. The object of research into controlled thermonuclear reactions is to heat isotopes of hydrogen to such high temperatures that their nuclei acquire sufficient energy by random thermal motion to join together when they collide, forming new and heavier nuclei and releasing energy in the process. At these high temperatures all matter is gaseous and consists of positive ions

and negative electrons in equal concentrations and so is electrically neutral and highly conductive. The name plasma has been given to matter in this form. Much remains to be learned about the properties of plasma. Present research is directed to studying ways of forming, containing, and heating plasma and to diagnosing the behaviour of the constituent particles under a variety of conditions.

Zeta I and Sceptre III and IV

100. The Fourth Annual Report, paragraphs 130 to 140, referred to experiments at Harwell on ZETA, a ring shaped apparatus in which deuterium gas is heated to high temperatures. The gas, initially weakly ionised, forms the single secondary turn of a transformer: when an electric charge stored in a condenser bank is discharged through the primary of this transformer, a large pulse of current (up to 200,000 ampères) is induced in the gas, causing it to be heated to temperatures in the region of a million degrees centigrade and so to become a plasma. This type of gas discharge is called a pinched discharge, because the gas is compressed inwards by the electromagnetic forces of the current and thus moves away from the walls of the tube. Reference was also made in the Fourth Annual Report, paragraph 145, to a similar but smaller apparatus, Sceptre III, which was built, with assistance from the Authority, at the laboratories of Associated Electrical Industries Limited at Aldermaston Court. A more complete understanding of the processes occurring in ZETA and in Sceptre III is necessary, and experimental work on them continued during the year.

101. Originally the ring shaped tube, or torus, of ZETA was fitted with a liner consisting of 48 aluminium sections separated from one another by "teflon" insulators, but trouble was frequently encountered from arcing between the liner sections. A continuous stainless steel liner has now been fitted, as a result of which the apparatus is much more reliable. Fitting this liner, together with other minor modifications, has led to an improvement in the purity of the gas in the torus. Modifications have also been made to the electrical circuit so that larger currents can be passed through the gas without increasing the electrical energy stored in the condenser bank. Observations have been made using currents up to 270,000 ampères. A new condenser bank has been installed, capable of delivering 10 times as much energy as the original.*

102. Measurements of the electrical characteristics of ZETA and Sceptre III, of the microwave noise and other radiation emitted, of the neutrons, protons and X-rays produced, and of the magnetic field distributions, have all added materially to knowledge of the behaviour of the plasma. It has been shown that, although both photographs of the discharge and measurements of the changing magnetic field within it suggest that the current channel is confined by its own magnetic field and kept away from the walls of the torus, there is an excessive loss of energy to the torus walls during the current pulse. The exact mechanism by which this energy is being lost is not fully understood, but there is some evidence that energetic electrons are

* The energy stored in these experiments is conveniently expressed in joules. An energy of a million joules (1 megajoule) is not a large amount—it is about a quarter of a kilowatt-hour, enough to boil about two pints of water—but in a practical machine this amount would be discharged in about a thousandth of a second, corresponding to an average rate of use of 1,000 megawatts. The storage capacity of the condenser bank for ZETA I was about half a megajoule.

continually being lost to the torus walls and are being replaced by much less energetic ones. The main object of the present experimental programme is to discover the reason for this energy loss. The electron energy has been found to be considerably less than the energy of the impurity ions in the discharge which, as stated in paragraph 137 of the Fourth Annual Report, corresponds to a temperature of 5 million degrees centigrade. The electron temperature as determined from the microwave noise emitted, from the measured resistance of the current channel, and from an examination of the relative intensities of certain spectral lines emitted by impurities in the plasma, is only about half a million degrees centigrade. This is an unexpected result. It had been expected that the electrons, being lighter, would acquire more energy than the ions, and that the ions would acquire energy as a result of collisions with electrons. Evidently the reverse is true.

103. A further discovery is that current flows throughout the volume of the current channel; there is no tendency for it to flow in a thin skin on the surface of the current channel, in the way that might be expected in a highly conducting plasma. This discovery is important because theoretical studies of the behaviour of plasma in the presence of magnetic fields in cylindrical systems suggest that only if such skin-currents are formed will the current channel be stable and not wriggle about in the tube and touch the walls from time to time. Instabilities of this kind lead to serious losses of energy from the discharge.

104. X-rays have been detected which have been produced by collisions with the torus walls of electrons accelerated to high energies. In certain circumstances electrons can "run away"; the more they are accelerated the less likely they are to make a collision and lose their energy, and they may acquire large energies before being lost to the torus walls. There is some evidence that these run-away electrons could be a cause of instabilities in the current channel.

105. The problem of run-away electrons can be overcome in principle by operating at higher gas pressures. To reach the same temperatures at such pressures, higher currents are necessary. An important aspect of the new capacitor bank installed on ZETA is that it will give the higher currents necessary for effective experimentation at high pressures. Similar conditions can be obtained in the apparatus known as Sceptre IV, which is already nearing completion in the A.E.I. laboratories. Sceptre IV has roughly the same dimensions as Sceptre III, but will be capable of passing currents of up to about a million ampères.

106. However, the experimental observations suggest that a more radical attack must be made on the problems of current and magnetic field distributions than can be achieved on ZETA, and design studies have been carried out for a system capable of operating both at much higher pressures and also at faster rates of current rise (to give a skin effect).

Small Scale Apparatus

107. During the year there has been a considerable expansion of the work on smaller scale gas-discharge devices. In order to check theoretical predictions about the stability of a pinched discharge experiments have been

done with cylindrical systems, in which currents of 250,000 ampères, rising to peak value in a few microseconds, have been passed between disc shaped electrodes at the two ends of the cylindrical discharge tube. Skin-currents have been obtained, but the experiments are still in too early a stage for results on stability to be reliable.

108. Other experiments are being made on a small toroidal system with a bore of only 4 inches. Currents of 100,000 ampères, rising to peak value in one microsecond, have been passed in the gas, and magnetic probe measurements have shown that there is a skin-current in the early part of the pulse. There is evidence of the formation of shock waves when the plasma collapses away from the walls of the torus.

109. Several other straight and toroidal systems are being built, with the objectives of studying different methods of confining plasmas, the formation of skin-currents and their effect on the stability of the discharge, and the effect of pre-heating the gas so that it is more nearly fully ionized at the beginning of the current pulse. These systems will also be used to study the heating of plasmas by shock waves. In ZETA experiments plasmas have been heated, as an electric fire is heated, by virtue of the resistance they offer to the passage of an electric current (Joule heating) but this method becomes progressively less effective as the plasma temperature rises, because the resistance of the plasma then decreases. Consequently other methods of heating may be required to reach high ion temperatures; one of the most promising of these is shock heating, that is to say the heating produced by the passage of a shock wave travelling at supersonic speed in the gas.

Technological Development

110. Some of the formidable technological problems which will have to be solved if a thermonuclear reactor is to be built are being investigated. Methods must be devised for storing hundreds of millions of joules of energy in such a way that the energy can rapidly be injected into the reactor; currents of several million ampères will have to be handled, and toroidal apparatus will have to be made to withstand conditions much more severe than those encountered in ZETA. Considerable progress has been made, in conjunction with industrial firms, in the development of cheaper and more reliable condensers from which the energy can be extracted quickly and of novel types of switches suitable for the rapid switching of currents of the order of a million ampères. Studies have been made on storing energy in iron-cored coils (inductive storage) rather than in condensers. Inductive storage appears to be more economic than capacitive storage, but it is harder to extract the energy sufficiently rapidly for some purposes.

111. Other experiments have been directed to finding ways of overcoming the troubles caused by the formation of arcs between the plasma and the metal walls of the torus; these arcs cause the metal walls to vaporise locally and so to release impurities into the discharge. Small scale experiments with a liner in the form of a matrix of small, electrically isolated metal pieces have given encouraging results.

Work at the Atomic Weapons Research Establishment

112. At A.W.R.E., Aldermaston, research has continued on various types of pinch discharge, using experimental scale apparatus, also with the object of achieving high plasma temperatures. As in the work discussed above, an essential requirement has been that the electrical energy from the condenser bank should be discharged into the gas discharge tube extremely quickly, i.e., in less than one microsecond. The problems presented by the necessary special condenser circuits and fast switches, all of low inductance, were formidable but most of them have been overcome.

113. Most of the work has been done with linear discharges between two plane parallel electrodes. Two main types of discharge have been studied, known respectively as the Z and Θ type. In the first, the direction of the current in the gas is parallel with the axis of the discharge tube; in the second the discharge current flows in closed circular paths round the axis of the tube. Theoretically the Z type of discharge is the more efficient as a means of heating but the Θ type has the decided advantage, again theoretically, that it is more stable; both types have, therefore, been studied with the main aim of elucidating the fundamental phenomena of heating and stability.

114. For work on Z type discharges, specially designed fast condenser banks of modest energy have been used. One of these is MAGGIE, a million ampère generator storing 50 kilojoules; this generator can provide a current with a rate of rise of 5 million ampères per second on short circuit. Fast discharge would lead to rapid pinching in hot plasma and the aim of the work has been to investigate this rapid pinching as a means of heating deuterium gas before either instabilities or cooling by the two electrodes in the discharge tube become important. Neutrons are emitted in the discharges and their properties have been examined in detail; it has been demonstrated that these neutrons do not arise in the more normal "sausage" instability noted in other work on controlled thermonuclear reactors. This result was reported at Geneva.

115. The Θ type discharge makes more severe demands on the condenser bank than the Z type, but nevertheless the development of low inductance banks at A.W.R.E. has proved adequate for fruitful work with this type. The stability of the Θ type discharge is being studied, using special diagnostic techniques, and so, too, are various features of the neutron emission observed in straight Θ discharge tubes when driven by a simple external conducting loop. The main effort, however, has been to understand the plasma phenomena arising during pinching and to study the longer term behaviour of the hot plasma as it is affected by various parameters, such as the degree of pre-ionisation, i.e. ionisation of the gas before the energy of the bank is delivered to it. Pre-ionisation plays a vital role in this type of discharge because it largely controls the extent to which magnetic fields are trapped within the imploding plasma sheath. The diffusion of such trapped magnetic fields through the hot plasma is a subject of considerable interest and value; it is hoped that it may offer a useful approach to the problem of determining plasma temperature. Results of value in connection with trapping and diffusion have been obtained.

116. Other investigations have been concerned with oscillations of the plasma; the period of these oscillations has been examined and a theoretical explanation of their formation arrived at. It seems possible that they may provide a means of determining the degree to which the ionised gas is collected in the sheath and they are believed to be of significance in the mechanism of plasma heating.

117. Experimental observations seem to bear out the theoretical expectation that the Θ discharge would show a good degree of stability, but to demonstrate this more satisfactorily it is necessary to use "crowbar" techniques, that is to arrange that either a short circuit is put across the discharge vessel at the instant of maximum current or that a subsidiary power source is brought into the circuit at the same instant. The effect of either is greatly to increase the time for which the large currents involved here can be maintained in the discharge vessel.

118. Exploratory studies of an entirely different method have been made at A.W.R.E. centring around a proposed experimental device called HITEX (high temperature experiment). The principle is that of the D.C.X. (direct current experiment) machine of the Oak Ridge National Laboratory of the United States Atomic Energy Commission, described at Geneva. The hot plasma is built up by injecting high-energy molecular ions (or neutral atoms) into the discharge vessel and arranging, by some means such as dissociating the injected molecular ions, that the plasma is contained in an externally-generated magnetic field, produced by coils driven from ordinary power sources. In so far as most of the ions tending to leave the plasma will be reflected by the magnetic field back into it, the device is in effect a mirror machine of a particular type. Provided that the ions are trapped and contained in this way, a hot plasma can be built up. This approach has the fundamental feature that the problems of heating, containing and stability are largely separated, with the considerable advantage that these important aspects can be investigated more easily than when they are inter-dependent.

119. A good part of any effort in the C.T.R. field must consist of the solution of difficult diagnostic problems, such as the accurate measurement of temperature, magnetic field, distribution, and ion and electron densities. At A.W.R.E. high speed streak cameras have been designed, Kerr cell techniques adapted, and time-resolved spectroscopy on the microsecond time scale developed for these purposes.

C.T.R. Advisory Committee

120. In December, 1958, an Authority Advisory Committee was set up under the Chairmanship of the Member for Scientific Research with the following terms of reference:—

- (i) to examine and keep under review all aspects of the Authority's research programme on controlled thermonuclear reactions;
- (ii) to advise the Member of the Authority responsible for research policy on the merit of proposals for new work;
- (iii) to make recommendations to the Member on changes in policy which to them seem necessary.

Membership of the Committee is:

Sir John Cockcroft, O.M., K.C.B., C.B.E., F.R.S. (*Chairman*).

Mr. J. B. Adams.

Dr. T. E. Allibone, F.R.S.

Professor P. M. S. Blackett, F.R.S.

Professor Sir Edward Bullard, F.R.S.

Dr. S. C. Curran, F.R.S.

Professor B. H. Flowers.

Mr. D. W. Fry.

Professor M. J. Lighthill, F.R.S.

Professor H. W. B. Massey, F.R.S.

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

Professor H. W. B. Skinner, F.R.S.

Professor Sir George Thomson, F.R.S.

The Committee has been set up for two years in the first instance.

CHAPTER VII

OTHER RESEARCH AND DEVELOPMENT

Part I

RESEARCH GROUP

121. The functions of the Research Group centred on Harwell, and now extending to the Atomic Energy Establishment at Winfrith, are, broadly, to obtain basic knowledge in all the physical sciences upon which atomic energy depends, to use this knowledge to determine the technical and economic feasibility of new or different methods for developing nuclear power and also to widen and increase the applications of radioisotopes. Some of this work is reported, *inter alia*, in the chapters of this report dealing with reactors, isotopes, controlled thermonuclear reactions, and health and safety. There remains a large body of research which does not fit into these categories though it is of great scientific and technical importance. It is not possible to describe, or even to list, all this work in a few pages; instead some selected items of basic research, done in the Research Group during the year, are reviewed. In the Fourth Annual Report these items included work in reactor and nuclear physics, chemistry, and electronics. In this report the subjects chosen are the effects of irradiating metals, solid state physics, and particle accelerators.

Metallurgical research

122. The fuel of a nuclear reactor is a metal, or a metallic compound. Other metals, some of them unusual, are used in the fuel element can, in the control mechanism and in structural parts of the reactor, and in its pressure vessel. These metals are subject to bombardment with neutrons and other types of radiation. An essential part of the development of atomic energy is the understanding of the effects produced in these metals by these processes.

123. Ordinarily a metal is made up of crystals orientated at random with respect to one another, the constituent atoms in each crystal being arranged in a three dimensional lattice. There are always defects in the individual crystals: vacancies in the lattice where a site that would normally be occupied by an atom is empty; interstitial atoms squeezed into the lattice between normal occupants; and dislocations or discontinuities in the lattice. The numbers of these defects and dislocations influence the mechanical properties of the metal. Consequently, any process which affects these defects and dislocations will change the mechanical properties.

124. The effects produced by neutrons are important in both non-fissile and fissile metals. Though much detail remains to be cleared up, the mechanism by which neutrons cause damage in non-fissile metals is fairly well understood. Neutron bombardment increases the number of defects by knocking atoms out of their positions in the lattice, so producing vacancies and interstitial atoms. The numbers of defects, and their subsequent behaviour, vary with the metal and with temperature.

125. Studies have shown that one such effect upon the mechanical properties of the ductile metal niobium (a canning material) at room temperature is to cause the metal to harden. This hardening increases without further irradiation if the metal is annealed at about 150°C. Recovery from irradiation hardening commences at 350°C and is complete after about 1 hour at 600°C.

126. One of the most important metals being studied is steel. At total fast neutron doses of 10^{19} neutrons/sq. cm and at temperatures up to 300°C, the interstitials form clusters, some of them in the neighbourhood of dislocations; the vacancies do the same. This impedes the movement of dislocations causing changes in the mechanical properties of the metal, of which the most significant is that it becomes less ductile.

127. In a fissile metal such as uranium the effects of irradiation are complex, and arise primarily from the fact that atoms undergoing fission are replaced by twice as many fission product atoms, some of which are gaseous. During the past year interest has been increasingly focused upon the effects at the high temperatures expected in power reactors. At temperatures of 600–800°C the metal is soft and has a low creep strength, and the swelling which occurs is due to the gaseous atoms accumulating in nearly spherical bubbles. The gas pressure within the bubbles causes them to expand, thus deforming the surrounding metal plastically.

128. At lower temperatures (around 450°C) the unirradiated material is strong, but increases in volume due to irradiation have been observed, particularly in materials based upon the alpha uranium structure. It is believed that temperature fluctuations cause internal stresses which reduce the creep strength of the material, and that swelling in alpha uranium can be considerably reduced in this temperature range by keeping the metal at a constant temperature during irradiation. This hypothesis is being checked experimentally and there is already some evidence to support it.

129. Metallographic studies have indicated that the size and method of formation of gaseous bubbles are affected by such metallurgical factors as flaws and non-metallic inclusions in the metal, and considerably more work is needed to define all the processes contributing to the swelling of fissile metals.

130. In some non-fissile metals, also, gases are formed as a result of neutron bombardment. Thus neutron reactions with beryllium produce helium which may be either precipitated as gas bubbles in the metal, or remain in solid solution in the metal. As long as the helium atoms remain in solution there will be little swelling. Small bubbles can form at low temperatures, however, and the swelling will depend upon the pressure of gas within the bubbles. As the temperature is increased the number of bubbles decreases, but they grow in size and the swelling will be determined by the rate at which the bubbles coarsen. Under the temperature conditions likely in advanced gas-cooled reactors, the dimensional changes produced by swelling should not be serious.

131. In all these investigations into irradiation effects, the essential tools are strong sources of neutrons produced by high-flux reactors, and apparatus in which highly radioactive samples can be examined and their physical properties measured. These are available at Harwell, at Calder Hall and at Dounreay.

Physics of the solid state

132. Besides specifically metallurgical work, research is being done into the properties of solid materials generally. Although advances are rapid the subject is wide and complex; many years of difficult theoretical and experimental research will be required. Three of the many topics being studied are reported here: work on graphite, on metals and alloys, and on diffusion in solids.

Graphite

133. The Research Group is participating extensively in the Authority's graphite programme and investigations have been carried out on its basic properties. This work is concerned with obtaining information on the effects of irradiation which are important in reactor design and operation: these include dimensional stability under irradiation, decrease in thermal conductivity with irradiation, and stored energy phenomena.

134. A feature of current work is that by irradiating small samples of graphite inside special fuel elements in the highly rated reactors DIDO and PLUTO, it has become possible to produce irradiation damage at a rate about twelve times greater than will occur in any existing or projected graphite-moderated reactor. A study of irradiation effects is in progress covering such variables as temperature of irradiation; neutron dose and dose-rate; and the energy distribution of neutrons.

135. A fundamental study of irradiation damage in graphite is also being made. Samples irradiated in DIDO and PLUTO are being examined by the methods of X-ray diffraction, electron microscopy, and paramagnetic resonance. This work is aimed at providing a means of discriminating between the various types of complex defect which exist in highly irradiated graphite. In addition to standard reactor graphite, natural graphite crystals and artificial graphites are being examined. These studies should determine the significance of effects at crystal boundaries and may make it possible to predict the effects of irradiation in new types of graphite. Graphite is also being irradiated at low temperatures using high energy electrons. This treatment produces a simple form of radiation damage and thus

assists the interpretation of the more complex effects produced by neutrons at high temperatures.

Metals and Alloys

136. Much work has been and is being done in studying the physical properties of fissile and fertile elements, particularly thorium, uranium and plutonium, and their alloys with each other and with other elements.

137. The properties of these alloys follow no simple pattern from which those of yet unstudied alloy systems might be predicted. This is an indication of the complexity of the electronic structure of the uranium group metals. This complexity is similar in many ways to that of the transition group of elements, among which are many of the more familiar and industrially important metals. In neither case yet have the electronic structures, even of the pure metals, been fully elucidated.

138. Many of the experimental techniques developed in recent years for studying the electronic properties of metals and alloys are used, including particularly measurements of electron specific heat, the single crystal elastic properties, and electron and nuclear magnetic resonance phenomena in both pure metals and alloys. Neutron diffraction, in addition to other applications, is used extensively to study the magnetic properties of metals and alloys. The advent of high-flux reactors, with the neutron choppers which provide high intensity sources of monochromatic neutrons, has increased considerably the scope of all these investigations. Theoretical studies have been made of the experimental results obtained at Harwell and at other centres engaged on similar problems, and the basis of the currently accepted theory of metals examined in the light of these results.

Diffusion in solids

139. In spite of considerable effort over a number of years the processes of solid state diffusion, and the factors which determine diffusion rates, are still little understood, and the study of this subject is continuing.

140. An understanding of diffusion in solids is important in many aspects of reactor technology, such as the compatibility of cladding materials with the fuel, loss by diffusion of fission products from fuel elements, and mass transfer in liquid-fuel systems. Diffusion processes are also important in relation to mechanical properties, rates of sintering, and rates of recovery from radiation damage.

141. Among work of a more fundamental nature, a comparison has been made of the diffusion rates of transition and non-transition elements in the noble metals, and an attempt has been made to understand the electronic and other factors determining such rates. Measurements of self-diffusion of alpha uranium have called for novel methods of analysis. Measurements of self-diffusion in gold have been made which are of value in studying the behaviour of point defects in this material. This is relevant to an understanding of radiation damage recovery processes.

Work on particle accelerators

142. The need for particle accelerators in nuclear and radiation research is well known and the Research Group has always devoted effort to the design and construction of these tools. Research of this nature is carried

out at Harwell for the benefit both of the establishment and, through the National Institute for Research in Nuclear Science, of the universities.

143. Four new machines are in course of commissioning or construction. The largest of these, the 7 GeV* proton synchrotron, is being built for the Rutherford Laboratory of the National Institute by the Authority, with a team of physicists and engineers from the Atomic Energy Research Establishment and with the constructional assistance of the Industrial Group. The energies of the particles from this machine will lie between those of the American Bevatron at Berkeley and the Russian 10 GeV machine at Moscow, but it is expected that the current in the beam will be somewhat higher than in the case of either of these machines. Construction is proceeding rapidly. The huge monolith concrete foundation for the 7,000 ton, 150 ft. diameter magnet, the arched concrete roof over the magnet room, and the shield bridge, 28 ft. thick, which forms part of the shielding between the magnet room and the experimental area, have been completed. The major components of the machine have been designed and ordered, and production items are being delivered. Among the latter are the 20 ton magnet blocks, of which there are about 350, to be delivered at the rate of one each working day.

144. This machine is a co-operative venture between British universities and the Authority, working through the National Institute, which will enable the universities to take a prominent place in high-energy nuclear physics. It is expected to be in operation by 1962.

145. A second machine being built at Harwell by the Atomic Energy Research Establishment and industry for the National Institute is the 50 MeV proton linear accelerator. The three tanks of the machine have been installed and protons have been accelerated in the first tank to 10 MeV, with a reasonable current in the beam. The machine will be handed over to the National Institute in April, 1959. Further developments of the machine are being considered, notably its use for experiments with polarised beams of protons and as a time-of-flight spectrometer.

146. Two other machines are being commissioned for use by A.E.R.E. The first is a 25 MeV electron linear accelerator, designed to produce the unusually high beam current of 0.75 ampères, with a mean power in the beam exceeding 25 kW. This machine has been built by industry. It is being brought into use for nuclear physics experiments.

147. The second new machine is one of two vertical 12 MeV tandem electrostatic generators, jointly designed by the Atomic Weapons Research Establishment, Atomic Energy Research Establishment, and an industrial firm, for use at Aldermaston and at Harwell. These accelerators will be in operation in mid-1959.

148. Theoretical and experimental research on other types of accelerators has been carried out in order to prepare for future developments. The main emphasis of this research has been on machines using the so called fixed field, alternating gradient method of focussing the particle beam, with a spiral ridged magnet poleface.

* 7 giga-electron-volts i.e. 7,000 million electron volts.

Part II

INDUSTRIAL GROUP

General

149. The aim of research and development in the Industrial Group is to provide the information that is necessary for the Group to discharge its commitments, particularly in support of the efficient operations of its factories and of the reactor design programme.

150. The Calder Hall type of reactor and its immediate development are being studied so that the Group may continue to advise and guide the electricity boards and the industrial consortia. In this field of work there is close collaboration between the R. and D. Branch and the laboratories of the industrial consortia and of the Central Electricity Generating Board. This ensures that duplication of effort is avoided and that, by mutual exchange of information, the most recent developments are immediately available to further the national nuclear power programme. In addition to the collaborative programme, the Authority undertake irradiation work for the consortia and development in connection with the supply of fuel elements.

151. An essential step in the development of fuel elements is the detailed examination of standard and experimental fuel elements after service in the Authority's and, in due course, the electricity boards' reactors. Techniques have been successfully developed throughout the year for dimensional, X-ray and metallurgical examination of fuel elements by remote operation behind heavy shielding in facilities known as caves. Based on this experience an extensive set of caves is being designed for installation at Windscale which initially will enable the examination of about 2,500 Calder and civil fuel elements to be made each year.

152. The Research and Development Branch has been strengthened by two changes. Firstly the Technical Section of the Engineering Branch has been added to the theoretical groups of the R. and D. Branch to form the Central Technical Services. Within this section at Risley a computing group has been set up which is equipped with a Ferranti "Mercury" digital computer. An IBM 704 digital computer and a PACE analogue computer will be added. Secondly, the Instrumentation Laboratory at Capenhurst has been considerably strengthened, following the recommendation, in paragraph 28 of the Final Report* of the Fleck Committee, that the Authority should increase the instrumentation of its plants. Emphasis has been placed on the study of schemes of instrumentation and control, to ensure that effective instruments shall be installed in the plants and reactors of the Industrial Group, and that the most up-to-date concepts of instrumentation and control shall be available to the design teams.

153. The research activities of the Industrial Group extend beyond the Group's laboratories. During the last five years the number and value of extra-mural agreements between the Industrial Group and universities, research associations and industry have increased, until they now account for about a tenth of the Group's annual expenditure on research and development.

154. In addition to the work on Calder and advanced gas-cooled type reactors, the R. and D. Branch has devoted some of its effort to other

* Cmnd. 471.

reactors of interest to the Authority, particularly the heavy water-moderated, gas-cooled reactor and the high temperature gas-cooled reactor.

155. The work of the R. and D. Branch is not limited to *ad hoc* solutions of problems. Background research is undertaken over a wide range of topics to develop a better understanding of appropriate systems and processes. Examples are: advanced studies of heat transfer processes, investigation of the properties of uranium of extremely high purity, and the isolation of rare elements such as protactinium and technetium.

Calder type reactors

Fuel Elements

156. The most significant contribution to further development has been derived from detailed examination of Calder fuel elements after they have been irradiated in the reactors. During the past year major advances have been made in the techniques for the examination of irradiated fuel elements and a large effort has been expended on regular examination. Over 800 fuel elements have been examined. Precision measurements on the fuel show that even after long periods of irradiation and thermal cycling in reactors, the changes which occur are small, and that the dimensional stability of the fuel has been maintained over long periods. The prediction that creep of the uranium would be accelerated by irradiation has been confirmed. There was, therefore, an increased possibility of bowing of the fuel elements. Quantitative measurements were made to determine the restraint required to prevent distortion of this type. As a result, a satisfactory technique of bracing the fuel elements has been evolved, so that bowing is no longer a problem.

157. A comprehensive study of the relationships between ductility and grain size in magnox has shown that increased ductility can be obtained by reducing the grain size. Methods of producing cans with a much finer grain size have been developed by the introduction of a low temperature hydraulic pressurising process in association with new can manufacturing techniques.

158. This work, specific to the Calder Hall type of fuel element, is being supported by more basic studies of fuel element technology. Theories of plasticity have been applied to the analysis of probable fuel element behaviour. The endurance of fuel elements is being studied theoretically by calculating the total strain imposed on the cans; the strain arises from the small dimensional changes in the uranium induced by the operating conditions of irradiation and temperature, and features of can design may lead to local concentrations of strain. The ability of the can to withstand these strain concentrations is determined by its available ductility, which is established from studies of the modes of deformation of magnox and by tests on complete cans. A further requirement of fuel element development is to be able to predict with great accuracy the statistical behaviour of fuel elements under operating conditions. Basic studies of the metallurgy of uranium are being undertaken so that production methods may be controlled more precisely to yield a fuel of great uniformity and consistency. The experience gained with Calder type fuel elements is being applied to the design of fuel elements for the civil reactors. A proportion of the civil reactor fuel elements operating at the higher temperatures is expected to exhibit some swelling of the fuel due to release of fission product gases.

Particular attention is being given to this problem, both with respect to can design to accommodate swelling and to the metallurgical features of the fuel to reduce the extent of swelling. An extensive irradiation testing programme has been planned to confirm and support the civil fuel element designs.

Moderator

159. Under reactor conditions, the graphite moderator exhibits two effects of importance: most of the energy absorbed from the neutrons is released as heat but some of the energy is stored in the graphite; and under the influence of irradiation a small proportion of the carbon dioxide reacts chemically with the graphite.

160. The stored energy in the moderator of the Calder reactors has been continuously monitored by refined calorimetric measurements on graphite specimens which have been inserted in the core and on specimens taken from the moderator structure itself. The relationship between the rate of storage of energy and the temperature of the graphite has been measured experimentally: energy is stored less rapidly as the temperature of the graphite is raised. As a result of these measurements, a decision could be taken on the method of reducing the rate of storage of energy in the Calder type reactors; the method chosen is to raise the graphite temperature by inserting magnox or graphite sleeves in channels between the coolant stream and the bulk graphite structure. Data so far obtained from Calder, together with the results of laboratory heat transfer experiments, show that the sleeving is adequate to ensure that no Wigner energy releases will be necessary in the lifetime of sleeved reactors.

161. The reaction between graphite and carbon dioxide in Calder reactors is being followed by weight loss measurements of specimens and by determinations of the amount of carbon monoxide in the coolant gas. Results show that the radiation-induced reaction presents no problem in these reactors, the loss of carbon from the core and the deposition of carbon from the coolant gas being unimportant. For reactors where ratings and pressures are higher, the reaction may be of more significance and the relevant work is described later in this chapter.

Steel

162. The work on steels is being carried out collaboratively with the consortia and C.E.G.B. and covers three fields: the development of techniques for inspecting the reactor vessel during construction; a study of the behaviour of pressure vessels under the temperature and irradiation conditions encountered during the life of the reactor; and the development of improved steels with the particular object of meeting the demands of more advanced reactor designs.

163. A problem presenting particular difficulties is that of the non-destructive inspection of welded joints in thick plate. Radiographic techniques using a multicurie gamma source or MeV linear accelerators are being developed for site use. This work is being done in association with the C.E.G.B., the Armament Research and Development Establishment of the Ministry of Supply, and with industrial concerns. Ultrasonic, magnetic and leak detection inspection methods are also being developed for use

where radiography is difficult or impossible; some of these have already found application on reactor sites.

164. Work has continued on a range of available pressure vessel steels and welded joints to establish their long term high temperature properties. The notch ductility of these materials is also being determined, since this is an important factor in assessing susceptibility to brittle fracture. Due to the greater degree of heterogeneity in thick plate, particular attention is being paid to the effect of plate thickness. A programme for the irradiation testing of steels is under way and specimens in different metallurgical conditions are now being irradiated under different fluxes and temperatures. Those representative of the present conditions of the top of the Calder Hall pressure vessel have been tested and show that no appreciable change in notch ductility has yet occurred.

165. Work on the development of steels is being undertaken in collaboration with the steel industry. Attention has been given to improvements in quality of standard steel plate by modifications to manufacturing practice. Development is also being directed to the production of stronger pressure vessel steels. For this purpose large scale casts of selected low alloy materials have shown promise and fabrication trials are being undertaken by the pressure vessel manufacturers. The development of large steel forgings of comparable properties is also under way, together with the development of suitable welding electrodes.

Reactor Physics

166. The R. and D. Branch, in collaboration with the Operations Branch, has continued experiments on the Calder reactors during the year, both during the commissioning phase and during normal operation of the reactors. The object of these experiments is two-fold: to provide additional information for the efficient operation of the reactors, and to obtain experimental data which can be used to confirm and extend reactor physics theory. Experiments have included the transient behaviour of the reactor.

167. The knowledge of reactor behaviour and the experience of computer calculations are being applied to the design features of the civil reactors. These reactors present a more complex control problem than the Calder reactors because of their increased size and higher rating. The broad features of the control systems to ensure the absence of instabilities in both total power and neutron flux distribution have been established. One problem has been the comparison of the different methods used by other organisations for the analysis of reactor performance. A standard reactor, representative of the civil type, has been specified which allowed different analytical approaches to be compared and resulted in finding new methods of analysis.

Advanced Gas Cooled Reactor

Fuel Elements

168. Following the choice of beryllium as a canning material for the A.G.R., the R. and D. Branch embarked on an extensive programme to solve the many technological problems of processing the metal powder to the finished fuel assembly. Lack of ductility is the foremost problem

in beryllium metallurgy. The mechanical properties of beryllium are impaired by small traces of oxygen and nitrogen with which it reacts readily at elevated temperatures. The toxicity of finely divided metal powder or oxide adds considerably to experimental difficulties.

169. The metal can now be formed into a wide variety of shapes, and the properties of these fabricated components are such that they can be incorporated into a satisfactory fuel element design. Progress has also been made with welding and pressure welding techniques. Attention is now being paid to the effect of irradiation on the behaviour of the metal itself and also on specimens representative of fuel element assemblies.

170. The uranium dioxide fuel will be contained in the beryllium cans in the form of high density pellets. A method of making the fuel on the laboratory scale has been established by the Research Group at Harwell. In the R. and D. Branch the process has been scaled up for the production of ton quantities. This experimental plant has been used to produce dense uranium dioxide pellets, to close tolerances, for the nuclear physics experiments for this type of reactor. The experience gained from this experimental plant has been applied to the formulation of a flowsheet for the production of the fuel for the A.G.R. prototype.

171. At one time it was thought that the fission product gases might be released from the fuel and seriously affect fuel element performance. The presence of the fission product gases in the helium filled cans would impair heat transfer, leading in turn to higher fuel temperatures and further gas release. This could distort the fuel elements. However, latest information suggests that the release of fission product gases is unlikely to limit the A.G.R. fuel element life.

172. The form of the fuel elements has been influenced by a detailed study of the stresses arising from interaction between the fuel and the can, and the effect of coolant pressure. Advantage has been taken of the favourable properties of beryllium and, at the same time, the limitations which its low ductility might have imposed have been taken into account.

173. The complete fuel element assembly, unlike the Calder fuel element, consists of a complex cluster of small individual fuel rods. The heat transfer and coolant flow properties of the assemblies are being studied to aid design optimisation. It has been shown, for example, that a substantial improvement in heat transfer can be obtained by roughening the surfaces of the fuel elements.

Moderator

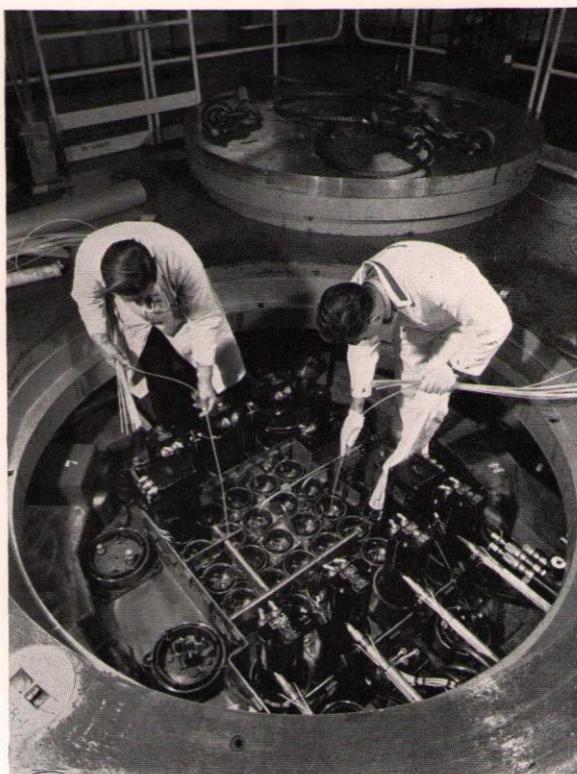
174. The higher flux and increased coolant pressure of the A.G.R. make studies of the reaction between carbon dioxide and graphite important. The programme of investigation has been designed to yield an understanding of this irradiation-induced reaction, and has two objectives: to allow the extent of loss of graphite from the main core structure and the deposition of carbon in the coolant circuit of the reactor to be predicted; and to develop means of inhibiting the reaction.

175. Under the influence of radiation, active chemical species are formed in the carbon dioxide gas and these are responsible for the reaction with the graphite. To supplement in-pile experiments, methods of activating carbon dioxide in the laboratory have been developed and these



CHAPELCROSS, DUMFRIESSHIRE, Britain's second nuclear power station. The first of its four reactors came into use for electricity generation on 25th February, 1959. The reactors are identical in design with those at Calder Hall.

MATERIALS TESTING REACTOR, PLUTO, at Harwell, showing cadmium neutron absorbers being lowered into reactor top. Materials of importance to the nuclear power programme can be tested in this and similar reactors to ascertain how they will behave under irradiation.





TANDEM ELECTROSTATIC GENERATOR, ALDERMASTON. This machine and a similar accelerator at Harwell are designed to yield basic information on the behaviour of nuclei which will be of value over a wide range of the Authority's research and development programmes.

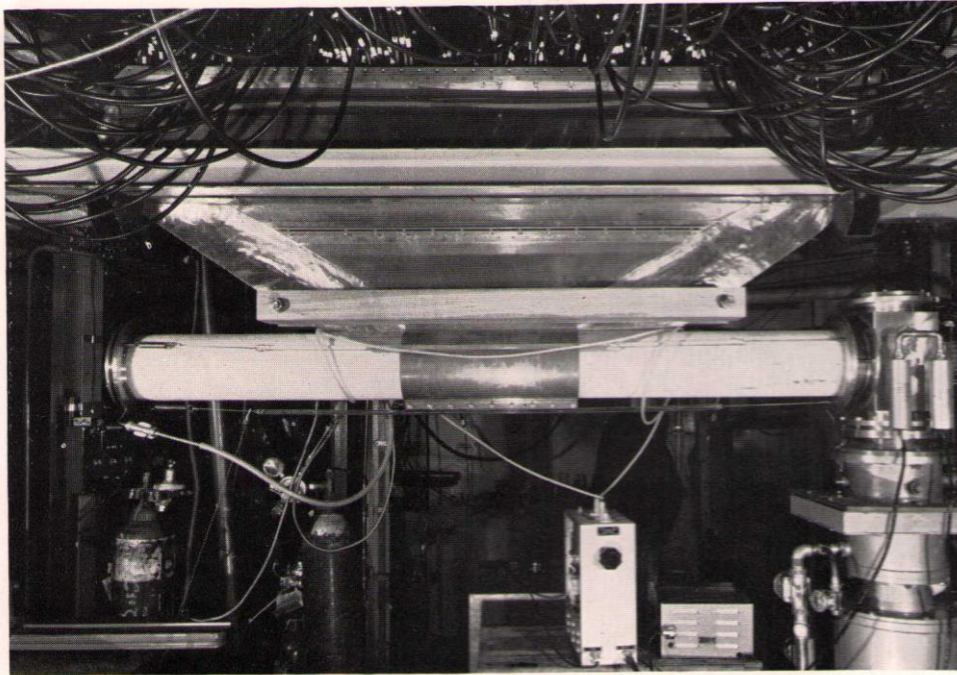


SPRINGFIELD, NEW FUEL ELEMENT CANNING LINE. The second Springfield uranium plant was opened on 7th June, 1958. It is designed to satisfy all the fuel element demands of the first civil power reactors, and to provide uranium and uranium oxide fuel elements for experimental and prototype reactors.

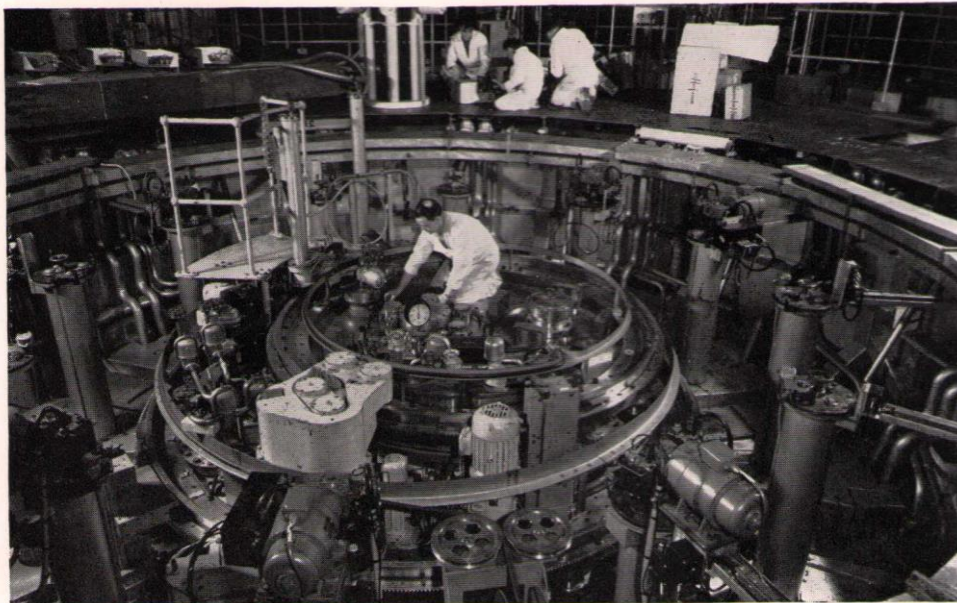
RADIOISOTOPES IN INDUSTRY. The use in industry of control instruments based on radioactive isotopes continues to grow. The photograph shows a thickness gauge being used for measuring thin steel sheet at a steel mill in South Wales.



GRAPHITE RESEARCH, HARWELL. Graphite is used as a moderator, i.e. as a material for slowing down neutrons, in the Calder Hall type reactors, including those being built by industry for the nuclear power programme. The photograph shows a laboratory worker taking a temperature reading of a graphitising furnace with an optical pyrometer.



FUSION RESEARCH. An experiment in position on the MAGGI condenser bank at the Atomic Weapons Research Establishment, Aldermaston. The single turn coil can be seen at the centre of the photograph. The coil surrounds a horizontal gravity tube, six feet long, containing gas at low pressure. The condensers are connected to the coil by the cables seen at the top of the picture. Peak currents of about 800,000 ampères are achieved. Observations of discharges in deuterium gas provide basic information for the fusion research programme.



FAST BREEDER REACTOR, DOUNREAY. This reactor, which should begin a period of low power testing during the summer of 1959, is being developed with a view to reactors of a similar type being put to commercial use in the 1970's. The photograph shows the top of the reactor vessel.

experiments are now adding valuable support to the results being obtained from the rigs in reactors. Information obtained on the radiation-induced reaction between graphite and carbon dioxide from in-pile experiments, coupled with information obtained from the Calder reactors, allows better predictions to be made of the moderator performance in advanced reactors.

176. The addition of a gaseous inhibitor, such as carbon monoxide, holds some promise of reducing the extent of the reaction. Another approach has been to develop protective coatings for graphite. Various protective coatings have been studied but their behaviour in the presence of radiation has so far been disappointing.

Reactor Physics

177. The physics problems of the A.G.R., arising from the new type of fuel element, have not been encountered in previous reactor studies, so new methods and techniques of calculation have had to be developed. These techniques have been applied to a complete performance assessment of the reactor, involving lattice and flux calculations, evaluation of control systems and instrumentation, thermal performance, commissioning and operational procedures and fuel cycles. The study has included several alternative core designs and the stability of each has been examined. As with all previous reactors, a wide range of possible fault conditions has been examined for each design of core. These examinations lead to design features with maximum efficiency and safety.

178. The basic reactor physics problems are being studied by the Research Group at Harwell, but for the full development of the A.G.R. type of reactor for power generation more extensive experimental facilities are necessary. The most important of these is the zero energy, high temperature research reactor, HERO. A distinctive feature of HERO will be its flexibility; a variety of core assemblies can be built up to study the reactor physics of different designs. Initially beryllium-canned uranium oxide fuels will be studied, but later studies will include plutonium-bearing oxide fuels for more advanced applications of the A.G.R. system. The reactor will be heated by hot carbon dioxide so that it can be operated at temperatures up to 500°C. In addition to HERO, fine structure and exponential assemblies will be constructed to provide the preliminary data for the full scale experiments in HERO.

Safety

179. The Authority's obligations for the safety of their plants and reactors have necessitated a continued effort by the R. and D. Branch to provide relevant theoretical and experimental information. For these appraisals the effect of a wide range of fault conditions on reactor operation has been assessed theoretically, and wherever necessary the behaviour of the reactor materials has been determined experimentally. For example, the reaction between graphite and carbon dioxide is endothermic, and hence inherently safe; but under a fault condition which admits air to the coolant circuit, the exothermic reaction between oxygen and graphite can occur. The heat produced by this reaction has been determined, taking into account factors which affect the rate of oxidation, such as the presence of irradiation damage and impurities in the graphite. The safety

of the system has been assessed by relating the rate of production of heat to rate of heat transfer in a variety of reactor conditions, using both theoretical treatment and experimental studies in a full scale graphite channel. The information obtained from these studies has enabled safe operating conditions to be specified.

180. The processing of fissile materials has demanded detailed examination of the criticality aspects of chemical plants, both to guide design and to ensure safe operating procedures. Existing techniques for the calculation of critical sizes are being refined, and the methods are being adapted to make the best use of the available computing machines. Experimental studies of criticality are continuing, chiefly on solutions of uranium compounds, with the aim of providing both basic information and data on particular plant configurations.

Processing

Springfields

181. During the past year effort has been concentrated on the second uranium production plant, and several objectives of the development work have been attained. Continuous processes have replaced the batch process wherever possible.

182. A notable achievement is the introduction of fluidised bed processes for the conversion of pure uranyl nitrate to uranium tetrafluoride. To accomplish this step a thorough knowledge of the basic features of fluidising these materials and the subsequent reaction kinetics is being built up on both a laboratory and pilot plant scale.

Windscale

183. The irradiated fuels from the civil power stations will be processed in a new separation plant to be built at Windscale. New developments since the original separation plant was built have resulted in much improved processes; the development has reached the stage where design of the production plant has commenced and tests of prototype plant are being undertaken. The increased throughput of the plant has made it necessary to consider criticality aspects of parts of the plant and to pay particular attention to the activity of effluents. All solvent extraction stages have been integrated into a continuous system and development work is well advanced to establish continuous process for some of the later stages in the production of plutonium metal. The extensive use of salt-free stages permits the evaporation of all fission product streams so that the major effluents will be distillates of negligible activity. Economic recovery of nitric acid will result from the introduction of the evaporation system.

184. A new process for the uranium purification stages of the existing separation plant has been developed which has resulted in reduced costs and more effective decontamination of effluents.

Capenhurst

185. The analysis of impurities in the process gas of diffusion plants and their associated chemical plants has long presented difficulties. Because of their reactivity and similarity in chemical behaviour, it is necessary to use physical methods of analysis.

186. Gas chromatography and mass spectrometry have been successfully adapted to the analysis of these corrosive gases. The methods give a satisfactory analysis of batch samples, but are not readily adaptable to continuous analysis of the process gas stream. Infra-red absorption techniques are free from this limitation and have been applied to the continuous analysis of hydrogen fluoride. Conventional spectroscopic apparatus employs a prism or diffraction grating to disperse the light, the wavelength of interest to the absorption measurement being selected from the spectrum. For the HF monitor, a new technique has been used; advantage has been taken of the development of optical interference filters which permit the passage of only a narrow band of wavelengths, light of all other wavelengths being absorbed by the filter. The use of interference filters allows a compact and robust instrument to be constructed which is suitable for incorporating directly into an operating plant.

Part III

WEAPONS GROUP

General

187. The Weapons Group has continued during the year to play a vigorous part in the Authority's contribution to scientific research. In particular the Group has ensured that its specialist knowledge and techniques have been brought to bear on problems outside the weapons research and development field. Its contribution to the progress of controlled thermonuclear research is referred to in Chapter VI. Examples of other interesting contributions are given below.

High Energy Machines

188. The 12 MeV tandem electrostatic generator and its counterpart at Harwell, already referred to in paragraph 147, represent the first of their kind to be completed in Europe. They provide for the maximum versatility for research into neutronics at high energies. The layout of the A.W.R.E. machine permits the high energy beams produced to be utilised at either ground or first floor level.

189. Among the other high energy machines, work with the 6 MeV Van de Graaff generator on ^3He beams merits special attention. When used in conjunction with a magnetic spectrograph which analyses the charged reaction particles, many excitation levels of product nuclei can be measured with considerable accuracy. For example, the position of 40 levels of ^{18}F , formed in the reaction $^{19}\text{F} (^3\text{He}, ^4\text{He}) ^{18}\text{F}$, have been determined below the excitation energy of 7.495 MeV.

Safety

190. In the field of design for safety, the Weapons Group experience of criticality has been drawn upon during the past year in a range of problems of importance to the Industrial Group. While all groups are responsible for their own safety the Weapons Group has a special charge for all work in the Authority, either specific or of a more general nature, on criticality problems of solid assemblies of fissile material.

191. Experimental work is also in hand with scale models to confirm the safe design of hypothetical nuclear reactor systems in the event of a sudden release of energy. This work draws upon the specialist experience of the staff at A.W.R.E., Foulness.

Applied Chemistry

192. The following are examples of work of general interest and application in applied chemistry.

Chelate derivatives

193. Certain radioactive materials, such as plutonium-239 and strontium-90, when absorbed by the human body, are difficult to remove from the bone or flesh structure. Biochemical research is being carried out all over the world to develop compounds for oral or hypodermic injection to assist in the process of excretion of these elements. Research work at A.W.R.E. has concentrated on an examination of soluble chelate complexes of the alkaline earth metal ions. The removal of radioactive strontium-90 from such a calcium-rich organism as the human body is complicated by the fact that the complex ions of strontium are generally eliminated from the body fluid at a much slower rate than those of calcium. The present research is directed to the development of chelate compounds to enable strontium complexes to be preferentially removed from the blood stream or voided from the urine. Complexes of the ethylene-diamine-tetracetic acid and derivative type have been synthesised and assessed by various physical chemical methods at A.W.R.E. Accurate values of pertinent equilibrium constants have been determined and the more promising chelate derivatives will ultimately be recommended to the medical authorities for a more comprehensive medical and biological study.

Particle size measurements

194. Measurement of particle sizes below 76 microns is usually based on the principle of differential sedimentation, coupled with a technique for determining the concentration of particles in each size group. One method is photo-sedimentation which derives the concentration from measurements of the attenuation of a beam of light passing through the suspended material.

195. The use of the conventional photo-sedimentometer with sedimentation under gravity is slow. Routine analytical work at A.W.R.E. has been speeded up considerably by the use of a system to increase the rate of sedimentation by centrifugal means. The liquid in which controlled sedimentation is induced is contained in a transparent cylindrical tank under the influence of a steady centrifugal force. The particles stream across a fixed beam of light, parallel with the axis of the cylinder, its attenuation being measured by the use of a null-deflection method, using a calibrated optical disc as a control. Size of particle against concentration is automatically plotted by a pen recorder. The instrument is being developed for continuous automatic operation and for the analysis of radioactive and toxic powders which may require special protective measures. It is estimated that in a routine comparison of powders, for example in the control of a grinding operation during powder manufacture, samples at the rate of 40 per day could be handled by semi-skilled labour.

Decontamination

196. Useful work has been done on the physical and chemical processes underlying radiological contamination as an aid to efficient decontamination techniques, for which requirements differ from conventional cleaning. As a result of studies in this field the operating mechanisms of contamination and decontamination are believed to be fairly well understood and a number of efficient decontamination compositions have been developed.

Data Processing

197. The extensive automatic data processing capacity at A.W.R.E. has enabled the Theoretical Physics Division to assist in speeding up the solutions of lengthy and difficult theoretical problems associated with a wide range of activity in the Group. The programme has included theoretical work on plasma physics related to controlled thermonuclear reactions, safety considerations in reactors and reactor kinetics. Assistance has been given to universities and other outside organisations whenever spare computing capacity has been available.

CHAPTER VIII

ISOTOPES AND IRRADIATION PROGRAMMES

Sales

198. The total sales of radioisotopes and related products despatched from Harwell and Amersham rose to £800,000 this year, compared with £650,000 in 1957-58. The proportion exported remained about the same as in the previous year, namely 60 per cent. Despatches were made to 55 countries.

Reorganisation of Marketing and Production

199. To meet the increasing demand for radioisotopes, and to improve their service still further, the Authority in March, 1959, reorganised their isotopes marketing and production arrangements, responsibility for which had hitherto been shared between the Isotope Division at Harwell and the Radiochemical Centre at Amersham. The scope of the Radiochemical Centre has now been widened to make it a single comprehensive organisation for producing and marketing radioisotopes, with its headquarters and main laboratories at Amersham, and production and irradiation facilities at Harwell and other Authority sites.

200. The Isotope Division, now re-named Isotopes Research Division, continues research into the properties of isotopes, and into new applications of them and their radiations. New laboratories for the Isotopes Research Division are nearly complete at the Wantage Radiation Laboratories, where the Technological Irradiation Group is already located. Most of the Division, including the Isotope School, will have moved to Wantage by mid-1959.

201. Both the reconstituted Radiochemical Centre and the Isotopes Research Division remain part of the Research Group of the Authority.

Production

202. The closing of the two Windscale reactors restricted the production of some of the longer lived isotopes, particularly carbon-14 and cobalt-60. It was possible, however, to make about 300,000 curies of cobalt-60 in the Calder Hall reactors during the year, and this material has provided sources for two large scale irradiation facilities; one for the experimental plant at the Wantage Laboratories, and the other for a commercial installation in Australia, which will be the first of its kind (see paragraph 207). Some 25 smaller sources of 100–1,500 curies each were supplied during the year, six of them (each over 1,000 curies) for radiotherapy machines.

203. The temporary experimental plant at Windscale for separating caesium-137 and strontium-90 from fission products was closed in November, 1958. The plant had provided 5 sources, each of about 1,400 curies, of caesium-137, which are being used for teletherapy in British hospitals, and also a stock for the manufacture of smaller capsules for industrial radiography and other purposes. This plant has also served its original purpose, which was to give information from which a larger plant could be designed.

Isotope Applications

204. The use of labelled compounds, particularly in biological research, continues to increase steadily. The demand for carbon-14 compounds was 25 per cent higher this year than last year. The range of compounds available is now over 200. Recent additions include cortisone-4-C. 14 which has been made by a new synthesis of high efficiency. About 20 tritium compounds are now available.

205. Among the new applications of isotopes which have been studied is a method of testing industrial filters with sized and labelled particulates. This method measures within 1 per cent the quantity of particles passing filters having up to 90 per cent efficiency. A gas analyser operating at temperatures up to 350°C. has been developed for measuring small leakages from systems: it uses an ionisation chamber filled with the gaseous mixture to be analysed. Tritiated water has proved highly successful in investigating problems of drying and for tracer work on water flows.

Large Scale Irradiation Work

206. Developments in the use of gamma irradiation have been continued by the Technological Irradiation Group at the Wantage Radiation Laboratories. Most of the 23 irradiation cells have been loaded with cobalt-60. The sources range in strength from 100 to 4,500 curies. The special installation at Harwell, using spent fuel elements from DIDO and PLUTO as a source of gamma radiation, now contains more than a million curies of gamma radioactivity, and medium scale irradiations have been carried out. Twenty miles of polythene tubing have been treated to raise the softening point, and a variety of hospital equipment has been sterilised.

207. The building of the first industrial gamma-ray sterilisation unit in the world is now in progress in Australia; this will sterilise animal fibres against anthrax. It will start operations using 150,000 curies of cobalt-60 supplied by the Authority, and has been designed to accommodate 500,000 curies.

208. Work on the application of radiation to chemical reactions has been continued on projects of interest to the oil, plastic and detergent industries. Radiation for grafting techniques has been applied to silicone rubbers to improve their resistance to oils and greases. The coating of synthetic fibres to prevent static generation, mentioned in paragraph 216 of the Fourth Annual Report, is proceeding well.

209. A meeting to discuss the Use of Ionizing Radiations for Food Preservation, sponsored by the Food and Agriculture Organisation of the United Nations, was held at Harwell in November, 1958. The meeting was attended by two hundred delegates from 20 nations. The conclusion was reached that the most promising method of treating food was to combine radiation with heat treatment and antibiotics or adrenalin injections. Much work is still required on problems of changes in flavour and odour that accompany irradiation.

210. For the control of insect pests in stored cereals, the radiation doses to sterilise grain weevils have been evaluated and are being checked by large scale experiments. Long term storage experiments are in progress to examine changes in the manufacturing and consumer properties of treated grain.

211. Sterilisation trials on disposable plastic hypodermic syringes, in collaboration with hospitals and manufacturers, show that useful applications of radiation are possible in this field.

Exhibitions

212. During the year the Authority's major exhibition of isotopes and their applications was at the Geneva conference, where half the Authority's stand in the Industrial Exhibition was devoted to a display of radioisotopes. Isotopes have also been shown by the Authority at four other exhibitions, and travelling exhibitions sponsored by them have toured Western Germany and South America.

Isotope School

213. More than 1,000 students have now attended the regular basic course of the Isotope School. In addition, several hundred students have attended shorter specialist courses.

CHAPTER IX

THE WEAPONS PROGRAMME

214. Research and development work on nuclear and thermonuclear weapons for Her Majesty's Government has proceeded. After the weapon tests carried out in 1957, further devices in the megaton range were exploded in the Central Pacific during the year. Three rounds were fired in 1958, one in April and two in September. All were burst high in the air to minimise the possibility of significant radioactive contamination in the Pacific Ocean or on its islands. In addition, tests of kiloton devices suspended from balloons were successfully fired on Christmas Island in August and

September, 1958. These operations were under the command of a Service Operational Commander. The responsibilities of the Authority lay in the provision and preparation of the devices to be tested and in the provision and manning of the measuring instruments. A Scientific Director was appointed by the Authority to assist the Operational Commander with technical aspects and to advise on radiological safety.

215. The new Defence Agreement with the United States already referred to in paragraph 3 of Chapter I covers not only weapons information but also the authorisation for the transfer of a submarine nuclear propulsion plant and materials. In the weapons field, the Agreement makes possible the exchange of classified information concerning atomic weapons "when, after consultation with the other Party, the communicating Party determines that the communication of such information is necessary to improve the recipient's atomic weapon design, development and fabrication capability".

216. Collaboration in the weapons field under the Agreement has been active and will be energetically continued.

217. A conference of experts to study methods of detecting violations of a possible agreement on the suspension of nuclear tests met in Geneva during July and August, 1958. The United Kingdom members of the Western Delegation were Sir William Penney and Sir John Cockcroft. A report of the Conference was published as Cmnd. 551.

CHAPTER X

HEALTH AND SAFETY

Review of the health and safety organisation

218. During the past year the Authority carried out a major review of their health and safety organisation in the light of the recommendations contained in the report of the committee (the Fleck Committee) appointed by the Prime Minister to examine The Organisation for Control of Health and Safety in the United Kingdom Atomic Energy Authority, which was published as a White Paper* in January, 1958. As a result of this review, the Authority reiterated, as a fundamental principle, that all their staff are responsible, through the normal management chain of command, for the safety of operations under their control. To assist the management in this task, specialist health and safety branches (whose functions are advisory) are located at the sites of all hazardous operations. The policy to be followed by the specialist branches is evolved by a simple committee structure. This is under the general supervision of a small committee comprising Members of the Authority under the chairmanship of Sir John Cockcroft. The Health and Safety Branch at Risley, in addition to its responsibility for controlling the Industrial Group health and safety organisation, acts as the executive organ of the health and safety committee structure. Its responsibilities include the preparation of Authority codes of practice and initiating assessments of the design, construction, operation and maintenance of

* Cmnd. 342.

reactors, and of radioactive chemical plants and laboratories. The diversity and scale of these responsibilities have called for a considerable expansion of the specialised staff required for this work. During the past year a vigorous recruitment campaign made good some of the more serious gaps in the organisation. The Authority also reviewed and extended their arrangements for liaison with local authorities, and with their own non-industrial and industrial staff, in health and safety matters.

The shortage of specialist health and safety staff

219. The acute shortage of people possessing the requisite qualifications was regarded by the Fleck Committee* as "one of the most important points that has emerged from our review". The reason for this shortage is that there is no general pool of experience in this type of work. Consequently, the Authority are rarely able to obtain trained men from outside and, in general, have had to train their own staff. In view of the great importance of this matter, the Fleck Committee recommended that the Authority should take the lead in building up the supply of specialised staff required to meet the needs of the nation as a whole. As reported in paragraph 248 of the Fourth Annual Report, the Authority have set up a Committee, under the chairmanship of Sir Douglas Veale, to advise them on this problem.

220. Since its formation, in the middle of 1958, the Veale Committee has been engaged on the complex task of assembling the necessary data upon which their recommendations will be based. This has involved detailed consultations with a large number of Government departments, with hospitals, universities and industry. The Veale Committee recognised the immediate urgency of providing for post-graduate studies in radiobiology and radiological physics, and submitted an Interim Report to the Authority recommending the initiation of courses at selected universities and the provision of studentships if possible in time for the 1959-60 academic year. This recommendation has been accepted in principle by the Authority. Details of the scheme are being worked out in collaboration with the University Grants Committee and the Department of Scientific and Industrial Research. The latter Department have agreed to make studentships available for accepted courses. The Medical Research Council, too, are prepared to make grants in suitable cases. Arrangements have also been made for a pilot summer school, giving background training, to be held at Oxford during the 1959 summer vacation.

Protection of the staff

221. In much of the work done by the Authority there are potential radiological hazards against which the most stringent precautions are taken. For the development of new reactors and plant the Authority need to produce, test and use materials which hitherto have not been handled by industry on a large scale, and in connection with which many special problems arise. For example, beryllium has highly toxic qualities. In addition to the health and safety problems which are peculiar to atomic energy development, the Authority, in common with other large industrial undertakings, have to take precautions against normal industrial hazards.

222. The Authority attach great importance to maintaining full statistical and other health records of atomic energy workers, and to supplementing these records with comprehensive records of the radiation exposure

* Cmnd. 342 (paragraph 93)

of every employee entering a radiation area. In protecting their employees and the general public from the effects of radiation, the Authority are guided by the maximum permissible levels of exposure laid down by the Medical Research Council on the basis of the recommendations of the International Commission on Radiological Protection.

223. The Authority's record stands up well to measurement against these maximum permissible levels, which relate both to external and to internal radiation. In general, the maximum permissible levels are now lower than those in force at the time when most of the Authority's existing plant was designed. Nevertheless, by modifications to plant and methods of operation, the average level of exposure of Authority employees has been kept at only a small fraction of the recommended levels. All workers thought to be liable to receive significant doses of radiation wear film badges, and during the whole of 1958 the average dose received by all Authority employees wearing film badges was 0.44 rad.* In fact, about 90 per cent of these employees received, on average, doses not exceeding 25 per cent of the maximum permissible level recommended by the International Commission on Radiological Protection (3 rads for a period of thirteen weeks).

224. The level of exposure of Authority employees varies according to the nature of their work. During the past year there were twenty-five occasions when the figure of 3 rads in thirteen weeks was exceeded. This is an improvement on the fifty-four occasions during the preceding year. Steps were taken in each case to ensure that long term dose levels were not exceeded.

225. Measurement of radiation levels plays a major part in keeping the radiation exposure of the Authority's employees to a minimum. Over 60,000 surveys of the level of surface contamination have been carried out, and over 200,000 air samples have been taken, in the past year. Continuing attention has been given in the design of plants and buildings to prevent the escape of radioactivity into working areas. By creating safe working conditions the necessity for special protective clothing and equipment has been reduced to a minimum.

226. Similarly, great care has been taken to control the hazards arising from non-radioactive materials with toxic qualities. For example, about 12,000 surveys were made during the year at Springfields to measure the concentration of beryllium in air to ensure that the recommended safe level was not exceeded.

Non-radioactive hazards

227. Records of industrial accidents are maintained by the Authority in a form similar to those in use in industry. The accident frequency rates during 1958 (i.e. the number of lost time accidents per 100,000 man hours worked) were 0.98 for the Industrial Group, 0.48 for the Research Group and 0.53 for the Weapons Group. These figures compare with the average frequency rate in 1957 of 1.71 for all industries which supply this information to the Factories Inspectorate, and of 2.02 for the non-ferrous metal extraction, refining and conversion industry.

228. The Authority regret to report the death of two of their employees as a result of an explosion at Aldermaston on 26th February, 1959. No

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

radioactive materials were involved in the accident. The Board of Inquiry set up by the Prime Minister submitted an interim report on 10th March, 1959, which concluded that the explosion must be regarded as an accident and did not arise as a result of negligence.

Research into health and safety problems

229. Research on a wide range of health and safety subjects was continued during the year. In addition to the considerable effort devoted to safety problems in reactor design, attention was given to the development of methods and equipment for radiation measurement. Studies were also undertaken of the behaviour of radioactive material in the human food chain. The nature and properties of airborne radioactivity were studied as a complement to the investigations made following the Windscale accident in October, 1957.

Fall-out from nuclear tests

230. Studies have also continued on the deposition of radioactive nuclides from fall-out from nuclear test explosions on grass and crops and their entry into the human food chain. The main source of deposition is rain and, accordingly, systematic radiochemical analysis of the significant nuclides in rain has been carried out.

231. As milk is an important contributor of strontium-90 to the human diet, an experiment was carried out, in collaboration with the Department of Agriculture in the University of Reading. In this experiment, both the diet of and milk from a herd of dairy cows were analysed regularly for more than a year. The results showed that there was a reduction by a factor of about 10 in the ratio of both stable strontium and strontium-90 to calcium in the passage of these elements from the diet to the milk of the cow.

232. Arrangements have been made for the Agricultural Research Council to take over from the Authority responsibility for monitoring agricultural products and soil, and for the Medical Research Council to take responsibility for monitoring human bone. The Authority will continue to monitor the radioactivity in air and rainwater in the United Kingdom and at various other locations throughout the world.

Whole body monitor

233. Techniques have been extensively developed for the measurement of radioactive materials within the human body. These permit the identification as well as the measurement of the radioactive materials, and are used regularly to study the subsequent history of the small quantities of radioactive material ingested or inhaled accidentally. These measurements can give valuable information about the metabolism of the materials involved.

Waste Disposal

234. The Authority are required by Section 5 (4) of the Atomic Energy Authority Act, 1954, to obtain authorisations from appropriate Ministers for the disposal of all radioactive wastes. Particular attention was paid during the past year to the arrangements for waste disposal from the

Authority's new establishment at Winfrith. Technical discussions took place with the Ministries concerned on the authorisations required there. New or revised authorisations were issued for a number of the Authority's other establishments, including Chapelcross.

235. The research programme on the distribution and accumulation of radioactive materials discharged from Windscale was expanded. In the freshwater programme, three experimental ponds have been constructed at Windscale for studying the accumulation and retention of radioactive materials through the food chain. In support of this work laboratory experiments have been carried out on the effect of hard and soft waters on the accumulation and loss of radiostrontium by aquatic life. A survey of six lakes, which differ in water composition, was made to determine the levels of the stable isotopes of strontium, caesium, calcium and potassium in fish, aquatic plants, plankton, mud and water.

236. The sea water programme was concerned with the mechanism of accumulation of various chemical forms of ruthenium-106 by marine materials. The accumulation of nitrosyl ruthenium-106 by marine algae and by fine particles of sand and mud was shown to be a surface phenomenon. The presence of fine particles in the sea was shown to reduce the amount of ruthenium accumulated by marine algae growing in the inter-tidal zone, while accumulation by bottom feeding fish, e.g. plaice, appear to be related to the nature of the sea bottom material and the invertebrates living within that material. The accumulation, retention and loss of radioactive isotopes of strontium and yttrium by lobsters were also studied.

Co-operation with Government Departments

237. During the past year the Authority continued to co-operate closely with the Government departments concerned with health and safety problems in the atomic energy field.

238. The Authority were consulted by the Ministry of Power in the preparation of the Nuclear Installations (Licensing and Insurance) Bill. They advised on the form of organisation the Ministry will need to carry out the functions to be laid upon the Minister. In practice, the Authority have in the past exercised a limited control, on the lines proposed in the Bill, to which private reactor owners have submitted voluntarily.

239. The Authority continued to provide advice to the Ministry of Labour and National Service in the preparation of draft Regulations under the Factories Acts. They were also represented on the Ministry of Transport and Civil Aviation's Committee on the Safety of Nuclear Ships, which has been carrying out preparatory work for the 1960 Convention on the Safety of Life at Sea, to be held under the auspices of the International Maritime Consultative Organisation.

240. Members of the Authority's staff continued to work in close collaboration with the staff of the Medical Research Council and of the Agricultural Research Council. The Authority are grateful for the considerable help which they have continued to receive during the past year from both these bodies.

International co-operation

241. The Authority continued to play a full part during the past year in the work of international organisations concerned with atomic energy health and safety problems. Regular contributions were made to the work in this field of the International Atomic Energy Agency and also to that of the United Nations Scientific Committee on the Effects of Atomic Radiation, the World Health Organisation, the European Nuclear Energy Agency (operating under the auspices of the Organisation for European Economic Co-Operation) and the International Commission on Radiological Protection. Participation in this work involved considerable expenditure of specialist effort, and emphasised the acute shortage of trained specialists in the health and safety field.

CHAPTER XI

PUBLIC RELATIONS

242. The growing realisation that atomic energy will play a continually greater part in everyday life is matched by a rising public demand for information on all aspects of the subject.

243. One of the most important channels of communication continues to be the newspaper and technical press, both at home and overseas. Press facilities for journalists of many countries, both individually and in parties, have been arranged by the Authority. Large scale press conferences during the year have included those on the Fleck Committee's Technical Evaluation Report* relating to the design and operation of the Windscale piles, and on the first viewing by the press of the Springfields uranium processing plant. An Authority press office was set up in Geneva for the duration of the United Nations Conference in September, 1958, and press officers also attended a number of overseas exhibitions to ensure effective liaison with local and visiting journalists.

244. As in past years, there were many calls on Authority members and staff to contribute to the press, television and radio, and to lecture to a wide variety of audiences. For these purposes about 1,400 papers were prepared during the year. Members and senior staff of the Authority have lectured in many countries, including France, Germany, Holland, Italy, Japan, Spain, Switzerland, Turkey, the U.S.A. and the U.S.S.R.

Exhibitions

245. The Authority took part in twelve exhibitions, nine of which were overseas, during the year. The principal overseas exhibition commitment was in connection with the Second Conference on the Peaceful Uses of Atomic Energy at Geneva from 1st to 15th September, 1958. The Authority presented two exhibitions: a Scientific Exhibition, 5,000 square feet in extent, at the Palais des Nations; and an exhibit of 3,500 square feet at the "Atoms for Peace" Commercial Exhibition held in the Palais des

* Cmnd. 471.

Expositions. The Authority co-operated with the Nuclear Energy Trade Associations' Conference, which was responsible for the organisation of the British section, the largest in the commercial exhibition.

246. At the Brussels Universal and International Exhibition, 1958, which lasted from April to October, the Authority contributed to the Board of Trade display in the Industrial Pavilion, the theme of which was the United Kingdom nuclear power programme, and to the International Hall of Science. Assistance was also given in the planning of certain exhibits in the British Government Pavilion, which included models of ZETA and of the fast breeder reactor at Dounreay. The Authority were awarded a Grand Prix Gold Medal for their stand in the section featuring the exploitation of nuclear energy.

247. As in previous years, the Authority and the Nuclear Energy Trade Associations' Conference co-operated with the Board of Trade to provide a display at the Hanover Trade Fair during April-May, 1958. In May, 1958, the Authority also presented an exhibit at the Madrid Atomic Energy Exhibition, which was seen by 800,000 visitors. In the following month a duplicate of this was displayed at an exhibition held in conjunction with an Australian Atomic Energy Commission symposium in Sydney.

248. A complete exhibition of approximately 1,200 square feet, similar to the Madrid and Sydney displays, was lent to the Board of Trade for presentation at St. Erik's Fair, Stockholm, during August and September, 1958.

249. In October, 1958, the Authority took part in the Fuel Efficiency Exhibition at Olympia, staging a display of 900 sq. ft., which included a cinema. During November, 1958 the Authority presented a display at the Electro-Heat and Productivity Exhibition in Glasgow, organised by the South of Scotland Electricity Board, and also took part in the Physical Society Exhibition, at which they presented a co-ordinated exhibit prepared by the Research and Weapons Groups.

250. In the same month the Authority contributed to a Commonwealth Relations Office display at the Indian Science Congress in New Delhi. The Authority also co-operated with the Board of Trade in the presentation of the United Kingdom Government display of atomic achievement at the Rand Easter Show in Johannesburg.

Films

251. The Authority completed production of seven films during the year. These included two training films; two technical films on the construction of the Calder Hall nuclear power station, "Reactors at Calder Hall" and "Full Power"; a description of metallurgical research and development at Harwell entitled "Metals of the Nuclear Age"; "Radioisotopes in Industry", which presents a selection of the current industrial applications of radioisotopes; and "More Power from the Atom", an up-to-date survey of the progress of the nuclear power programme.

252. Foreign language versions of many Authority films have been prepared, either by the Authority or by the Central Office of Information or the British Council. The two latter organisations undertake major responsibility for overseas distribution. During the year Authority films

have been shown in Argentina, Australia, Belgium, Canada, Chile, Columbia, France, Germany, Greece, Holland, India, Italy, Japan, Mexico, the Middle East, Nigeria, Norway, Pakistan, Peru, Russia, Southern Rhodesia, Spain, Sweden, Switzerland, Uganda, U.S.A. and Venezuela.

The majority of these films were shown to specialist audiences representing industrial, commercial and scientific organisations.

253. A library of 16 of the Authority's films was presented to the European Atomic Energy Community on the occasion of the signing of the co-operation agreement between Euratom and the United Kingdom Government on 4th February, 1959.

254. The Authority's film, "Criticality", has been adopted for training purposes in the United States, and some European countries have also expressed interest in its use.

255. Sixteen Authority films were shown at the Geneva Conference. Five were shown on the Authority stand in the commercial exhibition; these were projected with simultaneous sound tracks in four languages (English, French, German and Italian) and members of the audience could, by the use of earphones, tune in to the language of their choice. This device was so successful that it is to be used at other international exhibitions.

Publications

256. New publications during the year included "The Nuclear Energy Industry of the United Kingdom", a handbook for the guidance of prospective customers for British nuclear equipment, which was printed in English and four foreign languages; illustrated brochures on the Industrial Group and the A.E.R.E. Isotope Division; and a "Glossary of Atomic Terms". The whole range of existing brochures and leaflets was revised and reprinted in eight languages for the Geneva Conference.

257. 25,000 copies of "Atom 58", a popular version of the Authority's Fourth Annual Report, were printed. In addition, a revised version entitled "Atom in Britain" was printed in English, French, German, Spanish and Italian, and a total of 30,000 copies was issued at Geneva.

258. The circulation of "Atom", the Authority's monthly bulletin, rose in this period from 8,500 to 10,600 copies. About 2,700 copies of each issue were sent overseas.

Photographs

259. Fifteen hundred new negatives were added during the year to the Photographic Library, bringing the total number of subjects to 8,000. Enquiries for photographs averaged over 90 per week.

260. Over 20,000 prints were issued to newspapers, magazines, television producers, exhibition designers, authors, lecturers, universities and schools, and over 2,000 slides were loaned to lecturers.

Public Information Room

261. A public information room on the ground floor of the Authority's London Office was opened on 1st January, 1959. Its purpose is to provide

a convenient centre in London, where members of the public, firms and other organisations may consult published unclassified material (i.e. material with no security restriction) and seek advice on sources of information on atomic energy matters. The service is complementary to the established information services provided by the Authority at Harwell, Risley, and to a lesser extent, Aldermaston, for dealing with scientific and technical enquiries. Close liaison is maintained with Group libraries and other libraries outside the Authority. A reference collection of unclassified reports and other Authority publications is available, and indices and abstracts of atomic energy literature.

CHAPTER XII

COMMERCIAL RELATIONS

Relations with Industry

262. During the year the Authority continued their close association with industry in the further development of the Calder Hall type reactor. Industry is also associated with the development of the advanced gas-cooled reactor. Technical and professional staff drawn from industry have been seconded to work with Authority staff on its design and construction.

263. The Authority collaborated also with the shipbuilding industry in examining whether a gas-cooled, graphite-moderated nuclear reactor which will operate economically can be developed for marine propulsion. During the year collaboration agreements were concluded with the British Shipbuilding Research Association for the attachment of staff from the Association to Authority establishments.

264. To help British industry to compete for export business in the design and manufacture of radioactive chemical processing plant, the Authority arranged, through the British Chemical Plant Manufacturers' Association, for the training in Authority establishments of scientists and engineers from chemical plant manufacturing companies. A course of training for selected staff started in September, 1958.

265. A substantial amount of research and development work was carried out for the Authority by industry under extra-mural contracts. Work in hand included nuclear engineering; the development of equipment for the study of controlled thermonuclear reactions; health instrumentation; reactor control instrumentation, and studies of the properties of materials for the nuclear reactor programme. The amount of research and development work contracted out by the Authority tends to increase.

266. The Authority continued to act as consultants to the Central Electricity Generating Board and to the South of Scotland Electricity Board on the nuclear parts of the power stations which are at present being built for them. They also provided the boards with information about the latest techniques affecting the design, construction and operation of the stations, and assisted them in drawing up codes of practice for the safe and efficient operation of each reactor.

267. The Authority provided consultancy services to Agip Nucleare in connection with the nuclear power plant which is being built by the Nuclear Power Plant Company Limited at Latina in Italy. The Authority also gave technical assistance, in reviewing tenders, to the international panel of experts appointed to assist the Italian SENN organisation in selecting a nuclear power plant for Project ENSI. At the year's end, they were on the point of concluding an agreement to provide consultancy services to the Japan Atomic Power Company in connection with the company's proposed purchase of a United Kingdom designed nuclear power station.

Harwell Reactor School

268. During the year the pattern of the courses was similar to that of previous years. Four standard courses were completed. The scheme whereby the first six weeks of the standard course are spent at the Colleges of Advanced Technology at Birmingham, Bradford and Salford, was continued and proved successful. In addition, three courses were held for senior technical executives.

269. A special one week course was held on the Control and Instrumentation of Reactors. This course was open to overseas as well as U.K. students. Ninety-seven students attended.

270. Three hundred and thirty-nine British and 160 foreign students have attended the school during the year. Since the courses began there have been 1,104 British and 364 foreign students.

Calder Operations School

271. During the year 6 six-week courses have been held; four for British and two mainly for overseas students. There was also a course for senior executives. The training requirements of the consortia and of the generating boards reach a maximum during 1959. In order to accommodate the requisite numbers the school was expanded to take up to thirty students for each course. During the year the subject matter of the course has been gradually changed to give more information about the operating procedures of the civil stations.

Attachments of Staff from Industry

272. The arrangements whereby staff from industry are trained in and familiarised with the applications and problems of atomic energy by attachment to the Groups have continued. Representatives of British firms are working alongside Authority staff in such fields as the study of new reactor systems; basic shielding; corrosion studies; marine propulsion; controlled thermonuclear reactions, and the potential use of irradiation in industrial, and particularly chemical, processes. Over 300 professional and technical staff from industry have worked with Authority staff during the year. A team from the Department of Scientific and Industrial Research has been working with the Authority's staff on the application of radioactive isotopes to industrial uses. In addition a number of scientists from universities have made use of the large experimental installations at Harwell to carry out fundamental scientific research.

Sales of Technical Information

273. The Authority have undertaken further extensive filing of patent applications to protect inventions in the nuclear field both in the U.K. and abroad. The granting of patent licences continued as in past years. During

the year the Authority have completed the negotiation of comprehensive licence agreements with the consortia. These provide for the use, against payments of royalties, of relevant Authority patents and design and engineering information on the British type of gas-cooled reactor.

274. A number of other licence agreements were also concluded with companies which had previously applied for and had received information under access agreements.

Sale of Goods

275. *Fuel Elements.* The Authority are at present the only manufacturers of fuel elements for the Calder Hall type of reactor. Contracts are being negotiated with the electricity boards for the supply of new fuel elements, and for the repurchase of the fuel after irradiation. To enable the Authority to plan appropriate manufacturing and reprocessing capacity, the contracts may cover periods of ten years for each station; provision will be made, however, for selling and repurchase prices to be varied from year to year. The first deliveries of fuel for the U.K. nuclear power programme will begin towards the end of 1959.

276. The Authority also undertake to supply natural uranium fuel elements for any U.K. designed gas-cooled reactor constructed overseas, and to repurchase the fuel after irradiation. A statement of their terms has been made available for use by potential overseas customers. Contracts may be made either directly with a reactor operator, e.g. an electricity undertaking, or with a government agency in the purchaser's country. The Authority expect the contracts to be for a reasonable minimum period. Fuel supply contracts are dependent on the conclusion beforehand of a bilateral agreement between the U.K. and the overseas government concerned. This agreement includes an undertaking by that government that the fuel and equipment supplied, and the fissile material derived from the use of the fuel and the equipment, will be used only for peaceful purposes. During the year the Authority negotiated such a fuel supply contract with Agip Nucleare in respect of their Latina station. (See paragraph 272 of 4th Annual Report.) This fuel supply contract is the first overseas order of its kind to be placed in the U.K. Deliveries of the initial fuel charge will take place during 1961-62. Negotiations are also in hand for a fuel element supply contract for a nuclear power station which the Japan Atomic Power Company proposes to order from the G.E.C./Simon Carves Group of Companies.

277. *Other Products.* The Authority have made and sold enriched uranium fuel elements for research reactors of British design which have been and are being built in Australia, Germany and Denmark, and natural uranium elements for the Halden reactor in Norway. They have also sold, both at home and overseas, limited quantities of natural uranium, thorium, beryllium and zirconium. Some special chemical compounds have also been supplied. The Authority are also supplying the graphite moderator for the nuclear reactors of power stations. This nuclear quality graphite is manufactured under contract to the Authority, but the Authority assume responsibility for its inspection and testing as the graphite required for a nuclear power programme must meet an exacting specification.

278. The Authority are net exporters of electricity from their Calder Hall station and this is sold under contract to the Central Electricity Generating Board. Negotiations on the terms of supply of electricity from the Chapelcross reactors to the South of Scotland Electricity Board were proceeding at the end of the period.

CHAPTER XIII

INTERNATIONAL RELATIONS

279. With the continuing growth of interest in nuclear power and the steady expansion throughout the world of nuclear energy facilities, the extent and variety of the Authority's international commitments continue to increase. International collaboration should lead to speedier development of applications of nuclear energy in the collaborating countries than if each country worked entirely in isolation. The demands of international collaboration occupy an appreciable portion of the time of Authority staff, particularly of senior staff. The Authority, therefore, while fully participating under the various international agreements in which they are concerned, seek to avoid unnecessary duplication of international conferences, symposia, etc., covering substantially the same subjects.

International Organisations

Bagdad Pact Nuclear Centre

280. Events in Iraq in July, 1958, resulted in the closing of the Nuclear Training Centre in Bagdad. Between March, 1957, and June, 1958, the Centre had trained about 60 students from the Pact region (Iran, Iraq, Pakistan and Turkey) in radioisotope techniques, and also had encouraged a variety of isotope applications, principally in agriculture and medicine, in the region. At the end of the year, plans were made to reopen the Centre in Tehran in April,* 1959, and to hold the first training course in September. Future courses are likely to be longer than in the past and to include a period spent on isotope application projects. Mr. H. A. C. McKay has succeeded Mr. W. J. Whitehouse as Director of the Centre, and Dr. M. L. Smith is Deputy-Director. Both are from Harwell. The staff are drawn from all the countries of the Pact, the largest element being from the United Kingdom.

Euratom

281. An Agreement between Her Majesty's Government and the European Atomic Energy Community (Euratom) was signed in London on 4th February, 1959, by the Foreign Secretary and the Paymaster-General and members of the Euratom Commission. The agreement is intended to provide a comprehensive framework within which the U.K. and the European Atomic Energy Community can co-operate in nuclear energy matters. It provides for exchange of information, mutual assistance with atomic energy programmes, supply by the U.K. of fuel for reactors of U.K.

* The Centre was reopened in April, 1959.

design, co-operation in the development of measures to provide financial protection against third party liability, secondment of experts, and for periodical meetings between representatives of the U.K. and Euratom. It has been agreed that operation of the agreement will be supervised by a Committee consisting of a U.K. Minister and the Chairman of the Atomic Energy Authority and the Chairman and another Member of the Euratom Commission. Under this body there will be a technical working group of members of the staff of the Authority and of the Commission. A member of the Authority's staff will shortly be seconded as scientific attaché to the U.K. Government representative to the European Atomic Energy Community.

European Nuclear Energy Agency

282. During the year the Authority agreed to participate in two joint projects sponsored by the European Nuclear Energy Agency under the aegis of the O.E.E.C.

(i) Boiling Water Reactor

On 11th June, 1958, the Authority and representatives of Austria, Denmark, the Euratom Commission, Norway, Sweden and Switzerland signed an agreement to operate the boiling water reactor at Halden in Norway as a joint project for three years beginning 1st July, 1958. (Since then Finland has also become associated with the work.) Two scientists from the Research Group are working at Halden. The Authority are providing the first fuel charge.

(ii) High Temperature Gas-Cooled Reactor

An agreement to develop the high temperature gas-cooled reactor, which it is proposed to build at Winfrith, as a joint project with other member countries of the European Nuclear Energy Agency, was signed at O.E.E.C. Headquarters in Paris on 23rd March, 1959. The participants, in what has come to be known as the Dragon Project, are the Authority, the Euratom Commission, the Governments of Austria and Switzerland, and the national atomic energy organisations of Denmark, Norway and Sweden. The joint project, which is to operate in the first instance for five years, will carry development to the stage of building an experimental power producing reactor which at the end of the joint programme will belong to the Authority. The project will be under the direction of a member of the Authority's staff who has been nominated Chief Executive. It will be supervised by a Board of Management (the Authority members of which are the Member for Scientific Research, Mr. D. W. Fry and Mr. D. E. H. Peirson) and a General Purposes Committee. Scientists and engineers will be seconded by their respective Governments to form a joint design team. This type of reactor, if successfully developed, could be used for central power station generating plant or as a small system for isolated or mobile units. A detailed programme of work is now being drawn up; it is expected that part of the experimental work will be carried out in other European countries.

Staff of the Authority have participated during the year in other E.N.E.A. activities, notably the Health and Safety Committee.

International Atomic Energy Agency

283. The programme of the International Agency, which held its second General Conference in September, 1958, is making good progress. Increasing requests have been made to the Authority to supply experts to assist the Secretariat by taking part in scientific and technical panels, conferences and symposia, to lend experts for short periods to other member countries, and to take part in overseas exploratory and advisory missions. Several students nominated by the Agency have already been selected to fill free places offered by the Authority at their Wantage Laboratory and further nominations are likely to be made shortly.

United Nations

284. Reference was made in paragraph 284 of the Fourth Annual Report to preparations by the Authority for the Second United Nations Conference on the Peaceful Uses of Atomic Energy which was held in Geneva in September, 1958. The U.K. sent a strong team consisting of five delegates headed by Sir John Cockcroft, and nearly 300 advisers, many of whom were concerned with the oral presentation of scientific papers. The total number of papers presented by the U.K. was over 200. There were also about 400 U.K. observers. The advisers and observers were drawn from the universities, other research bodies, hospitals, Government Departments, electricity boards and industry generally, and from the Authority.

Report of the U.N. Scientific Committee on the Effects of Radiation

285. The report of the Committee, in the preparation of which members of the Authority's staff had taken an active part, was published on 10th August, 1958.

Co-operation with other International Organisations

286. The Authority co-operated with the International Labour Organisation in organising a course on radiation protection at Oxford in July, 1958. The European Meeting on the Use of Ionising Radiations for Food Preservation is mentioned in paragraph 209.

Commonwealth Countries

Commonwealth Conference and Tour

287. After the 1958 Geneva Conference, Her Majesty's Government invited representatives of Commonwealth countries to attend a conference in the U.K. and to make a tour of the Authority's establishments. Forty representatives from nine Commonwealth countries took part. The tour included a two day visit to Harwell, and visits to Calder Hall and the Dounreay Experimental Reactor Establishment. The conference also included a meeting with the Central Electricity Generating Board and a visit to the Bradwell C.E.G.B. nuclear power station site. On the last day of the tour delegates had the honour of lunching with Her Majesty the Queen, His Royal Highness The Prince Philip, Duke of Edinburgh, and other members of the Royal Family at Balmoral.

Canada

288. Agreement was reached in discussions with the President of Atomic Energy of Canada Limited on ways of securing even closer relations between

that Company, which is the official atomic energy organisation in Canada, and the Authority. Subsequently, further attachments of Canadian engineers to Authority establishments were arranged. In January, 1959, a Liaison Officer appointed by Atomic Energy of Canada Limited was posted to London where he will be in close touch with the Authority. The Authority have for some time had a liaison officer at the principal Canadian atomic energy research establishment at Chalk River.

Australia and New Zealand

289. Several senior members of the Authority's staff including Sir Leonard Owen, the Managing Director of the Industrial Group, visited Australia and New Zealand during the year and discussed common problems with colleagues in these countries. The Authority were represented by Sir Donald Perrott at the inauguration of the Australian HIFAR reactor in April, 1958.

India

290. The Authority continued to collaborate with the Indian Atomic Energy Commission in tackling the problems of a young and rapidly growing atomic energy project by lending specialist staff for short term advisory visits and for extended attachments. There were discussions with leading members of the Commission on their plans for introducing nuclear power into India.

United States of America

291. On 3rd July, 1958, a new bilateral agreement was signed by representatives of the U.K. and U.S. Governments which permitted much more far reaching and valuable exchanges of information on the military uses of atomic energy than have been possible since 1946. Under the agreement, the U.K. Government is also enabled to acquire a nuclear submarine propulsion plant and the necessary fuel core. This agreement followed on an amendment of the U.S. Atomic Energy Act enacted by Congress in July, 1958. The year was also marked by an extension of co-operation in the civil uses of atomic energy into a number of new fields. These new exchanges were, for the most part, concerned with basic research and development on problems which have become important to the programmes of both countries, such as the effects on reactor materials of prolonged exposure to high temperatures and irradiation and the compatibility of different materials in such conditions. In matters of this kind ready access to the results of complementary work is of the greatest value.

292. Team visits were arranged for the exchange of experience on safety problems, organisational questions and other matters. There were further meetings at which U.S. projects and designs for gas-cooled, graphite-moderated reactors were discussed in the light of U.K. experience of this system; and the technical collaboration between those involved in the U.S. and U.K. fast reactor programmes grew even closer. In the fast reactor field also, the Authority concluded an agreement on 8th August, 1958, with the Power Reactor Development Company which, in conjunction with Atomic Power Development Associates Inc. and the Detroit Edison Company, is building a large fast reactor power station near Monroe, Michigan. The agreement provides for the exchange of experience gained in the planning and

construction of the Dounreay and Monroe reactors and it is already clear that both sides will benefit greatly from these exchanges.

293. There was an increasing number of staff exchanges between laboratories in the two countries and three members of the Authority's staff are at present taking part in special long courses offered by the Oak Ridge National Laboratory.

294. In October, 1958, the new Chairman of the U.S. Atomic Energy Commission, Mr. John A. McCone, together with Dr. Willard F. Libby, a member of the Commission, made a tour of Authority establishments. The Chairman of the Authority and Sir William Penney made a similar tour of U.S.A.E.C. Establishments early in 1959. Authority representatives also had an opportunity to discuss matters of common interest with the Chairman and some of the members of the U.S. Congressional Joint Committee on Atomic Energy while they were on a visit to Europe.

Japan

295. The intergovernmental agreement with Japan, the negotiation of which was mentioned in paragraph 305 of the Fourth Annual Report, was signed on 16th June, 1958, and ratified by the Japanese Government on 5th December, 1958. Throughout the year the Authority were in close touch with the Japanese Atomic Energy Commission, the Japan Atomic Power Company and the other Japanese organisations concerned with atomic energy, and information and advice were given on many technical questions arising out of the decision to construct a U.K. type nuclear power station in Japan. At the invitation of the Japanese Atomic Energy Commission, Sir John Cockcroft, accompanied by Mr. P. Mummery, visited Japan in November, 1958, and had discussions with a number of interested organisations there.

296. The evaluation by the Japan Atomic Power Company of the bids submitted by three U.K. consortia for the Japanese nuclear power station project, and the subsequent negotiations, continued during the greater part of the year. Early in 1959 the Japan Atomic Power Company issued a letter of intent to the G.E.C./Simon Carves Group of Companies for the construction of a gas-cooled reactor of 150 MW(E) capacity. The Authority thereupon concluded a technical assistance agreement with the Japanese company. The Authority also issued a letter of intent relating to the supply of fuel elements for the reactor.

Other Countries

297. An agreement between the governments of the U.K. and Portugal for co-operation in nuclear research was concluded in July, 1958. Throughout the year, under this and other agreements now in force, the Authority continued to be involved in numerous co-operative activities. With the French Commissariat à l'Energie Atomique, for example, there were a number of exchanges of visits to discuss technical subjects of common interest and work was started on a joint programme of metallurgical research. As the French atomic programme develops increasing scope is being found for exchanges of value to both sides. Close and friendly relations also have been maintained with Belgium, Brazil, Denmark, the Federal

Republic of Germany, Italy, the Netherlands, Norway, Spain, Sweden, Switzerland and many other countries, both by direct contacts and by sharing in the work of the European Atomic Energy Society, of the Conseil Européen pour la Recherche Nucléaire (CERN), and other international bodies.

298. Early in 1959 a number of sister organisations abroad, with which scientific reports are exchanged, were presented by the Authority with micro-copies of U.K. unclassified reports, covering the years 1947 to 1956.

299. During the year, senior members of the Authority's research and development staff continued to travel abroad in order to learn of the latest advances being made in the atomic field in other countries. These visits were frequently reciprocated with much advantage to all concerned. Sir John Cockcroft and other representatives of the Research Group visited the Soviet Union to see work on controlled thermonuclear reactions, and other branches of nuclear research; and Soviet scientists were invited to visit Harwell to see the work there on thermonuclear reactions.

CHAPTER XIV

THE AUTHORITY'S STAFF

Senior Staff

300. At Appendix II are listed the Authority's Senior Staff in the London Office and in the Headquarters of the three Groups; officers in charge of other establishments, and the advisers to the Authority.

Strength

301. The total number of staff employed by the Authority increased from 30,341 on 1st April, 1958, to 35,260 on 31st March, 1959. The total number of non-industrial staff increased from 14,481 to 17,043 and industrial employees from 15,860 to 18,217. This represents a slightly increased rate of expansion over that of previous years.

Recruitment

302. The recruitment efforts made by the Industrial Group to implement the recommendations of the Fleck Committee*, and those necessitated by other parts of the Authority's programme, have confirmed that the main difficulty lies in attracting qualified engineers and scientists of sufficient experience for the higher management posts. Nevertheless, it has proved possible to fill most of the more important posts and the Industrial Group is almost up to strength. Recruitment of staff at lower levels has been reasonably successful. The intake from the universities has improved significantly.

303. Recruitment of industrial employees was satisfactory although difficulties were encountered in recruiting for certain craft grades in some localities.

* Cmnd. 338 and Cmnd. 342.

304. The Authority have made special provision to increase recruitment to training grades in order to take advantage of the greater numbers leaving school over the next few years.

Staff and Industrial Relations

305. The Authority Whitley Council for Non-Industrial Staff operated successfully during the year. There have been numerous informal meetings between representatives of both sides.

306. Agreement has been reached on the principles which should govern the Authority's promotion policy and on the general organisation of their promotion machinery. Agreement has also been reached on the procedure to be adopted in the event of redundancy among non-industrial staff.

307. The National Joint Industrial Council for the United Kingdom Atomic Energy Authority has continued to function well. The Council met on three occasions and the General Purposes Committee held five meetings. In the health and safety field agreement was reached on the establishment of local joint committees to discuss radiological and toxic hazards, and on staff representation on Boards of Inquiry into accidents.

308. A new trade union, known as the National Union of Atomic Workers, made representations to the Authority that it should be recognised as an organisation representing a substantial number of persons employed by the Authority and, as such, should be consulted by the Authority on matters affecting the employment of its members. After careful consideration of these representations, the Authority came to the conclusion that the present joint industrial negotiating and consultative machinery, established on 5th July, 1955, was working satisfactorily, and adequately achieved the purposes of section 7 (1) of the Atomic Energy Authority Act, 1954. Accordingly, on 6th April, 1959, the National Union of Atomic Workers was informed that the Authority saw no reason at present for amending the existing consultative arrangements.

309. There have been negotiations on other important matters, particularly on pay and conditions of service, which are mentioned separately in the following sections of this chapter.

Pay and Conditions of Service

310. The review of non-industrial staff grading and structure, which was undertaken to consider what modifications in the arrangements inherited from the Civil Service were necessary to meet the Authority's special needs, was taken to its final stages during the year. Proposals for recasting the present staffing structure will shortly be discussed with staff representatives through the Whitley Council machinery.

311. Discussions were held during the year on the claim by the Institution of Professional Civil Servants for substantial salary increases for scientists and engineers employed by the Authority, which was originally put forward at the beginning of 1958. Further action on the claim has been deferred until the results of the structure review are made available to the staff associations.

312. The $3\frac{1}{2}$ per cent salary rise awarded to non-industrial Civil Service staff on rates of pay up to about £2,100 per annum, and the consequential interim increase at just above that level, were reflected in increases in Authority salaries.

313. A claim by the Trade Union Side of the Authority National Joint Industrial Council for an increase in the rates of wages of industrial employees was settled by agreement between the two sides of the Council on 15th October, 1958.

314. An agreement affecting the grading and supervisory rates of pay of chargehands was made by the Joint Industrial Council on 12th November, 1958, in settlement of a claim made by the Trade Union Side for increased pay for chargehands and leading hands. The job evaluation scheme for determining lead rates above the national minimum rate payable to non-craft industrial grades, referred to in paragraph 318 of the Fourth Annual Report, was introduced with effect from 1st April, 1958.

Superannuation

315. A contributory pension scheme for industrial employees, on the lines of that already introduced for non-industrial staff, was agreed in the Joint Industrial Council and approved by the Prime Minister. Membership is compulsory for eligible industrial employees joining the Authority after 1st January, 1959, but optional for employees recruited before that date.

Training

316. Under the training arrangements made by the Authority, bursaries at universities and technical colleges have again been awarded to junior staff, and there has been a steady increase in the numbers taking advantage of day release facilities. In the 1957-58 academic year the examination results achieved by those part-time students taking national certificates were encouraging, the percentage of passes achieved by the Authority's staff being well above the national average.

317. During the year 23 student apprentices and 153 craft apprentices were recruited. In September, 1958, a fully equipped apprenticeship training shop was opened at the Authority's establishment at Winfrith. This is being used to provide first year training for student and craft apprentices in the Research Group.

318. Close liaison has been maintained with Local Education Authorities who, in certain cases, have introduced special courses to meet the needs of the Authority's staff.

319. The Authority's programme of full-time courses, both in specialist subjects and on management problems, remains an important and developing feature of their training schemes.

Housing

320. The number of houses owned by the Authority at 31st March, 1959, was 5,356 with 598 under construction or planned. 1,753 houses have been provided by local authorities for Authority staff coming into their areas and a further 684 are planned.

321. Following the coming into force of the 1957 Rent Act, the Authority have reviewed the level of rents charged for their houses and propose to increase net rents in most cases.

322. The Authority have also taken measures to encourage staff eligible for housing to purchase their own houses; these include the provision of loans and guarantees for excess mortgage advances.

Hostels

323. Additional accommodation completed during the year has brought the total number of places available for staff in the Authority's hostels to 1,792. The new hostel at Abingdon was nearly finished at 31st March, 1959, and extensions are being made to the Aldermaston hostel.

APPENDIX I
MEMBERSHIP OF ATOMIC ENERGY AUTHORITY
AS AT 31st MARCH, 1959

Chairman

Lord Plowden, K.C.B., K.B.E.

Full-time Members

Sir John Cockcroft, O.M., K.C.B., C.B.E., F.R.S.
 (Member for Scientific Research)

*Sir William Penney, K.B.E., F.R.S.
 (Member for Weapons Research and Development)

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

†Mr. W. Strath, C.B.
 (Member for External Relations and Commercial Policy)

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

Part-time Members

Sir Ivan Stedeford, K.B.E.

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

Sir A. Rowland Smith

Sir James Chadwick, F.R.S.

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

Secretary

Mr. D. E. H. Peirson

APPENDIX II
ATOMIC ENERGY AUTHORITY SENIOR STAFF
AS AT 31st MARCH, 1959

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)

INDUSTRIAL GROUP

Headquarters, Risley

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

* From 1st July, 1959, Sir William Penney will become Member for Scientific Research in succession to Sir John Cockcroft, who will remain a Part-time Member.

† On 1st April, 1959, Sir Alan Hitchman, K.C.B., succeeded Mr. Strath.

‡ From 1st April, 1959.

Dounreay Experimental Reactor Establishment

Dr. R. Hurst, G.M. Director

Works

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

Research and Development Laboratory, Culcheth

Dr. A. B. McIntosh Head of Laboratory

RESEARCH GROUP

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

Atomic Energy Research Establishment, Harwell

J. R. V. Dolphin, C.B.E. Engineer-in-Chief
Dr. J. V. Dunworth, C.B.E. Assistant Director, Reactor Research Policy
L. Grainger Head of Metallurgy Division
T. B. LeCren General Secretary
Dr. R. Spence, C.B., F.R.S. Chief Chemist
D. R. Willson, M.B.E. Technical Secretary

Atomic Energy Establishment, Winfrith

D. W. Fry Director

Radiochemical Centre, Amersham

Dr. W. P. Grove Director

WEAPONS GROUP

Atomic Weapons Research Establishment, Aldermaston

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

Woolwich Common (Electronics Engineering)

C. Smith Superintendent

Proof Range, Foulness

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

ADVISERS TO THE AUTHORITY

Mr. Anton Gray Senior Mining Adviser
Mr. S. J. Pears, F.C.A. Adviser on Accounting Matters
Mr. G. H. Nowell-Withers, C.B.E. Chairman of the Advisory Committee of the
Authority's Non-Industrial and Industrial
Superannuation Schemes and Adviser on
Pension and Taxation matters

APPENDIX III

BALANCE SHEET of the United Kingdom Atomic Energy Authority as at 31st March, 1958, together with the Report of the Comptroller and Auditor General thereon.

FOREWORD

1. The fourth Balance Sheet of the United Kingdom Atomic Energy Authority, as at 31 March 1958, is presented in the form prescribed by Treasury directive under the provisions of Section 4 (3) of the Atomic Energy Authority Act, 1954.

The Operating Account for the year ended 31 March 1958 is withheld from publication in the interests of national security.

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

3. In addition to the records to meet the requirements of Parliamentary accounting the Authority maintain a commercial system of accounting appropriate to their requirements, including the division between capital and revenue, to facilitate management control and commercial operation. The conventions adopted in relation to transactions on revenue account can be summarised as follows:—

(a) The Industrial Group operates factories, and the whole cost of their operation has been regarded as recoverable in the price of its products. Expenditure on fundamental research, including that at Dounreay Works, is treated as a charge to be borne by H.M. Exchequer. Expenditure on research and design in aid of future projects is carried forward for later amortisation and recovery.

(b) The whole of the cost of the operation of the Research Group, less the proceeds of sales of radioactive substances and other income, is regarded as the cost of fundamental research in the atomic energy field to be borne by H.M. Exchequer.

(c) The Weapons Group undertakes the production of components for weapons and research work in connection with weapons, both under contract from the Ministry of Supply. It also undertakes other research and development. The cost of the operation of this Group, less the amounts chargeable to the Ministry of Supply for production and research, and other income, is regarded as a charge to be borne by H.M. Exchequer.

4. The Balance Sheet at 31 March 1958 is in conventional form and sets out the assets and liabilities of the Authority at that date. The Capital Account reflects minor adjustments in respect of previous years, the additions thereto during the year, the deduction of the net cost of operations for the year and the addition of the special adjustment to the valuation of work in progress at 31 March 1958 (see Note 2 to the Balance Sheet).

5. The accounts include a charge for interest on capital which has been calculated, at rates prescribed by the Treasury for Government trading accounts, on the average capital employed during the year. The rates varied during the year and resulted in weighted averages of 5.59 per cent. on fixed capital and 6.00 per cent. on working capital.

From 1 April 1958 interest will be computed as if the capital required by the Authority on a long term basis were raised at ruling rates of interest year by year.

6. Work in progress was valued at factory cost, including an appropriate share of depreciation, overheads, London Office expenses and interest charges (see Note 2 to the Balance Sheet).

7. No provision has been made in the Authority's accounts for a pension scheme for industrial workers entering the service of the Authority after 1 August 1954. A contributory scheme for these workers has been formulated and approved since the end of the financial year and will come into operation from 1 January 1959.

27 November 1958.

UNITED KINGDOM ATOMIC

BALANCE SHEET AS AT

31 March 1957 £		£	£
I. CAPITAL ACCOUNT			
217,943,565	Balance at 1 April 1957	276,683,897	
	<i>Deduct—</i>		
70,833	Adjustments for previous periods	202,672	
218,014,398		276,481,225	
	<i>Add—</i>		
70,990,795	Net advances from Atomic Energy Office ...	95,203,965	
10,667	Assets taken over from Government Departments	—	
13,029,444	Interest on capital... ..	18,473,937	
302,045,304		390,159,127	
	<i>Deduct—</i>		
25,361,407	Net Cost of Operations for the year	42,433,428	
276,683,897		347,725,699	
	<i>Add—</i>		
—	Adjustment to valuation of work in progress at 31 March 1958 (see Note 2)	16,029,261	
276,683,897	Capital Account at 31 March 1958		363,754,960
II. RESERVE FOR LOSSES (in lieu of insurance) (see Note 3)			
	Balance at 1 April 1957	3,157,301	
	<i>Add—</i>		
	Amount charged to operating costs in the year ...	1,470,000	
		4,627,301	
	<i>Deduct—</i>		
	Charged in the year	1,979,802	
3,157,301			2,647,499
III. CURRENT LIABILITIES AND PROVISIONS			
10,829,094	Trade creditors and accrued liabilities	8,191,126	
250,000	Superannuation provisions	310,000	
			8,501,126
290,920,292			374,903,585
IV. PRINCIPAL NON-INDUSTRIAL SUPERANNUATION SCHEME			
5,799,568	Balance at 31 March 1958		8,056,445
V. PROTECTED PERSONS SUPERANNUATION SCHEME			
1,662,059	Balance at 31 March 1958		2,322,588
Notes forming part of this Balance Sheet are appended.			
£298,381,919			£385,282,618

ENERGY AUTHORITY

31 MARCH 1958

31 March 1957		As valued at 1 August 1954 plus additions at cost	Depre- ciation	
£		£	£	£
I. FIXED ASSETS, at cost or estimated cost less depreciation				
476,826	Freehold land	491,702	—	491,702
61,206,551	Buildings, ancillary installations, housing and hostels	84,061,495	9,845,559	74,215,936
64,019,897	Plant and machinery, motor vehicles, loose apparatus, tools and equip- ment	98,659,851	18,495,975	80,163,876
2,184,896	Furniture, fittings and office machi- nery	2,895,315	315,351	2,579,964
431,296	Capital assistance — assets with assisted contractors	410,688	177,004	233,684
128,319,466		£186,519,051	28,833,889	157,685,162
42,075,561	Assets in course of construction			59,469,134
170,395,027				217,154,296
II. SPECIAL DEVELOPMENT AND DEFERRED REVENUE				
EXPENDITURE LESS AMOUNTS WRITTEN OFF				
642,720	Initial production expenses		700,733	
2,398,971	Research and development expenditure in aid of design		2,586,530	3,287,263
III. LOANS, ADVANCES AND INVESTMENTS				
28,096,747	Loans and advances for the production of uranium, including accrued interest		29,871,330	
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 £11,777)		14,871	29,886,201
IV. CURRENT ASSETS				
19,869,250	Stocks of raw materials and stores		29,159,559	
61,754,031	Work in progress (see Note 2)		88,881,791	
7,041,573	Debtors, deposits and payments in advance		5,601,721	
707,102	Balances with Paymaster-General, with bankers and cash in hand		932,754	124,575,825
290,920,292				374,903,585
V. PRINCIPAL NON-INDUSTRIAL SUPERANNUATION SCHEME FUND				
5,765,446	Amount due from H.M. Exchequer (see Note 4)		8,014,846	
34,122	Insurance policies		41,599	8,056,445
VI. PROTECTED PERSONS SUPERANNUATION SCHEME FUND				
1,662,059	Amount due from H.M. Exchequer (see Note 5)			2,322,588
£298,381,919				£385,282,618

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

NOTES

These notes form part of the Balance Sheet as at 31 March 1958

1. Capital expenditure authorised but not provided for in these Accounts amounted to £80m.

2. Interest on capital and London Office overheads have been included in the valuation of work in progress at 31 March 1958. This is a change from previous practice, and is shown as an adjustment on the Capital Account. The valuation of work in progress does not exceed realisable value.

3. The Authority do not insure but carry their own risks for fire, explosion, common law, third party and similar accidents. A reserve for losses in lieu of insurance has been created.

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

	£
Transfer values in respect of Civil Servants transferred to the Authority	3,193,904
Excess of contributions and other receipts over benefits and other outgoings for the period 1 August 1954 to 31 March 1958	4,314,019
Interest on funds remaining with H.M. Exchequer	506,923
	<u>£8,014,846</u>

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

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

	£
Transfer values in respect of established industrial Civil Servants transferred to the Authority	738,711
Provisional valuation of H.M. Exchequer liability in respect of unestablished industrial Civil Servants transferred to the Authority	360,000
Excess of contributions and other receipts over benefits and other outgoings for the period 1 August 1954 to 31 March 1958	1,073,640
Interest on funds remaining with H.M. Exchequer	150,237
	<u>£2,322,588</u>

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

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 1958.

E. G. Compton,
Comptroller and Auditor General.

REPORT OF THE COMPTROLLER AND AUDITOR GENERAL

Audit

1. The receipts and payments of the United Kingdom Atomic Energy Authority are included in the transactions accounted for in the Vote for Atomic Energy (Class IX, Vote 7). Under Section 4 (3) of the Atomic Energy Authority Act, 1954, however, the Authority are required to prepare in respect of each financial year and to transmit to me, on or before 30 November following the end of the year, statements of account in such form as the Treasury may direct. The present is the fourth such statement and, in conformity with Treasury directions, consists of a Balance Sheet in a prescribed form. The Operating Account is withheld from publication in the interests of national security.

2. The Balance Sheet shows the Net Cost of Operations for the year to 31 March 1958 as £42,433,428. A copy of the Operating Account has been furnished to me and examined by my officers, who have also examined the subsidiary balance sheets and operating accounts of the Authority's constituent Groups and London Office and the various reports of the Authority's internal auditors on these accounts and on the Balance Sheet and Consolidated Operating Account.

Reserve for Losses (in lieu of insurance)

3. The sum of £1,979,802 charged to the Reserve for Losses (in lieu of insurance) includes £1,967,826 in respect of the provisionally estimated loss arising from the accident at Windscale No. 1 Pile on 10 October 1957. This amount includes the written down value of buildings and plant which were irreparably damaged, the value of irrecoverable materials and the cost of compensation payments.

E. G. Compton,
Comptroller and Auditor General.

Exchequer and Audit Department,
20 May 1959.

APPENDIX IV
THE AUTHORITY'S REACTORS AS AT 31st MARCH, 1959

Research and Experimental Reactors

NAME	LOCATION	DATE OF START-UP	PEAK NEUTRON FLUX	MAXIMUM HEAT OUTPUT	MODERATOR	COOLANT	FUEL	PURPOSE
1. GLEEP ...	Harwell	1947	3.7×10^{10} thermal n/cm ² /sec.	100 kW	Graphite	Air	Natural uranium metal and oxide	Routine graphite and uranium quality testing; research with oscillator; biological irradiations.
2. BePO ...	Harwell	1948	2×10^{12}	6 MW	Graphite	Air	Natural uranium	Isotope production and general radiation source.
3. DIMPLE ...	Harwell	1954	about 10^8	100 Watts	Heavy water	None	Varies	Thermal reactor and pile oscillator studies.
4. LIDO ...	Harwell	1956	10^{12}	100 kW	Light water	Light water	Uranium 235	Thermal reactor studies, including shielding.
5. DIDO ...	Harwell	1956	10^{14}	10 MW	Heavy water	Heavy water	Uranium 235	Nuclear reactor material studies isotope production, neutron physics, radiation chemistry.
6. NERO ...	Harwell	1957	about 10^8	Less than 100 Watts	Graphite	None	Enriched uranium	Investigations for advanced graphite-moderated reactors.
7. PLUTO ...	Harwell	1957	10^{14}	10 MW	Heavy water	Heavy water	Uranium 235	Studies on nuclear reactor materials, isotope production.
8. NEPTUNE* ...	Harwell	1957	about 10^8	Less than 100 Watts	Light water	None	Enriched uranium	Studies by an Admiralty team at Harwell, in association with Authority staff, on water-moderated core designs.
9. D.M.T.R. (PLUTO type)	Dounreay	1958	10^{14}	10 MW	Heavy water	Heavy water	Uranium 235	Studies on nuclear reactor materials.
10. HORACE ...	Aldermaston	1958	about 10^8	10 Watts	Light water	Light water	Uranium 235	To obtain basic nuclear information on HERALD.

* Admiralty experimental reactor.

Research and Experimental Reactors under Construction

NAME	LOCATION	DATE OF START-UP	PEAK NEUTRON FLUX	MAXIMUM HEAT OUTPUT	MODERATOR	COOLANT OR HEATING GAS	FUEL	PURPOSE
11. Fast Reactor	Dounreay	1959	—	60 MW	None	Sodium potassium alloy	Enriched uranium, plutonium	Fast reactor breeding studies.
12. HERALD ...	Aldermaston	1959	10^{14}	5 MW	Light water	Light water	Uranium ²³⁵	Neutron physics, radio chemical studies.
13. ZENITH ...	Winfrith Heath	1959	10^8	100 Watts	Graphite	Nitrogen used as heating gas	Ceramic elements containing highly enriched uranium oxide	Reactor physics investigations for high temperature gas-cooled systems. (800°C. in core, 400° C. in reflector).
14. AGR ...	Windscale	1961	3.5×10^{13}	100 MW	Graphite	Carbon dioxide	Enriched uranium oxide	Study of advanced power reactors
15. HERO ...	Windscale	1961	—	A few Watts	Graphite	Carbon dioxide used as heating gas	Enriched uranium oxide	Nuclear studies for advanced power reactors.

Plutonium/Power Producing Reactors (in production and under construction)

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

NOTE:

ZEUS was dismantled in September, 1957. ZEPHYR was dismantled in June, 1958. HAZEL was dismantled in September, 1958.

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