

UNITED KINGDOM
ATOMIC ENERGY
AUTHORITY

EIGHTH
ANNUAL REPORT
1961—62



LONDON
HER MAJESTY'S STATIONERY OFFICE

PRICE 6s. 6d. NET

UNITED KINGDOM
ATOMIC ENERGY AUTHORITY

EIGHTH ANNUAL REPORT

For the Period
1st April, 1961—31st March, 1962

*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
2nd July 1962*

LONDON
HER MAJESTY'S STATIONERY OFFICE
PRICE 6s. 6d. NET

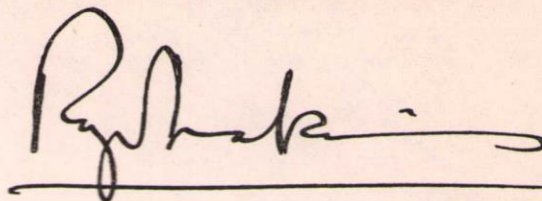
UNITED KINGDOM ATOMIC ENERGY AUTHORITY,
11, CHARLES II STREET,
LONDON, S.W.1.

1st June, 1962

MY LORD,

I have the honour to submit, in accordance with Section 3 (5) of the Atomic Energy Authority Act, 1954, the Eighth Annual Report of the United Kingdom Atomic Energy Authority. This Report covers the period from 1st April, 1961, to 31st March, 1962.

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

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

Chairman.

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

CONTENTS

	<i>Page</i>
CHAPTER I. General Survey	1
CHAPTER II. Membership, Finance and Accounts	2
Board Membership 	2
Finance 	2
Civil Research and Development 	3
Accounts 	3
CHAPTER III. Processing Plants	4
Springfields Fuel Element Production Plant 	4
Windscale Plutonium Extraction Plant 	5
Capenhurst Separation of Uranium Isotopes 	6
Development Work in Aid of Production 	6
CHAPTER IV. Magnox Reactors	7
General 	7
Fuel Elements 	9
Reactor Physics 	10
Graphite Moderator 	10
CHAPTER V. Reactor Development Programme	11
Introduction 	11
Deployment of Qualified Staff 	12
Advanced Gas-Cooled Reactors 	12
Windscale A.G.R. 	12
Reactor Physics 	12
Graphite Moderator 	13
Initial Fuel Charge 	13
Improved Fuel Elements 	13
Beryllium-Clad Fuel Elements 	14
Fuel Development 	14
Economic Prospects 	15
Safety 	15
Fast Reactor 	15
Dounreay Fast Reactor 	15
Prototype Fast Reactor 	16
Prototype Fuel Development 	16
High Temperature Gas-Cooled Reactors 	17
Steam Generating Heavy Water Reactor 	18
Submarine Reactors 	19
Merchant Ships 	19

	<i>Page</i>
CHAPTER VI. General Research and Development	20
Introduction	20
Radiation Damage	20
Ceramic Fuels	22
Direct Conversion of Heat to Electricity	24
Nuclear Physics Instruments and Accelerators	25
Nuclear Data	26
Basic Nuclear Research	27
International Collaboration in Nuclear Physics Measurements	29
Radioactive Aerosols	29
Neutron Dosimetry in Criticality Accidents	30
Criticality	30
CHAPTER VII. Plasma Physics and Fusion Research	32
General	32
ZETA	33
Pinch and Unpinch Stability Studies	33
Cusp Experiment	34
Theta Pinch Experiment	34
The Phoenix Mirror Machine	34
Shock Heating	35
Wall Effects	35
Low Pressure Switches	36
Other Experimental Studies	36
Theoretical Studies	37
International Collaboration	37
CHAPTER VIII. Isotopes and Irradiation Programme	38
Production and Marketing of Isotopes and Labelled Compounds	38
Applications of Radioisotopes	40
CHAPTER IX. Supporting Technical Developments	42
Introduction	42
Reactor and Plant Engineering	42
Concrete Containment Buildings and Pressure Vessels	42
Reactor Technology	42
Inspection Methods for Reactor Pressure Vessels	42
Welding Machine for Fuel Elements	43
Handling and Disposal of Radioactive Material	43
Development of Remote-Handling Methods	43
Treatment and Disposal of Radioactive Waste	43

	<i>Page</i>
Developments in Techniques and New Devices ..	44
Epoxide Resin Laminated Glass Vacuum Vessel ..	44
High Voltage Surge Generator	44
Neutron Tubes	45
Developments in Manufacturing and Workshops	
Operations	45
Radiographic Inspection	45
Planetary Swaging Machine	45
Electronics and Related Development	45
The Authority's Research Reactors	46
Utilisation of Materials Testing Reactors	46
Release of Stored Energy in BEPO	47
DAPHNE Reactor	47
High Speed Computer	47
CHAPTER X. Nuclear Weapons and Test Detection	47
Nuclear Weapons	47
Test Detection	48
CHAPTER XI. Raw Materials	49
Uranium	49
Thorium	51
Technical Services	51
CHAPTER XII. Commercial Operations	51
Introduction	51
Sale of Fuel Elements	51
Power Reactors—United Kingdom	51
Power Reactors—Overseas	53
Other Sales	53
Fuel for Research Reactors	53
Miscellaneous Sales	53
Electricity	54
Graphite	54
Radioisotopes	54
Royalties, Patents and Licensing	55
Consultancy	56
Collaboration	56
With Industry	56
With Consulting Engineers	56
With the Admiralty	57
Attachment Agreements	57

	<i>Page</i>
CHAPTER XIII. Health and Safety	57
Health and Safety of the Authority's Staff	57
Protection of the Public	58
Collaboration with Government Departments	59
International Co-operation	59
Research and Investigations	59
Fallout	60
Radiological Protection	60
Waste Disposal	61
Reactor and Plant Safety	61
The Evaluation of Reactor Sites	61
CHAPTER XIV. Information Services	62
Press	62
Exhibitions	62
Films	63
Publications	63
Information Centre	63
Photographs	63
The Authority's Schools	63
Isotope School	63
Harwell Reactor School	64
Calder Operation School	64
Libraries	64
Visitors	65
CHAPTER XV. International Relations	65
International Atomic Energy Agency	65
European Nuclear Energy Agency	65
Dragon High Temperature Gas-Cooled Reactor Project	66
Halden Reactor	66
E.N.E.A. Study Groups and Committees	66
Miscellaneous	66
Euratom	66
European Organisation for Nuclear Research (CERN)	67
Central Treaty Organisation (CENTO)	67
Co-operation with Other International Organisations	67
The Commonwealth Countries	67
Canada	67
Australia	68
Pakistan	68
India	68

	<i>Page</i>
United States of America	68
Union of Soviet Socialist Republics	69
Japan	69
France	69
Sweden	69
Greece	69
Spain	70
Denmark	70
Poland	70
Brazil	70
Visitors to Authority Establishments	70
CHAPTER XVI. The Authority's Staff	70
Senior Staff	70
General Manpower Position	70
Reduction in Capital Programme	71
Staff and Industrial Relations	72
Work Study	72
Benevolent Funds	72
Joint Health and Safety Committees	72
Superannuation	73
Training	73
Housing, Hostels and Canteens	73
APPENDIX I. Membership of Atomic Energy Authority as at 1st April, 1962	75
APPENDIX II. Atomic Energy Authority Senior Staff as at 1st April, 1962	75
APPENDIX III. The Authority's Reactors as at 31st March, 1962	78
APPENDIX IV. Balance Sheet as at 31st March, 1961	83
APPENDIX V. Summary of Estimates 1961/62 and 1962/63	87

UNITED KINGDOM ATOMIC ENERGY AUTHORITY
EIGHTH ANNUAL REPORT
1961—62

CHAPTER I
GENERAL SURVEY

1. During the year 1961/62 several landmarks were passed on the road to economical nuclear power generation. 17th October, 1961, was the fifth anniversary of the opening of Calder Hall by Her Majesty the Queen. The first reactors of the nuclear power stations at Bradwell and Berkeley achieved criticality on 19th and 27th August, 1961, respectively. Construction of the Authority's advanced gas-cooled reactor at Windscale was completed.

2. On the defence side, the Authority's research, development and production activities continued in accordance with the directions of Her Majesty's Government.

3. Also in accordance with government decisions, the Authority have embarked on a vigorous programme of research aimed at a reactor system which will be economically attractive to a wide range of shipping. This programme will be carried out in conjunction with industry.

4. During the year the Authority completed a review of all their civil research and development programmes. These programmes (which are described in the appropriate chapters of this report), together with the Authority's recommendations as to the general principles which should govern recovery by the Authority of a proportion of their expenditure, were submitted to ministers and given general approval. This gives a stable basis for the planning of the Authority's research and development effort, which is estimated to cost about £50 million per annum over the next five years.

5. The Authority's net expenditure in 1962/63 is estimated at £67,875,000 compared with £78,071,000 for 1961/62, a fall of over 13 per cent.

6. The production reactors and the processing plants have continued to perform satisfactorily; process efficiencies have been improved during the year. Progress on the advanced gas-cooled reactor supported the expectation that electricity generated from A.G.R. stations will be as cheap as, and later cheaper than, electricity generated from conventional stations in the United Kingdom. The Dounreay fast reactor reached a power level of 11 MW(H) in December, 1961, more than double the power reached previously by any other fast reactor. The Authority and the industrial consortia have made further cost studies of various types of water-moderated reactor systems.

7. Production of uranium declined in 1961/62 except in the United States of America. Among the producers who closed down during the year were Radium Hill in South Australia and Urgeiriça in Portugal, which first produced radium fifty years ago. The Authority's stockpile of uranium continued to increase.

8. The Authority's commercial sales during the year realised over £20 million, with an additional £500,000 for consultancy services and royalties. The first two contracts with the Central Electricity Generating Board for fuel elements (for Bradwell and Berkeley) were signed in May, 1961. A contract to supply fuel for the Latina nuclear power station in Italy was signed in December, 1961.

9. Relations between the Authority and the corresponding organisations in other countries continued to expand during the year. In addition, the Authority played their full part in the work of international organisations such as the International Atomic Energy Agency. On 5th March, 1962, Her Majesty's Government applied formally to open negotiations with the object of acceding to the treaty establishing the European Atomic Energy Community (Euratom).

10. The Authority were honoured by a visit by Her Majesty the Queen Mother to Dounreay on 14th August, 1961.

CHAPTER II

MEMBERSHIP, FINANCE AND ACCOUNTS

Board Membership

11. The Minister for Science re-appointed Lord Citrine as a part-time Member of the Authority for the calendar year 1962.

12. The appointment of Sir Leonard Owen as a full-time Member of the Authority expires on 30th June, 1962. He has been re-appointed as a part-time Member for the two-year period 1st July, 1962, to 30th June, 1964. Sir Leonard will continue as chairman of the Boards of Management of the Production and Engineering Groups.

13. In March, 1962, the election of Sir William Cook to Fellowship of the Royal Society was announced.

14. The membership of the Authority as at 1st April, 1962, is set out in Appendix I.

Finance

15. The Authority's grant for 1961/62 was a net total of £78,071,000 (including a sum of £6,211,000 for the National Institute for Research in Nuclear Science). The estimates were published as part of the Atomic Energy Vote (Civil Estimates Class IX, 8).

16. A supplementary estimate of £10 was approved by the House of Commons on 13th June, 1961. This token provision was made to obtain sanction for possible advance payments by the Authority for graphite purchases.

17. The Authority's estimates for 1962/63 were presented to the House of Commons on 26th February, 1962, at a net total of £67,875,000, a reduction of £10,196,000 compared with 1961/62. The estimates (which include £6,790,000 for the N.I.R.N.S.) are summarised in Appendix V and compared with those for 1961/62.

Civil Research and Development

18. Within the grant for 1961/62 some £49 million was spent on the Authority's civil research and development programme, including £33 million of current expenditure and £16 million on capital facilities. The programme includes the reactor programme described in chapter V, the work on plasma physics and fusion research (chapter VII), general reactor technology and general research including isotopes research. The number of graduate or professional engineers or scientists employed on the whole programme at 31st March was 2,740. The current expenditure during 1961/62 on the various civil research and development programmes and the deployment of qualified staff at the end of the year were broadly as shown below.

	£ million Current Expenditure	Qualified Scientists and Engineers*
Reactor Programme (including both preliminary work and major development)	21	1,460
General Reactor Technology	4	300
General Research	5	520
Plasma Physics and Fusion Research	2	170
Isotopes Research	1	90

* (i) The staff figures relate to Reactor, Research and Weapons Groups, and include staff providing supporting scientific, engineering and administrative services.

(ii) In addition to the staff shown, there were 200 scientists and engineers doing civil research and development for outside bodies on repayment terms. They were mainly engaged in consultancy (e.g., on behalf of the electricity generating boards) and work on contract for the Organisation for Economic Co-operation and Development Dragon Project.

(iii) Supporting services are also provided by the Production Group in fabricating and processing fuel, and by the Engineering Group in constructing capital facilities for the civil research and development programme.

19. The level of general research is designed to provide the minimum necessary effort on fundamental problems in fields such as nuclear physics, chemistry and metallurgy, together with the essential scientific base for the Authority's development activities including those on reactors. The general work in the field of reactor technology, on which the successful development of individual reactor systems largely turns, includes work on materials both for reactors and for their fuel.

Accounts

20. The Authority maintain a commercial system of accounting to enable accounts to be prepared in the form directed by Her Majesty's Treasury under Section 4(3) of the Atomic Energy Authority Act, 1954. In addition to the commercial accounts the Authority maintain records necessary to meet the requirements of Parliamentary accounting.

21. The Balance Sheet as at 31st March, 1961, was submitted to the Comptroller and Auditor General on 29th November, 1961, and will in due course be presented to Parliament.† (The Operating Account is withheld from publication in the interests of national security.) The Balance Sheet value of the assets at

† Ordered by the House of Commons to be printed on 17th April, 1962, and now on sale at H.M. Stationery Office (price 6d.). The Balance Sheet together with the Authority's Foreword is reproduced in Appendix IV.

31st March, 1961, was over £550 million, an increase of some £50 million in the year. The accounts for 1961/62 are still subject to audit, but it is expected that the corresponding figure for 31st March, 1962, will be of the order of £560 million. The valuation of fixed assets is now fairly steady since new capital expenditure is approximately balanced by depreciation, and the continued rise in the total assets figure in the two years was due partly to an increase in work in progress, as throughput built up in the production plants, and partly to increased stocks of raw materials.

22. Civil trading, which is dealt with in more detail in chapter XII, has now reached significant proportions, and the Authority therefore felt it right to call in consultants to advise on their accounting and costing systems in the main production plants. The recommendations of these consultants have been adopted, and the systems are devised to provide information for management at all levels on the cost of products and services and on the outturn of trading. A trading budget for 1962/63, and forecasts for the following two years covering all substantial commercial activities, have been prepared to assist internal financial control.

23. Provision of £5 million to cover future losses on sales of fuel elements at the special prices quoted in 1956 (see paragraph 246) and on graphite trading (see paragraphs 258 and 259) was made in the balance sheet as at 31st March, 1961.

CHAPTER III

PROCESSING PLANTS

Springfields Fuel Element Production Plant

24. The Springfields plant, originally set up to meet a military requirement, has been greatly expanded in recent years to make civil fuel elements for the national power programme and for export. From a small plant, making the earliest fuel element assemblies by what are now relatively crude methods, it has become a substantial and efficient factory producing annually about 200,000 fuel elements. In addition to their commitments for the home market, the Authority are under contract to supply the first fuel charge for the British-built reactor at Latina near Rome and negotiations are currently under way for the supply of fuel to the power station being built by a British consortium at Tokai Mura in Japan. The growth of fuel element production in recent years is shown in FIG. I (see page 7). Capital investment in plant and equipment in this factory has increased accordingly.

25. The extended fuel element production plant is now operating well. It has produced the first charges for the Bradwell and Berkeley reactors and some 62,000 elements have been despatched. In total about 2,000 tonnes of natural uranium have been fabricated during the year and approximately 200 tonnes of uranium have been converted into other forms for sale to a variety of customers. A second but smaller plant has been commissioned during the year to produce pellets of sintered uranium dioxide for advanced gas-cooled reactor

fuelling. This plant converts enriched uranium hexafluoride from the Capenhurst diffusion plant into uranium dioxide which is compacted and sintered into pellets of high density. The pellets are then loaded into stainless steel tubes which are sealed and assembled into clusters for loading into the reactor. Procedures to ensure a consistent product of high density have been evolved during the year.

26. During 1961 attention has been paid to improving the efficiency of the processes used at all stages of fuel manufacture. A 40 per cent. increase in throughput has been achieved at the solvent extraction stage needed to purify the uranium solution before conversion into metal, and a concentrated development effort on the new fluidised bed plant commissioned last year has greatly reduced maintenance costs and markedly raised throughput. This plant converts uranyl nitrate solution from the solvent extraction plant into uranium tetrafluoride in three stages. These are: decomposition of uranyl nitrate to uranium trioxide, reduction to uranium dioxide and hydrofluorination to uranium tetrafluoride. By improved operational control of the reduction stage, the time required for the hydrofluorination step has been greatly reduced. As a result the fluidised bed plant capacity has been increased overall by about 30 per cent. beyond the design throughput. Furthermore, the process efficiency has been improved and economies have been made in the consumption of raw materials such as hydrofluoric acid.

27. Development of the magnesium reduction process, by which uranium tetrafluoride is converted into a metallic ingot, has enabled the ingot size to be increased without affecting the quality of the metal and has yielded increases in efficiency and plant capacity on what was already an efficient process. Similarly, improvements in the welding process in the fuel element assembly section have increased plant throughput by reducing the number of fuel elements requiring rectification.

Windscale Plutonium Extraction Plant

28. Although it is over ten years since the plutonium extraction plant was first commissioned, it has operated during 1961 at a higher throughput despite some major maintenance required for the first time. Certain parts of the plant contain hot concentrated nitric acid solutions of strongly radioactive substances and, after ten years of operation behind concrete walls, corrosion difficulties have arisen. It has been necessary to enter the medium active cells to repair the plutonium evaporator stage, and a spare evaporator, which had been provided in the original installation against this contingency, has been connected without exposing the personnel involved to significant radiation doses.

29. Considerable technical effort has been devoted during 1961 to developing continuous processes to replace small-scale batch processes for plutonium production. This work has enabled precipitation of plutonium oxalate from solutions of the nitrate to be carried out continuously and one continuous unit now replaces three batch units. Further experimental work has shown that one tubular evaporator constructed from titanium can replace four glass evaporators for concentrating plutonium nitrate solution. The development of a continuous process for converting plutonium oxide into plutonium fluoride is in hand.

30. Storage of radioactive fission products is costly because of the elaborate design of vessel which must be employed to eliminate the possibility, over an extended period, of any leakage occurring. Storage costs can, however, be minimised by reducing the bulk quantity of the fission product solution which has to be stored. Further concentration has been achieved during the year by allowing evaporation to take place in the storage vessels under the influence of naturally occurring fission product heating. By this means storage costs have been halved.

31. An improved effluent treatment process for treating low activity effluent before discharge into the sea has been introduced and has made possible a reduction in the radioactivity discharged per unit of throughput.

Capenhurst Separation of Uranium Isotopes

32. The diffusion plant fulfilled all commitments for delivery of enriched uranium during the year.

33. It will be recalled that the plant was built during the decade 1950/60 to meet the military demands for enriched uranium. Following the completion of the final extensions towards the end of 1959, it has been possible to devote increasing attention to improvements in efficiency and a reduction in the operating costs.

34. Possibilities of reducing the electrical power charges have been investigated. These have included a "disconnectable load agreement" with the Central Electricity Generating Board, under which a large block of power can be released to meet national needs at peak usage periods. A substantial reduction in the maximum demand component of the power charge is possible in return for this agreement which will be in force on 1st April, 1962.

35. During the course of the year there was a major change at Capenhurst arising from the transfer of the Reactor Engineering Laboratories to Risley. The original purpose of the laboratories, to undertake development work in aid of the diffusion plant process, had been almost completely superseded by reactor engineering development following the completion of the diffusion plant. The majority of the industrial labour force and an appreciable number of the staff have been absorbed on other work, necessitating redeployment of personnel in all grades. This has been successfully carried out with the full co-operation of all concerned.

Development Work in Aid of Production

36. Development work on existing processes has been described in the above sections. In the following paragraphs some development projects associated with new plants or processes are noted.

37. As more nuclear power stations are commissioned, increasing quantities of spent nuclear fuel will arise. This will require chemical reprocessing to remove plutonium and fission products and a new plant is under construction for this purpose, since the existing plant would be overloaded. A major effort in aid of the design of a new separation plant is nearing completion and considerable experimental work has been done on a pilot plant simulating the activity conditions to be encountered in the main plant. Ways of concentrating effluent and improved techniques for fission product storage are also being

developed. The new plant will include continuous processes for plutonium handling including precipitation, drying and fluorination, and the necessary techniques are being developed.

38. Study has continued during the year of the gas centrifuge which might, in the long term, find an application as an alternative to the gaseous diffusion plant or as a means of supplementing its output for the production of enriched uranium.

39. Improved methods of manufacturing oxide fuel for the advanced gas-cooled reactor are being studied, particularly continuous methods of converting uranium hexafluoride to uranium dioxide and improvements to the existing processes for sintered pellet production.

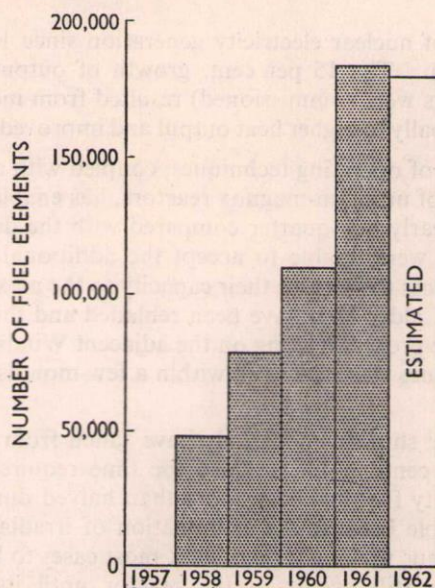


FIG. I. Fuel element production

CHAPTER IV

MAGNOX REACTORS

General

40. The first nuclear power station at Calder Hall has shown an outstanding performance during its five and a half years of operation and the information which is becoming available on the prospective life of the reactors themselves is also encouraging. Comprehensive inspection has shown no evidence to suggest that the life of magnox stations will be limited to twenty years, the period hitherto chosen, with deliberate caution, for amortising the capital cost of the civil stations. The reactors have shown a high and increasing availability and no more maintenance is required now than when they were first commissioned. The proportion of the year during which the station is generating electricity has steadily increased. Availabilities of 85 per cent. are normal

and 90 per cent. availability has been demonstrated over a period of twelve months. Such availabilities compare well with those achieved by the latest conventional coal-fired power stations. This is a notable achievement because the reactors are not designed for continuous refuelling.

41. Since the first reactor was commissioned in 1956 three more have been built on the Calder Hall site and four at Chapelcross in Scotland. The combined electricity output of these stations has now exceeded 6,000 million kilowatt hours and one eighth of the South of Scotland Electricity Board's requirements were met in 1961 from the output of the Chapelcross reactors. During the autumn of 1961 a storm interrupted the national grid and the west Cumberland area was, for a time, supplied exclusively with electricity produced from nuclear reactors.

42. The growth of nuclear electricity generation since 1956 is illustrated in FIG. II (see page 10). The 15 per cent. growth of output in 1961 (a period when no new reactors were commissioned) resulted from increased efficiency of operation, due principally to higher heat output and improved reactor availability.

43. Development of operating techniques, coupled with a better understanding of the behaviour of uranium-magnox reactors, has enabled their heat output to be increased by nearly one quarter compared with the design rating. Since the turbo-alternators were unable to accept the additional steam, it has been necessary at Chapelcross to increase their capacity to the maximum by reblading. Half the turbines at Calder Hall have been rebladed and the remaining surplus steam will be used for process heating on the adjacent Windscale site. The cost of reblading the turbines was recovered within a few months from the increased electrical output.

44. Major reactor shut-down periods have fallen from over 9 per cent. in 1960 to under 8 per cent. in 1961. Also the time required for the detection and discharge of faulty fuel has been more than halved during the year. The latter has been possible because the examination of irradiated fuel has shown how faults develop, thus making it possible in most cases to leave the occasional faulty element which still occurs in the reactor until its discharge can be integrated with a normal shutdown. The mean load factor has increased from 79.2 per cent. in 1957 to 88.1 per cent. in 1961.

45. An extensive experimental programme in Production Group reactors supports the civil power programme and the large number of reactor channels which contain experimental fuel is illustrated by FIG. III (see page 11) which shows the loading diagram for a typical reactor. Of particular importance is the life of the standard Calder fuel element which, although it was designed for a much shorter life, has remained in some cases in the reactor for four and a half years, giving an average output of 3000 MWd(H)/t. This is significant because it is equal to the life assumed in calculating the performance of the civil reactors, which will contain improved and stronger fuel elements. Although prototypes of the latter have not yet remained on test for as long as the standard Calder element, a few channels have attained 2300 MWd(H)/t and the results so far obtained justify complete confidence that an average irradiation of 3000 MWd(H)/t will be attained.

46. The recent results from production reactors give assurance that the parameters used in assessing the cost of nuclear power were not optimistic but rather that in some respects they were unduly pessimistic. The high load

factors achieved at Calder Hall without continuous refuelling indicate that the continuously fuelled reactors of the generating boards may well exceed the 75 per cent. load factor assumed for economic comparisons.

47. Eight magnox power stations with an aggregate output capacity of 3,500 MW(E) have now been ordered by British electricity generating boards; in addition two magnox stations are under construction at Latina and Tokai Mura. Throughout the year the Authority have continued to devote effort to the remaining problems of magnox reactors and their fuel elements and also to the provision of a consultancy service on the technology of magnox reactors. This work is described in the following paragraphs.

Fuel Elements

48. Work over the year has been concerned principally with assessing the performance, both in- and out-of-pile, of the various designs of civil reactor fuel elements. Confidence in their ability to meet the target average irradiation of 3,000 MWd(H)/t has been reinforced by the satisfactory results of this work.

49. Reference was made in paragraph 45 to the direct experiments on civil reactor fuel elements which are being carried out in the Calder and Chapelcross reactors. Other in-pile experiments are designed to test the ability of fine grain magnox cans to withstand growth of the uranium bar in the low temperature regions of the reactor without developing porosity; a number of channels of elements of this material have attained over 2,000 MWd(H)/t satisfactorily. In addition, fuel elements fabricated from another magnesium alloy of even higher ductility are being irradiated.

50. Further studies of highly irradiated uranium at temperatures around 600°C (see paragraph 106), together with accurate measurements of hundreds of Calder bars, have confirmed that swelling should not limit the life of fuel elements with the quality of uranium selected for production of the civil fuel elements. Surface wrinkling and directional growth of bars, both of which depend on the tendency of individual crystals to change shape under irradiation, may be controlled by alloying combined with a heat treatment to refine and randomize the grain structure. The beneficial effects of chromium and molybdenum in this respect have been confirmed. More recently, however, it has been shown that similar advantages can be obtained, without the neutron absorption and other disadvantages of alloying additions, by close control of the production uranium, especially its iron content; current optimization studies are expected to lead to even greater dimensional stability of the uranium bars without extra costs.

51. Considerable emphasis has been laid on thermal cycling experiments and analysis because of the possibility that thermal cycling may limit fuel element life. From evidence of extensive tests in the Calder reactors, it is now considered that present fuel element designs will withstand the thermal fluctuations which will arise during base load operation of the civil reactors.

52. Out-of-pile testing has continued in endurance loops and heat transfer rigs. Extensive endurance tests have shown that the incorporation of a spring-loaded arm at the end of the fuel element holds it firmly against the wall of the channel, removing any tendency for the element to move in the gas stream. The work has led also to recommendations for improved designs of flow splitters and braces whose weaknesses were exposed during testing. Exposure to the gas stream may eventually cause some deformation of the fins of fuel

elements which will change their heat transfer characteristics; these effects are being measured.

53. Facilities for the routine examination of irradiated civil fuel elements are now operational; a comprehensive programme for the post-irradiation examination of fuel elements discharged from the civil reactors has been drawn up in consultation with the Central Electricity Generating Board.

Reactor Physics

54. Progress has been made on calculations of reactor performance by methods which rely principally on basic data such as nuclear cross-sections and neutron reaction rates. The calculations of both initial reactivity and the reactivity required to achieve 3,000 MWd(H)/t have been confirmed to within about 1 per cent. from experience with the Calder and Chapelcross reactors and with the initial loadings of the Bradwell and Berkeley reactors. Reactor kinetics calculations have continued on the variations in power distribution in an axial direction of the civil reactors under various operational conditions; they have shown that present control equipment is adequate to control all such variations.

Graphite Moderator

55. Further results of experiments to determine the storage of Wigner energy at high irradiation levels have accumulated during the year and they confirm that at the operating temperatures of the civil reactors, at which considerable thermal annealing will occur, Wigner energy storage is of minor significance. Current work on irradiation growth of graphite indicates that although stresses will be imposed by dimensional changes, they are substantially relieved by irradiation-induced creep of the graphite. A method of examining Calder reactor fuel channels by scanning with a television camera is now in regular use; no deterioration of the moderator graphite has yet been detected.

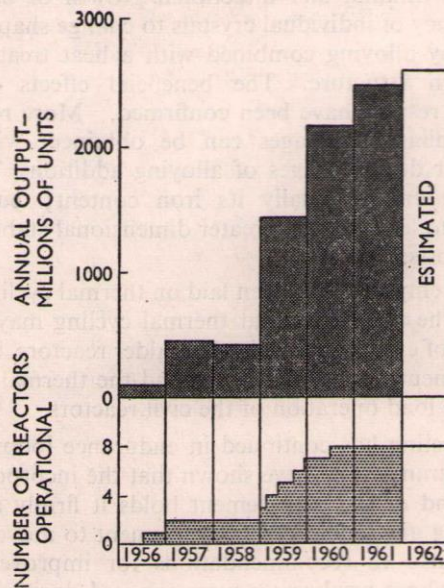


FIG II. Nuclear electricity generation in Production Group reactors.

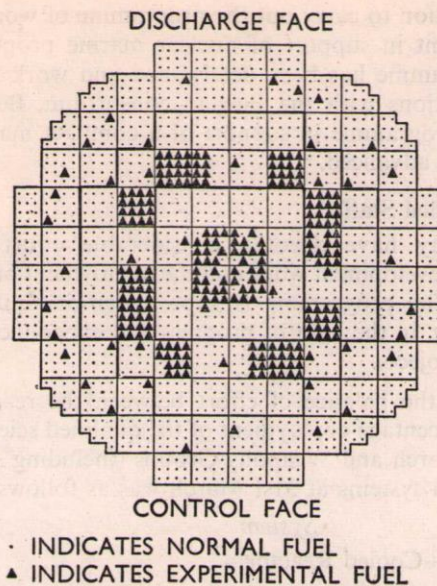


FIG III. Fuel loading diagram of a typical production reactor.

CHAPTER V

REACTOR DEVELOPMENT PROGRAMME

Introduction

56. The construction of the advanced gas-cooled reactor (the A.G.R.) at Windscale is complete, commissioning is in progress and the reactor should be critical in the summer of 1962. The stainless steel-clad fuel for the first charge has been made and problems arising from the oxidation of graphite by the carbon dioxide coolant have been overcome. The Authority are confident that electricity generated from A.G.R. stations will be as cheap as, and later cheaper than, electricity generated from conventional stations in the United Kingdom.

57. The difficulties encountered during the start-up of the Dounreay fast reactor have been overcome and a power level of 11 MW(H) was reached early in December, 1961. The reactor is now being recharged with improved fuel elements and will be operated at higher power in the next few months. The next important step in the fast reactor programme is the building of a prototype fast reactor (P.F.R.) which will lead directly to fast reactor generating stations in the mid-1970's. Design and development work is in hand and progress has been made with suitable plutonium fuels for the P.F.R.

58. The culmination of studies undertaken during the year has led the Authority and the consortia jointly to conclude that the development of a prototype steam generating heavy-water-moderated reactor (S.G.H.W.) of pressure tube construction, with boiling light water cooling and provision for superheating, would be a valuable addition to U.K. reactor technology.

59. The organisation to carry out the programme of work approved by Her Majesty's Government in support of nuclear marine propulsion has been set up, a detailed programme has been determined and work has begun. By 1st April, 1962, negotiations with the Belgian consortium, BelgoNucléaire, for a joint development programme in support of a compact marine reactor known as Vulcain were well advanced.*

Deployment of Qualified Staff

60. The Authority have devoted considerable effort to the long-term planning of reactor development work and the deployment of resources available for this purpose. The programme is kept under continual review with the object of maintaining, in the light of progress and experience, a correct balance of effort between projects.

61. To illustrate the balance of effort between the reactor projects under development, the percentage deployment of the qualified scientists and engineers in the Reactor, Research and Weapons Groups (including supporting services) engaged on advanced systems at 31st March was as follows:

System	Percentage
Advanced Gas-Cooled Reactor	26
Fast Reactor	37
High Temperature Gas-Cooled Reactor†	18
Heavy Water Reactors	13
Civil Marine Propulsion Reactors	6

Advanced Gas-Cooled Reactors

62. The advanced gas-cooled reactor is a development of the carbon dioxide-cooled, graphite-moderated reactor system to higher operating temperatures and ratings. The higher operating temperatures will lead to steam conditions comparable with those prevailing in the latest turbine practice and overall thermal efficiencies of 40 per cent. should be achieved.

Windscale A.G.R.

63. The pressure testing of the outer containment of the Windscale A.G.R. was successfully carried out over the 1961 August Bank Holiday when the site was clear. Engineering commissioning operations including pressure tests, blower tests, control gear and refuelling machine tests and proving of the irradiation loop equipment were carried out in the early months of 1962. The reactor should be critical in the summer of 1962, and, after initial physics experiments, should be operating at power later this year.

Reactor Physics

64. Experiments to check the accuracy of theoretical physics calculations for the A.G.R. core have been carried out during the year in the sub-critical stack APEX (approach to critical experiment) and in other facilities in the Reactor Development Laboratory at Windscale and at the Atomic Energy Establishment,

* An agreement between the Authority and BelgoNucléaire was signed in Brussels on 16th May, 1962.

† Including staff seconded to or supporting the Organisation for Economic Co-operation and Development high temperature project Dragon.

Winfrith. Values for neutron fine flux distribution, power distribution and fuel element hot spot factors have been obtained, using some of the 2.5 per cent. enriched stainless steel-clad A.G.R. fuel charge. Techniques are now being developed to measure power distribution using irradiated fuel.

65. The construction and commissioning of the heated zero energy HERO reactor have been completed and criticality was achieved on 5th February. Initially the reactor has been used to speed up the commissioning of the A.G.R. itself by providing experimental data on core reactivity and control rod effectiveness using a small core of actual A.G.R. fuel clusters. Later it is intended to use HERO to provide essential experimental physics data for various core arrangements for large A.G.R. generating stations.

Graphite Moderator

66. Much experimental work has been concentrated during the past year on the major problem of the oxidation of the graphite moderator by the irradiated carbon dioxide coolant. The results of a series of experiments have proved that the oxidation of the graphite is reduced by a large factor by the addition of carbon monoxide to the carbon dioxide coolant. The proportion of carbon monoxide to carbon dioxide required is about 7 per cent. The technique used was to incorporate radioactive carbon-14 in graphite blocks, and to irradiate these in a carbon dioxide/carbon monoxide gas in the materials testing reactors at Harwell and Dounreay under conditions of temperature, pressure and radiation intensity typical of A.G.R. The amount of carbon-14 found in the gas was a measure of the degree of oxidation of the graphite blocks. With carbon dioxide gas alone the carbon-14 activity in the gas was high. The addition of carbon monoxide reduced the activity and at 7 per cent. concentration of carbon monoxide the carbon-14 activity was scarcely detectable. There is now no fear that the life of the graphite structure of an A.G.R. station will be reduced because of graphite oxidation.

Initial Fuel Charge

67. The manufacture of the complete first charge of fuel elements for the Windscale A.G.R. was completed in February. This fuel element consists of two assemblies of fuel rods encased in a graphite sleeve; each assembly is a cluster of 21 fuel rods spaced on and supported by stainless steel grids; each fuel rod consists of a 0.015-inch thick stainless steel can 21 inches long and 0.4 inch diameter containing sintered pellets of 2.5 per cent. enriched uranium oxide. Large numbers of these fuel elements will be tested in the Windscale A.G.R. under conditions appropriate to a large generating station.

Improved Fuel Elements

68. The stainless steel-clad elements described above are of conservative design. There is considerable scope for further development leading to improved thermal efficiency and reduction of generating costs. The following improvements are being investigated: the use of thinner cans which will reduce the loss of neutrons by absorption and thus permit a smaller enrichment; the use of longer steel cans and simpler components which should reduce fuel manufacturing costs; raising the operating temperature of the fuel elements to give a higher outlet gas temperature, which will improve efficiency; increasing

both the burn-up and the rating of the fuel element. Batches of these improved fuel elements are now being made and will be tested in the Windscale A.G.R. as soon as the reactor is on power.

Beryllium-Clad Fuel Elements

69. Although a satisfactory manufacturing process for large-scale manufacture of beryllium tubes has been developed in conjunction with industry and the previously reported corrosion problem overcome by the addition of a small amount of calcium, serious difficulties have arisen because the tubes as made had insufficient ductility at low temperatures and were likely to fail on shutdown and cause serious contamination of the reactor. Improvement of the low temperature ductility required a change in the manufacturing method and this, together with the alloying with calcium, would require the repetition of the whole of the expensive programme of both in-pile and out-of-pile evaluation tests. In addition remaining uncertainties on the irradiation behaviour and likely limitations upon can temperature made doubtful the achievement of a burn-up much in excess of 6,000 MWd(H)/t at a can temperature of 600°C. On the other hand, confidence in the irradiation performance of the stainless steel canned fuel is increasing and there seems no reason why 20,000 MWd(H)/t should not be achievable, and on this basis beryllium-clad fuel ceases to be economically attractive. Work on the development of beryllium as a canning material for A.G.R. fuel has therefore been stopped.

Fuel Development

70. It is necessary to ensure that the release of fission product gases from the uranium dioxide fuel does not result in pressures within the containing stainless steel can sufficiently high to burst it. For this reason the uranium dioxide fuel temperature is restricted. Experimental irradiation work at Harwell and Dounreay, with uranium dioxide irradiated to burn-ups of 10,000 MWd(H)/t at central fuel temperatures below 1,600°C., has indicated that fission gas release can be predicted with reasonable accuracy from a knowledge of the diffusion characteristics of the gases in uranium dioxide, obtained by the neutron activation technique. With uranium dioxide in the density range 10.4–10.6 gm/cc a maximum gas release of less than 4 per cent. from the fuel into the can would be expected during the life-time of fuel elements in advanced gas-cooled reactors. Considerably higher burn-up should be achievable without damage to the can.

71. With the aim of securing consistency in the manufacture of ceramic fuel, techniques have been developed at Springfields for examining the micro-structure of compacted fuel and evaluating the manufacturing conditions that control it. The latter evaluation involves detailed investigation, by various methods including electron diffraction and microscopy and X-ray diffraction, of the structure at various stages of manufacture. X-ray diffraction has been used to determine the phases present and the shapes and size of crystallites as well as the strain built into the structure. Work on the characterisation of uranium dioxide powders has shown that oxide prepared from ammonium diuranate or uranyl fluoride comprises monocrystallite particles of which the most important characterising property is the size and shape. The highest density in compacts is achieved with powders consisting of small (about 0.2 microns) and regularly shaped particles.

Economic Prospects

72. Estimates have been made of the cost of generating electricity from A.G.R. generating stations consisting of two reactors each of 500 MW(E). The assumptions used were that the overheads would be spread over a programme of at least 6,000 MW(E) of A.G.R. stations, that the reactors would be used on base load at 75 per cent. load factor, a station life of 20 years and an interest rate of 6 per cent. The estimates indicated that the capital cost of such a station should be about £80 per kW installed and the generating cost about 0.45d. To this figure an addition would have to be made for the recovery of the costs of development. The cost of electricity from the first station in the programme would be higher than 0.45d: the cost would decrease below 0.45d. as the development potential of the system was exploited.

73. As already indicated (in paragraph 46) some of the assumptions listed above may well be unduly pessimistic. Experience at Calder Hall supports the expectation that load factor could be higher than 75 per cent. If 85 per cent. were assumed, the unit cost of electricity from an A.G.R. station would be reduced by about 0.04d. There can as yet be no final proof of the life of a reactor. An assumption of 30 years could be as realistic as 20 years. On such an assumption there would be a further reduction of 0.03d. per unit.

Safety

74. During the year further studies of the safety characteristics of an A.G.R. station have been made. Important features are the dimensional stability of, and the retention of fission products in, the uranium oxide fuel under irradiation, and the compatibility of uranium dioxide with carbon dioxide. These features of the A.G.R., coupled with the protection against an uncontrolled release of fission products provided by reactor lay-out and a fission product treatment plant, could result in relaxation of the present siting requirements of nuclear stations. An experimental programme to establish the relevant data will be established during the early years of operation of the A.G.R.

Fast Reactor

Dounreay Fast Reactor

75. Impurities in the sodium potassium coolant of the Dounreay fast reactor caused blockages in the primary circuits. This difficulty has been overcome by the installation of an external by-pass cold-trap and by successive dumping and subsequent careful filtering of the bulk coolant on refilling the reactor circuit.

76. The entrainment of the blanket gas into the coolant, causing instability in operation, has been overcome. The gas was found to be leaking through control rod ducts and thermocouple tubes. Modifications have been carried out and tested with complete success.

77. During the operation of the Dounreay fast reactor (D.F.R.) embrittlement and corrosion of some niobium and vanadium fuel element cans were found to result from the presence of hydrogen and oxygen in the liquid metal coolant, and steps have had to be taken to reduce the amount of hydrogen and oxygen to low level.

78. During the visit of Her Majesty the Queen Mother on 14th August the low power operation of the reactor was demonstrated as the first step in the

resumption of experimental work. By October experiments at low power had confirmed that gas entrainment had been eliminated, and measurements of the pressure co-efficient of reactivity established that the small residual amounts of gas in the core were operationally insignificant. In accordance with the scheduled physics programme, the reactor power was gradually increased from 13th November. On 22nd November a power level of 5 MW(H) was reached and on 23rd November, 7.5 MW(H); with each power increment, tests were carried out to demonstrate the operational stability of the reactor until, on 13th December, a power level of 11 MW(H) was recorded. With the completion of the power run on 16th December the reactor was shut down for the replacement of the present fuel core with one of improved design, to enable the reactor to be run at higher powers during 1962.

79. This period of operation of the D.F.R. has demonstrated the satisfactory operation of the plant, and the reactor proved to be very stable. A large number of reactor physics measurements have been completed including the measurements of power coefficients and shielding efficiency.

Prototype Fast Reactor

80. The magnox power stations now being commissioned or built will produce large quantities of plutonium during the early 1970's. At the present time it seems that the most effective way of using this plutonium fuel is to burn it in fast reactors, which have particularly suitable nuclear properties. It is important to have an economic and proven design of fast reactor available to match the production of plutonium. The power producing fast reactors will differ in design and in fuel from the D.F.R. The next stage will be the development, design and construction of a fast reactor incorporating these changes and large enough to serve as a prototype for large civil stations. During the year a reference design study has been made in order to identify the important design features and to define the necessary development programme. Compared with the design of the experimental D.F.R. the prototype will have a smaller number of primary coolant circuits with large mechanical sodium pumps and large heat exchangers.

81. The most promising fast reactor designs under consideration have lower power densities and a softer neutron spectrum than the core of the D.F.R. The neutrons with lower energies have considerable influence on the physics of a large fast reactor and precise knowledge is not available. This will be obtained from experimental work planned for the new zero energy reactor ZEBRA, now being completed at Winfrith, which is expected to be critical in the latter half of 1962. Experimental checks will be made of theoretical methods for calculating critical size and neutron spectrum, together with important control information related to Doppler and sodium temperature coefficients.

Prototype Fuel Development

82. Two fuels are at present under development. In one, granules of mixed oxides of uranium and plutonium are enclosed in a stainless steel can; in the other, mixed carbides of uranium and plutonium are canned in stainless steel.

83. Irradiation results at high temperatures and high burn-up during the year on the first of these fuels, the stainless steel cermet, are encouraging. Samples in rod form of a dispersion of granules containing 50 per cent. by

volume of plutonium oxide/uranium oxide in a steel matrix have been successfully made at Dounreay and have so far reached 8 per cent. burn-up of heavy atoms with negligible dimensional change. The metallurgical structures also showed very little deterioration as the result of irradiation. The next phase of the programme is aimed at the preparation and irradiation of specimen fuel elements.

84. Research during the past year has shown that, by carefully controlling the particle size and surface properties of the feed powders and the nature of the sintering atmosphere, high density pellets of either uranium carbide or uranium-carbide/plutonium-carbide can be produced by sintering at moderate temperatures (1,550°C). It has also been found that certain metals "wet" the carbide and work is proceeding to develop a suitable bond between carbide fuel and the stainless steel can to improve heat transfer and the mechanical strength of the fuel element at high temperatures.

85. Each type of fuel now under consideration has its own particular processing problems. Although the final separation between plutonium, uranium and fission products would be carried out by a nitric acid solvent extraction method, head-end treatment and reconstitution vary with each fuel. Chemical engineering development in aid of recovery processes and an examination of methods of recovery of scrap material have made good progress over the period.

High Temperature Gas-Cooled Reactors

86. A large proportion of the Authority's effort on the H.T.R. system has continued to be in support of the Organisation for Economic Co-operation and Development high temperature project Dragon, a 20 MW(H) reactor experiment at A.E.E., Winfrith. Experimental work with the zero energy reactor ZENITH, in support of the Dragon reactor, was completed during 1961.

87. The development of satisfactory fuel elements is one of the key problems of the H.T.R. system. In the Dragon reactor the design is based on a graphite fuel element, in which any fission products released from the fuel are purged away within a sleeve of impermeable graphite which forms the main structure of the element; thus, it is hoped, fission product contamination of the main helium coolant stream would be avoided. The purge gas is taken to a plant where fission products and chemical impurities are removed before the purified coolant is returned to the main circuit.

88. For studying possible fuel elements for the Dragon reactor under near-operating conditions, a high temperature gas-cooled loop has been built in PLUTO. The loop is a closed circuit arrangement built into one of the horizontal holes in the reactor. The fuel element inside the loop is being operated at a maximum temperature of 1,200°C. under pressure (10 atmospheres) in a stream of extremely pure helium.

89. The Authority's economic assessments of H.T.R. systems have included a study of a 1,000 MW(H) land based design using fuel elements which do not retain fission products. The estimated generating costs were comparable with those for an A.G.R. station and did not show the improvements expected from such a major extension of gas-cooled reactor technology. This was largely because of design limitations on the core imposed by the involved and costly design of fuel element and because of the expensive chemical plant required to

purge the coolant system of fission products. Thus an essential requirement of a satisfactory fuel element design would appear to be its ability to retain fission products.

90. Theoretical studies have shown that the H.T.R. system has the potential of operating satisfactorily with a range of highly enriched fuel cycles; plutonium as well as highly enriched uranium may be used for the initial fissile material, and uranium-238 as well as thorium-232 for the fertile material.

Steam Generating Heavy Water Reactor

91. The limited programme of research and development designed to elucidate certain key problems of the S.G.H.W. reactor system has continued in collaboration with Atomic Energy of Canada Limited. Satisfactory progress has been made with the commissioning of a large heat transfer rig for burn-out and hydrodynamic instability tests of designs of S.G.H.W. fuel rod clusters. The steam-cooled loop in reactor NRX at Chalk River has been commissioned, a calibration fuel charge has been irradiated and irradiation has begun of the first design of stainless steel-clad fuel element rated at 42 MW(H)/t at 640°C can surface temperature.

92. The consortia are carrying out development work under contract to assist the design of satisfactory mechanical joints for the pressure tubes, and for satisfactory seal plugs for the fuel loading tubes.

93. The chemical and mechanical properties of a number of zirconium alloys for pressure tubes and fuel element cans are being investigated. Zirconium alloys oxidise in steam or water. One consequence of this oxidation is that hydrogen, released from water molecules, accumulates in the metal; this accumulation may, in some circumstances, affect the mechanical properties of the metal, especially if the solubility limit for hydrogen is exceeded. Reactor irradiation might affect this corrosion process by changing both the oxidation rate and the proportion of the hydrogen which accumulates in the metal. Experiments have been made to elucidate these consequences of irradiation. First results have revealed several new effects, in particular that there is an increase in the rate of oxidation during exposure to a strong flux of fast neutrons and, with it, a proportionate increase in the accumulation of hydrogen in the alloy. The increase is not great at first but becomes greater as oxidation proceeds. Preliminary results with alternative alloys suggest that the accumulation of hydrogen may be considerably lower in some alloys, especially in zirconium-niobium alloys.

94. A programme of theoretical and experimental physics on water-moderated systems has been continued at Winfrith. Theoretical methods have been developed which should predict neutron behaviour in a reactor such as S.G.H.W. containing both light water at one temperature and heavy water at another. Preparations have been made for carrying out sub-critical experiments against which these methods can be tested.

95. The zero energy reactor DIMPLE has now been moved from Harwell to Winfrith. DIMPLE will now be used for the study of the reactor physics of a range of water-moderated cores; these experiments will include safety and control experiments.

96. The preliminary investigation of plutonium/water systems, in the sub-critical assembly HELEN I at Winfrith, has shown that methods of calculation for uranium/water systems using current nuclear data may not be satisfactory when applied to plutonium/water systems.

Submarine Reactors

97. The Authority have continued to act as nuclear consultants to the Admiralty and in addition have carried out reactor safety assessments. Assistance has been given on further developments including the design of shore-based facilities and a waste disposal chemical plant. The formation and fate of activated corrosion products in a high pressure water system made from ferritic steel have been studied in a loop in DIDO. Information on this subject, and on the behaviour of the highly protective magnetite film have, together with studies on the effects of irradiation on pressure vessel steels, played an important role in establishing ferritic circuits for high pressure water reactor systems.

Merchant Ships

98. The Minister of Transport announced on 8th November that Her Majesty's Government had decided not to proceed at present with the construction of a nuclear powered ship. It was considered that, although it was technically feasible to build a nuclear powered ship, available designs of marine nuclear propulsion units did not offer sufficient economic promise to justify building a merchant ship at the present time. Instead, a vigorous programme of research, aimed at an economically attractive marine propulsion unit, had been authorised by H.M.G. The programme is being carried out by the Authority in conjunction with United Kingdom industry. A working group on marine reactor research, chaired by the Permanent Secretary, Ministry of Transport, has been set up to advise and make recommendations on the programme of research required to advance nuclear propulsion for merchant ships.

99. Economic studies of a 65,000 d.w.t. tanker, with a propulsion unit of 20,000 s.h.p., have indicated that, to be competitive with conventional propulsion, reactor costs as estimated in 1961 would need to be reduced by a factor of about three and fuel costs by about one-third. It is with this ultimate objective that a number of water reactor systems are being studied. These include the steam-cooled, heavy-water reactor; the steam generating, heavy-water reactor and versions of the pressurised water reactor. The long-term reactivity changes of one version of the P.W.R., initially heavily under-moderated, are controlled by the technique of "spectral shift", in which the ratio of heavy water to light water in the moderator is reduced with increasing burn-up. In addition to the work on water-moderated systems, the Authority are making a design assessment of the high temperature gas-cooled reactor system for marine propulsion applications.

100. A marine reactor design team has been formed within the Authority and a team of engineers has been seconded from the British Shipbuilding Research Association to study the special features of the design, operation and safety of a nuclear ship. Contracts have been let to The Nuclear Power Group, the United Power Company Limited, Rolls Royce Limited, and Babcock and Wilcox Limited for design studies of a series of water-moderated reactors. Experimental work on reactor physics, engineering problems, fuel elements and reactor materials is in hand.

101. During the year the Authority participated in a technical assessment by the European Nuclear Energy Agency of the economics of nuclear ships. In line with the prior British assessments the result showed that none of the reactors based on present designs and technology was economic.

102. In March discussions were proceeding on the possibility of collaboration in the development of a compact nuclear marine reactor known as Vulcain, proposed by BelgoNucléaire, a consortium of Belgian firms.

CHAPTER VI

GENERAL RESEARCH AND DEVELOPMENT

Introduction

103. Following the pattern of earlier annual reports the present chapter will be devoted to brief accounts of some of the Authority's research undertaken with rather more general objectives than those of the work described in the last chapter, which was concerned with particular reactor systems. There is space to describe only a few subjects and most of those chosen are different from the topics discussed last year. Detailed information about these researches, and about many others not reported here, has been or will be given in the scientific journals or in unclassified reports. Such publication is in accordance with the Authority's policy to make the results of unclassified research available widely, a policy which led during the year under review to the issue of 332 unclassified reports and the publication in journals of 390 papers by members of the Authority's staff.

Radiation Damage

104. Penetrating radiation, particularly neutron radiation, can damage materials through which it passes: for example uranium may grow or swell, steel become brittle, graphite expand, and ceramic fuels release fission gases. The detailed understanding of the causes that underlie these effects is therefore of major importance and a great deal of research is directed to acquiring such an understanding. Thus at Harwell the basic initial processes occurring in radiation damage have been studied in fissile and non-fissile materials. By bombarding crystals with inert-gas ions having energies in the range 10 to 100 keV, atomic collision cascades have been produced; in these an ion strikes an atom in the crystal and momentum is passed from this atom to its neighbour and so down a row of atoms until the last one receives enough momentum to be thrown out of the crystal. From observation of the atoms ejected from the surface of a crystal under such irradiation, the momentum distribution in these cascades has been deduced. In face-centred cubic crystals a very marked preferential ejection along particular close-packed directions was observed. This effect is thought to indicate the focusing of momentum in sequences of collisions along these directions. The effect of raising the crystal temperature was to broaden the angle around the preferred directions within which atoms were ejected; this has been attributed to the scattering action of thermal vibration on these focussed collision sequences. The angular deviation was measured

at temperatures down to 80°K: extrapolation from the lowest temperature showed that the deviation would still be positive at 0°K, which provides a new and direct demonstration of zero-point motion.

105. In work on irradiated alpha-phase uranium it has been shown, by transmission electron microscopy of thin films, that dislocation loops are formed. The loops are of two types, lying on different crystal planes, and analysis strongly suggests that they are responsible for irradiation growth. This conclusion is supported by the response of the loops to annealing and to irradiation at both high and low temperatures. For example, loop formation during irradiation at -195°C is about ten times faster than at 60°C , an observation that agrees with the recently discovered acceleration in growth rate with decreased temperature. This is the first experiment to give direct information on the mechanism of growth in alpha-phase uranium under irradiation.

106. A problem, which could become of increasing importance as the central temperature of uranium fuel in magnox reactors goes up, is the swelling of uranium caused by the inert gases produced by fission. Recent experiments in which cast uranium has been irradiated at high temperature (about 600°C) have shown that this effect is negligible in metal as manufactured in the United Kingdom, and that this result is a consequence of the composition (particularly iron and aluminium content) and the heat treatment used to reduce the grain size of the cast metal. If the iron and aluminium additions or the beta quenching treatment are omitted, the volume increase for a given burn-up in the high alpha range can be four times as great.

107. At Dounreay a series of enriched uranium specimens has been irradiated to 5 per cent. burn-up. These specimens were designed to allow for 30 per cent. swelling by providing free void in the fuel; strong cans made of nimonic alloy were used to resist the pressure of the fission product gases. The observations agreed with prediction and the tests have given useful information concerning the control of swelling and the effects of fission products in uranium.

108. Considerable progress has been made in understanding dimensional changes in irradiated graphite. A new analysis, based on the supposition that the growth of a single crystal is caused partly by the forcing apart of the atomic planes and partly by the formation of fragmentary new planes, is a great improvement over earlier ideas. Some of the predicted consequences have been quantitatively verified by annealing experiments. The closure of fissures parallel with the atomic planes, which has been postulated to explain the acceleration of growth rates under certain conditions, has been demonstrated by replica electron microscopy. Interpolation of growth data to temperatures other than those already studied and extrapolation to higher doses can now be made with more confidence.

109. In radiation damage studies at Windscale, the fractographic technique has been used; in this, surfaces exposed by fracturing specimens at room temperature are examined by the electron microscope. The method has been applied to investigate the ductility of beryllium irradiated with neutrons to exposures equivalent to more than 6,000 MWd(H)/t at high temperatures (650°C). Neutrons interact with beryllium nuclei to form helium atoms which may agglomerate into bubbles of gas. It has been shown that, after irradiation at high temperature, the gas bubbles at grain boundaries link up and grow

under the stress applied during testing. This process could bring about a decrease in ductility. This change has many features in common with a well known type of creep failure in other metals and alloys and the methods used for beryllium will probably prove valuable in studying this type of failure.

110. The fractographic technique has been used to observe the distribution of fission product gas bubbles formed in uranium under irradiation. It has also been possible to examine in detail the fine particles that are thought to have an important effect on the dimensional stability of fuel elements. A method has been developed for transferring these particles from the surface of the uranium on to a carbon film in such a way as to preserve their relative positions; the shapes and sizes of the particles can then be examined under an electron microscope. This development opens up a new approach to the study of the effects of the particles.

111. Research at Culcheth on radiation damage in stainless steels containing niobium has given interesting results. The steels were subject to high temperature tensile tests after neutron irradiation at temperatures over the range 450°C to 750°C. The irradiation temperatures were too high for damage caused by the usual atomic mechanism to remain, because atoms displaced from their normal positions by collision with neutrons would, at these temperatures, be sufficiently mobile to return to those positions. Despite this expectation, the ductility at 750°C decreased from 59 per cent. to 18 per cent. elongation, which is still adequate for the service required. This behaviour is similar to that of a material which has been heated at high temperature for a short time, for example 1,350°C for one second; the mechanisms also may be similar since irradiation results in small regions of very high temperature which last for short times. Another possible mechanism is suggested by the observation at Harwell that, in stainless steels, carbides precipitate under irradiation at a temperature at which they would not form in the absence of radiation: these precipitates could account for substantially decreased ductility. The investigations are continuing to obtain a clearer understanding of the phenomena and to determine methods of fabrication and heat treatment which will eliminate embrittlement.

Ceramic Fuels

112. The high promise of ceramic fuels for power reactors is responsible for a wide programme of general research into these materials. One subject of investigation is the release of fission product gases in irradiated oxide ceramic fuels. Excessive gas release might cause a fuel element can to be ruptured and activity to escape into the coolant; the fuel element designer must therefore know how fast, and by what mechanism, gas is released. Experiments on the prediction of gas release in uranium dioxide irradiated at central fuel temperatures below 1,600°C are reported in paragraph 70. When centre temperatures are increased above 1,600°C, substantially higher releases are observed than those predicted from extrapolation of diffusion data; these releases are associated with grain growth phenomena above this temperature. It is possible for almost complete release to occur from part of the fuel in which grain growth takes place.

113. To understand the behaviour of oxides as reactor fuels, the stability of various phases in the uranium-plutonium-oxygen system has been studied over a range of temperatures including those used in fuel fabrication and in

reactor operation. The rapid oxidation of uranium dioxide, which occurs in air at temperatures in the range 500°C to 1,000°C, is suppressed by the addition of 25 to 30 per cent. plutonium dioxide. In strongly reducing atmospheres, on the other hand, compositions containing 40 per cent. or more of plutonium dioxide lose oxygen at high temperatures with the result that two phases appear on cooling. Work is proceeding to establish the effects of these changes (gain or loss of oxygen atoms) on the properties of these materials.

114. Irradiation tests have also shown that the addition of 1 per cent. plutonium dioxide to uranium dioxide has little effect on its behaviour as a fuel compared with the behaviour of stoichiometric uranium dioxide. No apparent differences in the effective thermal conductivity or the fission gas release characteristics were observed up to burn-ups of 3,000 MWd(H)/t. This evidence indicates therefore that plutonium could be used in place of uranium-235 for moderate enrichment in fuel elements based on uranium dioxide without affecting the performance; tests are being carried out to higher burn-up.

115. Two other ceramic type fuels are being investigated; these are the carbides of uranium and plutonium, which are discussed in connection with fast reactors in paragraph 84, and dispersed fuels. The latter are those in which particles of fissile compounds are dispersed in a matrix of moderator or some supporting metal. They should have advantages over bulk fuels in that their thermal conductivity will be higher, they will retain fission products better, and fission damage will be localised. Principal examples of ceramic dispersions are uranium dioxide in beryllia and uranium carbide in graphite. It has been shown that bodies of high density and low permeability can be fabricated from very pure beryllium oxide powders by sintering as well as by hot pressing. For example oxide powder with a purity of 99.6 to 99.8 per cent. has been sintered to 97 per cent. theoretical density at 1,500°C in air or hydrogen. Dispersions of uranium dioxide particles in these bodies have been fabricated and, with a protective skin of beryllium oxide, show promising fission gas retention characteristics when tested by a method involving a short irradiation.

116. In the fissile-carbide/graphite systems, phase relationships have been found to be more complex than was thought hitherto. For the uranium-carbon system, for example, the phases in equilibrium with graphite over the range 1,000°C to 2,000°C have yet to be firmly established. The existence of a single phase carbide (UC_2) in contact with graphite is not normally observed and structures containing all three carbides of uranium, UC , U_2C_3 and UC_2 , may exist in contact with graphite under given conditions. The existence of multi-phase structures such as these may be controlled by the presence of small amounts of impurities; the structures are being studied because the phases that exist, and the change of phase structure with temperature and time, have an important bearing on fuel performance.

117. Chemical work at Harwell and at Dounreay on ceramic fuels has included studies of the co-precipitation of uranium and plutonium from nitrate solutions by a variety of agents, aimed at developing a production method for making a mixed oxide which has uniform composition and is suitable for consolidation. The usual method of precipitation, by adding ammonia, gives rise to precipitates with poor filtration characteristics. The relevant properties of the precipitates produced by other reagents have been assessed quantitatively and it has been found that precipitation by oxalic acid has marked advantages.

Mixed oxides of uranium and plutonium are also intermediates in a possible route for the production of mixed carbides. It has been demonstrated that the conversion of the oxide to carbide by heating with carbon can be carried out at a comparatively low temperature by keeping the system under vacuum to remove carbon monoxide formed in the system.

Direct Conversion of Heat to Electricity

118. In many present methods of producing power, the heat energy of fuel is used to raise steam which, in its turn, is used to drive a turbo-electrical alternator or propulsion machinery. There exist, however, several physical effects in which heat energy is converted directly to electrical energy. Devices based on these effects would make it possible to avoid the steam cycle and would appear to offer decided advantages in power generation provided that the practical problems could be overcome at the right price. For some applications operational advantages might outweigh an increase in cost but for base load electricity generation the effect on cost per kilowatt hour would be of principal importance. The methods could be applied to nuclear reactors and, because of the implications for future types of reactor, the Authority are making small scale exploratory studies of the possibilities. Present indications are that it is improbable that any of the methods could be used in a reactor in such a way as to replace steam equipment altogether, but one or more of them might just possibly be attractive in conjunction with a steam cycle to raise the overall efficiency of generation.

119. The physical effects under study include thermionic emission in a diode, the magneto-hydrodynamic process, and the thermoelectric effect. Most effort is being given to the thermionic-diode method. In this method, the electrically heated cathode of an ordinary diode is replaced by a nuclear fuel element heated to high temperature by fission; direct current can then be extracted from the anode of the diode. It is conceivable by this means to add some 10 to 15 per cent. to the efficiency of a normal steam cycle. It is necessary to neutralize the space charge of the diode by adding positive ions in some way. Two diodes are being prepared for an experiment in a reactor. In these the cathodes are solid solutions of uranium carbide and zirconium carbide and space charge is neutralised by caesium ions. Technical difficulties arise from incompatibility between caesium and other materials and for later development the possibilities of producing ions by other methods are being studied.

120. In magneto-hydrodynamic conversion, an ionized gas or vapour is passed at high speed through a transverse magnetic field and an electro-motive force is induced in the same way as in an ordinary generator. Power may be drawn as either direct or alternating current depending on the nature of the magnetic field. The principle is simple but much work is necessary before a practical device can be made. Research being done includes a theoretical study of the design of gas ducts and experimental measurements of the electrical conductivity of thermally-ionized vapours at high temperatures around 2,000°C.

121. As a result of improvements in materials, the thermoelectric method, in which heat is converted directly to electricity at a junction between dissimilar metals, is now useful for very small reactors for special purposes, although the method is unlikely to be suitable for large scale electricity generation except in association with the steam turbine. Developments in solid materials,

particularly semi-conductors, are being followed and experimental work is being done on thermoelectric generators using existing materials; the possibilities of liquids for this application are also being studied.

Nuclear Physics Instruments and Accelerators

122. The Authority's programme of research in nuclear physics is directed partly to obtaining the nuclear data required for the reactor programme and partly to increasing knowledge of nuclear structure and reaction mechanisms. These areas of applied and basic research overlap to a great extent. Because advances in nuclear physics depend upon, and consequently generate, advances in techniques of accelerating and detecting elementary particles, the work often produces developments of value to other branches of science and engineering.

123. An example of the foregoing is the development at Harwell of improved charged particle detectors made from the semi-conductor silicon. These detectors are able to discriminate between particle energies which are closely similar in value and to respond rapidly to a particle, producing an output signal within 10 nanoseconds (a nanosecond is a thousand-millionth part of a second). They are compact and hence facilitate the design of target chambers. Numbers of detectors may be operated simultaneously to accumulate precise information rapidly, thus enabling more efficient use to be made of an accelerator. The development of these detector systems has revolutionised work with low energy particles (at present below about 10 MeV) such as are produced by electrostatic accelerators.

124. Silicon semi-conductor detectors have been adapted for fast neutron detection by making use of a reaction which transfers energy from the neutrons to charged particles; by these means an energy resolution better than 150 keV has been achieved with a helium-3 neutron spectrometer. Such an instrument may be made extremely compact and should be valuable for neutron spectrum measurements within fast-reactor critical assemblies; this is important because hitherto no detector small enough for this purpose has yielded unambiguous results. A similar instrument employing the proton-recoil method provides a convenient and stable neutron flux monitor.

125. Further development of these semi-conductor detectors is directed particularly to establishing production methods and to finding ways of making larger detectors. Two forms of silicon junction-diode are being studied: surface-barrier junctions and impurity-diffused junctions. Extra-mural contracts have been placed to facilitate supply and exploitation of various forms of these detectors within the Authority. In addition to the nuclear physics applications, small detectors have been applied, with promising results, to some medical and health physics problems on the detection of radioactive contamination in orifices in the body and in confined spaces. An upper limit to the useful size of the detectors is imposed by thermally generated noise, and the sources and nature of this noise are being investigated. To increase the area, multiple detector assemblies have been made with effective areas of about 20 cm²; a detector of this size would be useful in general assay and identification of alpha-active samples. Methods are also being investigated for increasing the effective thickness of the detectors in order that they can be used for more penetrating particles.

126. The high voltage generators at Harwell have been used to aid research in fields other than nuclear physics. For example, neutrons from the Cockcroft-Walton generator have been used in preliminary investigations into a method for measuring the amount of silicon in coal by activating it through the $^{28}\text{Si}(n,p)^{28}\text{Al}$ reaction. The 5 MV Van de Graaff generator has been used as a neutron source for shielding studies. The cyclotron has been employed as a proton source to irradiate solar cells for the Royal Aircraft Establishment, so that the effects of the Van Allen radiation on artificial satellites can be assessed.

127. A new accelerator is IBIS, a commercial machine comprising a 3 MV electrostatic generator and auxiliary gear, which produces intense bunches of ions less than 1 nanosecond in duration (see FIG. IV on page 31). These will be used to produce pulses of fast neutrons having an intensity ten to twenty times greater than the best previously available in the energy range covered. The energies of neutrons scattered by a sample are measured by timing their flight electronically, the short pulse making this measurement very precise. IBIS is to be used first to obtain the inelastic scattering cross-section of uranium-238 and other data needed for fast reactor design.

Nuclear Data

128. In order to calculate the rates at which different nuclear reactions will occur in a reactor, it is necessary to know, for each possible reaction, the probability that a neutron will collide with a nucleus and produce that reaction. The probabilities are measured in terms of nuclear cross-sections and have to be determined for all the reactions—whether the neutron is scattered or captured by the nucleus or causes fission in it—and for neutron energies from 0.01 eV up to several MeV; this information is needed for the nuclei of fuel and of constructional and cladding materials, and also for the nuclei of fission products formed in burnt fuel. Cross-section measurements therefore constitute a major programme of research.

129. One laboratory working in this field is the Neutron Project Laboratory at Harwell, which has now been in operation for two years (see Sixth Annual Report, paragraph 121). An electron linear accelerator is used with a uranium target to produce intense bursts of neutrons whose speeds and hence energies are determined by the time-of-flight method (cf IBIS). Practical experience with the machine has shown it to be equal in power and resolution, and superior in flexibility, to other instruments in its field. Among experiments carried out, the fission cross-section of plutonium-241 has been measured with high resolution in the neutron energy range 3 eV to 10 keV; this isotope has an important effect on the reactivity of highly irradiated fuel and therefore on fuel costs in a reactor. To supply data for reactors working on the thorium/uranium-233 cycle, the total cross-section of thorium-232 has been measured from 100 eV to 60 keV neutron energy.

130. For technical reasons it is difficult to measure and analyse the neutron scattering cross-sections of fissile materials at the so-called resonances (where there are sudden increases in cross-sections over a narrow range of neutron energies) but successful measurements have been made on plutonium-239 using one of the neutron project spectrometers; from data derived from these measurements the spins of the neutron resonance levels have been deduced.

131. Because they influence neutron economy in reactors and efficiency in neutron shields, the neutron capture cross-sections of different materials are much needed. A new and simple capture-gamma detector has been devised which permits these data to be obtained with high resolution for most heavy elements, over the energy range from a few eV to 20 keV. Another quantity of basic importance to reactor design is the number of neutrons emitted by a fissile nucleus per neutron absorbed and its variation with neutron energy. The energy dependence of this quantity for uranium-235 has been measured from thermal energy to 100 eV. The resolution was the highest yet achieved, the effects of individual resonances being clearly resolved: as a result of this improvement a successful theoretical analysis can be made of the statistical distribution of the widths of the fission resonances.

132. Towards the end of the year the linear accelerator in the Neutron Project Laboratory equipment was improved by adding a fast modulator which has enabled the length of the electron pulse to be reduced, resulting in an order of magnitude improvement in energy resolution. The modified apparatus has been used to study the neutrons ejected from the oxygen-16 nucleus by energetic X-rays generated by the linear accelerator; many groups of neutrons of clearly defined energy have been observed up to 10 MeV which hitherto had been only partly resolved.

133. At the Atomic Weapons Research Establishment nuclear data work has been concerned especially with fast neutron reactions. The accuracy of fast neutron data for uranium-235 has been improved. The number of neutrons emitted in fission has been measured to an accuracy of 1 per cent. as a function of neutron energy up to 14 MeV. The fast neutron fission cross-section of uranium-235 has been redetermined, for neutron energies below 500 keV, using improved methods of measuring fast neutron flux and of assaying uranium-235. The new values lie 10 to 15 per cent. below the previously accepted data and are believed to be more accurate. To check these new data, experiments have been carried out with uranium-235 and with mixtures of uranium-235 and uranium-238 using the Versatile Experimental Reactor Assembly (VERA).

134. New beam pulsing equipment on the 6 MV Van de Graaff generator has made possible the study of the inelastic scattering of fast neutrons for incident energies up to about 8 MeV. Comprehensive new scattering data have been obtained for the elements sodium, aluminium and iron, all of which are important for fast reactors.

Basic Nuclear Research

135. Basic nuclear research is directed to improving our still imperfect understanding of the arrangement of the constituent particles within nuclei and of the forces that hold them together. Experiments in this field are not easily understood except by the specialist but one or two will be briefly described as an indication of the kind of work that is being done.

136. One experiment at Harwell is concerned with the mechanism of beta decay, i.e., a radioactive transformation in which the nucleus gives out a negative electron or a positron (positive electron); many nuclei decay by this process. The mu meson, one of the elementary particles of high energy physics first discovered in cosmic radiation, decays in a similar way. The fundamental question arises, is there a universal interaction common to all these processes?

The energy release and life-time for mu meson decay are well known and one method of answering the question is to measure accurately the energy of the positrons emitted in the beta decay of certain nuclei together with the half-lives of the nuclei. But direct measurement of the positron energy is difficult; in the experiment, therefore, the energy has been determined from measurements on the reverse process. For example, aluminium-26 decays by positron emission to magnesium-26; in the reverse direction magnesium-26 can capture a proton and emit a neutron to become aluminium-26. So by bombarding magnesium-26 with protons of accurately known energy from the tandem generator and measuring the energies of the emitted neutrons, the corresponding maximum positron energies have been found to an accuracy of about 0.1 per cent. The results, combined with accurate life-time measurements, are being compared with other positron decays and with the mu meson decay to test the question of the decay mechanism.

137. The purely nuclear forces that bind nucleons (protons and neutrons) together to make nuclei can be studied in experiments concerned with interactions between individual nucleons rather than between nucleons and nuclei. Using the 166 MeV synchro-cyclotron, beams of polarised nucleons with energies up to 100 MeV are fired at stationary protons; at this energy the relative velocities of moving and stationary nucleons are comparable with the relative velocities of nucleons inside a nucleus. Experiments have been done on the scattering of polarised protons by stationary protons (hydrogen nuclei) and the data used in a theoretical analysis which has the ultimate object of representing all the measured experimental quantities in terms of new parameters that are related to methods of expressing nuclear forces. In other experiments the equally important scattering of polarised neutrons by stationary protons was investigated in the energy range 20 to 110 MeV.

138. A programme of research on nuclear structure has been carried out at A.W.R.E. with the tandem generator in close collaboration with staff and research students from Oxford University. Three experiments may be mentioned. In the first, beams of oxygen ions with energies up to 50 MeV were used to study the energy level structure of medium-mass nuclei. Of particular interest are results on the energy levels of nuclei containing even numbers of neutrons and protons, which are believed to arise from collective vibrational motion. A systematic study of many such nuclei indicates that a definite vibrational level pattern exists but it appears to differ from that expected theoretically in several interesting and important respects.

139. Proton beams with energies up to 14.5 MeV have been used to study the energetic γ -rays which arise from oxygen-16 and calcium-40 produced in the reaction $^{15}\text{N}(p,\gamma)^{16}\text{O}$ and $^{39}\text{K}(p,\gamma)^{40}\text{Ca}$. To some degree, these reactions are the inverse of photo-disintegration processes and the energy levels of interest are those that give rise to the familiar giant resonance phenomena of photo-disintegration. The work is being done in collaboration with the Institute of Theoretical Physics in Copenhagen.

140. Equipment for accelerating tritons has been installed and high energy triton beams are being used to study fission processes in nuclei which cannot be investigated by the usual methods of neutron bombardment. Examples are the nuclei uranium-237 and uranium-239; these are produced in large quantities in thermonuclear explosions but their radioactive decay rates are too rapid

to allow detailed study of their nuclear properties in the laboratory. Addition of a neutron to uranium-237 and uranium-239 leads to uranium-238 and uranium-240 respectively and these nuclei can also be reached, in a high state of excitation above the fission barrier, in the nuclear reactions $^{238}\text{U}(t,p)^{238}\text{U}$ fission and $^{238}\text{U}(t,p)^{240}\text{U}$ fission. Thus by counting coincidences between disintegration protons, fission fragments and neutrons, much can be learned about the properties of these unstable elements.

International Collaboration in Nuclear Physics Measurements

141. Collaboration between the U.K., Canada and the United States of America in the determination of important nuclear data is co-ordinated by the Tripartite Nuclear Cross-sections Committee. Collaboration includes where necessary the production of isotopes as well as the measurement of their nuclear cross-sections. Under the guidance of the committee, the plutonium isotopes of mass numbers 240, 241 and 242, whose properties are important at high burn-up in plutonium-containing fuel, have been produced. Substantial quantities of plutonium-240 and -241 have been made by collaborative effort; thus plutonium-241, formed from plutonium-239 in the Canadian high-flux reactor at Chalk River and in the American MTR at Idaho Falls, has been chemically processed at the United States Atomic Energy Commission's Oak Ridge National Laboratory and the two isotopes separated at Harwell in HERMES (the Heavy Element Radio-active Material Electromagnetic Separator). Another co-operative production was that of uranium-232, formed by neutron irradiation of protoactinium-231; the protoactinium was separated from by-products of uranium processing at Springfield, irradiated in the high-flux reactor at Oak Ridge, and the uranium-232 is being extracted at Oak Ridge.

142. More recently the European-American Nuclear Data Committee has been inaugurated, to extend the collaborative objectives of the tripartite committee over a wider geographical area. An example of the kind of collaboration which might be achieved is the proposal for a major facility for the development, fabrication and distribution of special foils and targets for the measurement of basic nuclear data. As the tripartite committee countries have already done so much to produce special materials it has been suggested that the proposed new laboratory should be set up elsewhere in Europe.

Radioactive Aerosols

143. Work has continued at Harwell on the nature and properties of radioactive aerosols; particular attention has been paid to iodine, radioactive isotopes of which are formed as fission products in nuclear fuel. Iodine is a volatile, but also very reactive, material and fission product iodine may be released as vapour or gas from a damaged fuel element; if this happened the problem of removing it from a coolant gas or the air might arise. Though readily released into the atmosphere by heating, iodine is rapidly adsorbed on surfaces and this adsorption is particularly important when the total mass of the element present is very small; a layer one molecule thick is held by many surfaces at temperatures far above the boiling point of the iodine.

144. The tendency to adsorption on surfaces makes it difficult to do laboratory experiments with iodine at the extremely low vapour concentration permissible, for safety reasons, in plant operation. For this reason, and to gain experience with methods of removing iodine from air on a large scale, experimental releases were made in the airtight containment buildings of DIDO and

PLUTO, which have a capacity of 7,000 cubic metres. The isotope iodine-132 was used because its half-life (2.3 hours), though long enough for experimental purposes, was short enough to ensure that residual activity decayed to a negligible level in the course of a day. Elemental iodine was released as vapour and the amount in the air of the building was measured after various time intervals up to five hours.

145. The experiments established several facts. Most of the iodine liberated was rapidly adsorbed on walls and other surfaces inside the building, so that the airborne concentration fell to a few per cent. of its initial value within an hour. After about an hour there remained an airborne concentration which fell only slowly with time. The iodine that remained in the air was no longer in the form of elemental vapour; some was adsorbed on very fine airborne particles, some was present as gaseous compounds of iodine with trace impurities in the air. It was established also that the most efficient filtration plant for air containing iodine at very low concentrations is an activated charcoal bed in series with a very efficient mechanical filter.

Neutron Dosimetry in Criticality Accidents

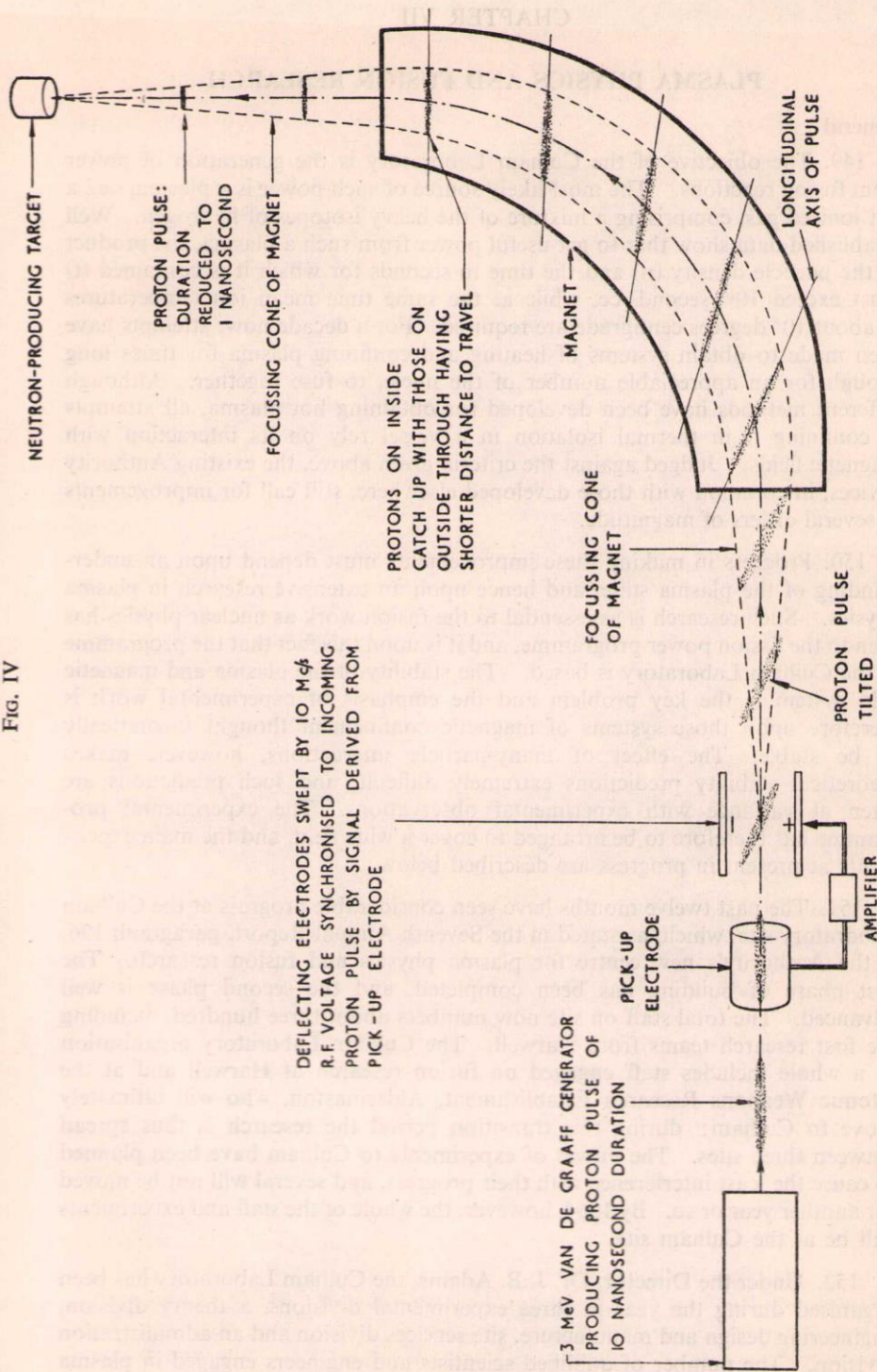
146. Accidents in the U.S.A. and Yugoslavia have emphasised the importance of being able both to identify rapidly all those persons who have been exposed to the gamma rays and neutrons emitted from the accidental assembly of critical quantities of fissile material and to assess the radiation dose received. Identification can be done by having all persons in an establishment carry indium foil in their passes; the slow neutrons from criticality accidents produce in this foil radioactive indium-116 which can be measured with a geiger counter.

147. Turning to the assessment of dose, the methods for measuring gamma dose are well developed, those for neutron dose less so. The criticality dose-meter for neutrons evolved at Harwell consists of a small button-shaped capsule of metal or plastic containing sulphur, cadmium covered and bare gold foils, and indium foil. The activity produced in these gives a measure of the number of neutrons in the energy ranges less than 0.5 MeV, 0.5 to 1.0 MeV, and above 1 MeV respectively. In addition a useful measurement of the total number of neutrons incident on the body is provided by the radioactive sodium-24 produced in the sodium of the body or blood. Experimental work has been carried out at Dounreay and Winfrith using mixed gamma and neutron radiation to study these techniques of dose evaluation.

Criticality

148. A new laboratory designed specifically for remotely controlled experiments on plutonium critical assemblies has been brought into use at Dounreay. Two zero energy reactors are being installed within a gas-tight and heavily shielded vessel. With one of these the first experimental data have already been obtained on the critical sizes of plutonium precipitates and sludges by using polythene-plutonium oxide blocks. The other will be used to study the criticality of plutonium solutions. Experiments at Dounreay and Aldermaston on uranium assemblies have included some in which two or more vessels containing sub-critical quantities of material are separated by shielding or by constructional materials.

FIG. IV



IBIS: METHOD OF BUNCHING PROTON PULSE

CHAPTER VII

PLASMA PHYSICS AND FUSION RESEARCH

General

149. The objective of the Culham Laboratory is the generation of power from fusion reactions. The most likely source of such power is a plasma, i.e., a hot ionised gas, comprising a mixture of the heavy isotopes of hydrogen. Well established data show that to get useful power from such a plasma, the product of the particle density (n) and the time in seconds for which it is contained (t) must exceed 10^{14} seconds/cc, while at the same time mean ion temperatures of about 10^8 degrees centigrade are required. For a decade now, attempts have been made to obtain systems of heating and confining plasma for times long enough for an appreciable number of the nuclei to fuse together. Although different methods have been developed for obtaining hot plasma, all attempts at confining it in thermal isolation in a vessel rely on its interaction with magnetic fields. Judged against the criteria given above, the existing Authority devices, in common with those developed elsewhere, still call for improvements of several orders of magnitude.

150. Progress in making these improvements must depend upon an understanding of the plasma state, and hence upon an extensive research in plasma physics. Such research is as essential to the fusion work as nuclear physics has been to the fission power programme, and it is upon this fact that the programme of the Culham Laboratory is based. The stability of the plasma and magnetic field system is the key problem and the emphasis of experimental work is therefore upon those systems of magnetic confinement thought theoretically to be stable. The effect of many-particle interactions, however, makes theoretical stability predictions extremely difficult, and such predictions are often at variance with experimental observations. The experimental programme has therefore to be arranged to cover a wide field, and the main experiments at present in progress are described below.

151. The past twelve months have seen considerable progress at the Culham Laboratory site, which, as stated in the Seventh Annual Report, paragraph 196, is the Authority's new centre for plasma physics and fusion research. The first phase of building has been completed, and the second phase is well advanced. The total staff on site now numbers about three hundred, including the first research teams from Harwell. The Culham Laboratory organisation as a whole includes staff engaged on fusion research at Harwell and at the Atomic Weapons Research Establishment, Aldermaston, who will ultimately move to Culham; during this transition period the research is thus spread between three sites. The moves of experiments to Culham have been planned to cause the least interference with their progress, and several will not be moved for another year or so. By 1964, however, the whole of the staff and experiments will be at the Culham site.

152. Under the Director, Dr. J. B. Adams, the Culham Laboratory has been organised during the year in three experimental divisions, a theory division, engineering design and manufacture, site services division and an administration division. The number of qualified scientists and engineers engaged in plasma physics and fusion research in the Authority is about 170.

ZETA

153. It is a measure of ZETA's usefulness that, after four years' service, it is still in continuous experimental use. The number of electrical discharges through this deuterium filled, ring shaped apparatus now exceed half-a-million, and observations on these have enabled the Authority to make the most comprehensive study yet attempted of conditions in a toroidal pinch system. Experiments have continued on the far infra-red radiation emitted using a new fast photoconductive detector developed at the Royal Radar Establishment, Malvern. This has enabled time-resolved measurement of electron temperature and density to be made, affording a direct demonstration of the phenomena of plasma loss to the walls and subsequent re-injection. These findings give striking confirmation of the picture previously obtained from optical measurements made on the spectral line emission of impurity ions in the plasma. Another noteworthy series of experiments has resulted in a better understanding of the ion energies obtained by measurements on the Doppler broadening of spectral lines. The ion energies now appear to comprise a constant and a turbulent component. The former can be taken to represent the thermal energy of the ion, suggesting ion temperatures around one million degrees centigrade.

154. Spectroscopic, electric field and energy balance methods have brought further information about plasma loss. Whilst the mechanism is still not clear, it has been found that the loss tends to increase in a linear manner with the energy retained by unit mass of the plasma in each discharge pulse. The excess electrical resistance (the amount by which the measured plasma resistance exceeds that calculated from its observed electron temperature) also varies in the same way. Transport of plasma to the walls, and the process which heats the ions well above the electron temperature, would appear to be the source of the excess resistance.

155. During the last few months of the year under review, ZETA has been fitted with new primary windings which will permit an extended range of working conditions.

Pinch and Unpinch Stability Studies

156. Whereas plasma carrying current between electrodes in a straight discharge tube is pinched towards the axis, it may be repelled outwards against a surrounding axial field by arranging a solid central conductor to return the discharge current back along the axis of the plasma column. Theoretical considerations suggest that less rigorous conditions apply to this hard-core (or unpinch) system. In experiments of this kind similar field fluctuations have been observed using internal and external search coils in both pinch and unpinch discharge and it has been shown conclusively that they are not due solely to the presence of the internal coil themselves. Detailed study of the fluctuations from several coils measured simultaneously has indicated that the expected cylindrical shaped discharge develops a spiral disturbance around its surface. This behaviour is similar to that predicted on the theoretical assumption that lower electrical conductivity exists at the outer layer of the discharge. This possibility has not yet been proved to be the cause of the phenomena. Similar results were obtained in a longer hard-core tube, which suggests that the disturbing effect of the electrodes is not the main cause.

Cusp Experiment

157. By passing currents in opposite directions around a pair of coils facing each other, a magnetic field with a central spindle cusp enclosure is obtained between the coils. Relatively stable containment is to be expected for plasma in this central region as the magnetic field, and hence the restoring force, increases with radius in all directions—except towards the apices, where a high loss rate is to be expected. In this cusp experiment the plasma is generated and pre-heated by two colliding shock waves being then adiabatically compressed by rapidly developing a cusped magnetic field around it. High density plasma (greater than 10^{16} ions per cc) of relatively low temperatures have been obtained, and as yet no large scale instabilities have been observed in the equilibrium state, i.e., when the plasma and magnetic pressures become equal. Those instabilities arising under certain conditions during the compression phase are not thought to be a fundamental limitation of the configuration itself. The brief containment time of 20 microseconds appears to be a consequence of normal diffusion processes associated with the relatively low plasma temperature of some $200,000^{\circ}\text{C}$. In an effort to attain higher temperatures attention is now being paid to improving the shock pre-heat system.

Theta Pinch Experiment

158. The study of the heating and stability of theta pinch systems has continued at A.W.R.E. In these experiments the single primary turn surrounding the discharge vessel passes currents which build up to 10^6 amps in a few microseconds. An electrical breakdown occurs in the gas and the rapidly changing flux induces currents around the resulting plasma which is pinched towards the axis of the tube. Under certain conditions a magnetic field may be trapped in the plasma, acting in the opposite direction to the main field. Considerable effort has been devoted to explaining the mechanism by which such trapped reversed fields give rise to the soft X-ray and neutron production.

159. The effect of these reversed fields now appears to be twofold; the closure of the field lines round the plasma can induce a rapid axial contraction which heats the plasma and leads firstly to an instability responsible for heating the ions: this is a dynamic effect and predominates in short coils. Secondly the reversed field provides large field gradients and hence high current densities in the plasma which produce a very rapid, though otherwise conventional, form of Joule heating. If this rapid Joule heating process can be closely controlled it is likely to become an important means of heating a plasma quickly.

160. Further work has been devoted to studying a rotational instability of the plasma. When hot, the plasma is found to rotate very rapidly, with peripheral speeds up to 2×10^7 cm/sec. The centrifugal forces accompanying this rotation lead to instabilities in which the plasma splits into two cylinders which rotate about a common axis. It is believed that detailed study of the onset of this process will lead to information on stabilising and damping processes in plasma at high temperature.

161. To extend these experiments a new low inductance 1 megajoule condenser bank has been ordered for erection at Culham.

The Phoenix Mirror Machine

162. Ions injected into the weaker central field of axially symmetric magnetic field systems tend to be reflected back and forth by the adjacent field maxima,

although they will ultimately escape. If the injected particle can change its identity within such a mirror system, more effective trapping is possible. In the original experiment at A.W.R.E. it was intended to inject neutral atoms and ionise them by impact with residual gas or by crossing a subsidiary plasma stream at the centre of the mirror machine. It has recently been discovered that a significant number of these neutral atoms are in a highly excited state and that these are ionised by disruptive forces when they cross the strong magnetic field. This effect increases the initial rate of plasma build-up by several hundred times. Suitably excited hydrogen atoms have been obtained by charge exchange processes between accelerated protons and water vapour.

163. The principle outlined above is dependent on the highly excited atoms having sufficient life-times to travel from the water vapour exchange chamber to the high magnetic field region. Measurements of these life-times and of the population of the highly excited states are being made by the atomic cross-section group. This information has materially affected the development of the Phoenix experiment.

164. The maintenance of ultra high vacua (10^{-9} mm Hg) in the presence of gas released by powerful neutral beams has been helped by using titanium coated surfaces cooled by liquid nitrogen. Over half the incident hydrogen molecules adhere to such surfaces at their first impact.

Shock Heating

165. Shock waves provide a possible method of heating a plasma to high temperatures so rapidly that energy loss mechanisms will not have time to become serious. Preliminary experiments have been conducted with a straight tube in which a rapid pinch effect was developed on a plasma carrying a current which was built up to 100,000 amps in a microsecond. Associated theoretical studies using an I.B.M.7090 computer have demonstrated the broad principles, and in particular the importance of the initial and wall conditions. A larger shock wave experiment, again using a straight tube, is under construction at Culham.

Wall Effects

166. Studies have been made in conjunction with the Metallurgy Division at Harwell on some of the ways in which interaction occurs between plasma and the surrounding walls. The interactions inevitably introduce impurities into the plasma and cause a marked increase in radiation losses.

167. If the walls are metallic, arcs may occur with the plasma as one electrode and the wall as the other. Experiments using molybdenum have shown that non-metallic inclusions were responsible for the arcing. There appears to be a critical size of inclusion for arc initiation which depends on the plasma conditions. It has been shown that molybdenum can be depleted of its inclusion content by a combination of heat treatment with electrical discharges, becoming completely non-arcing.

168. Plasma instabilities can give rise to a very rapid energy transfer to the walls. With non-metallic wall materials this produces very high instantaneous surface temperatures. Enhanced evaporation results and the high mechanical stresses set up in such non-conducting materials may cause surface cracking and further contamination. Materials and surface treatments are being studied with the object of minimising these effects.

169. In addition to the wall material itself entering the plasma, chemical interactions can occur at the walls. Materials which have the insulating and refractory properties needed in some experiments generally contain oxides. A plasma gun has been developed and used to investigate the evolution of water vapour when hydrogen plasma encounters such surfaces.

Low Pressure Switches

170. Research has led to a better understanding of the physical parameters affecting the performance of low pressure switches. These offer a much lower inductance and reduced electrode erosion compared with the high pressure switches used so far. Very useful information has been obtained on the triggering of these lower pressure switches. Their wide range of operating voltage makes them particularly suitable for clamping duty.

171. When a capacitor bank is used to supply energy to an experiment the simplest form of switching normally results in an oscillatory current. In general the experimentalist can only use the period up to the first reversal of current. A clamping switch may be used to short circuit the capacitor at the instant of peak current in the experiment. The current pulse is thus maintained in the same direction for much longer, thus extending the useful experimental period. An additional advantage is that the clamping switch considerably reduces the oscillatory voltage across the capacitor. For a given capacitor life this allows the size and consequent cost of the capacitor bank to be reduced by a factor of as much as four.

Other Experimental Studies

172. The probability of removing the single electron of a helium ion by the impact of another electron has been measured for the first time. The equipment, which uses crossed beams of electrons and singly charged helium ions, will be used for making similar measurement of direct interest in fusion research.

173. A new method of plasma confinement has been demonstrated using magnetic fields rotating about the axis of a cylinder of plasma. Here theory and experiment have proved to be in good agreement, although the period of time for which the plasma has been confined is, as yet, insufficient for the investigation of its hydromagnetic stability.

174. A technique has been developed for measuring very small concentrations (1 part in 10^4) of neutral atoms in a plasma which is virtually fully ionised. In the neutral state, the atoms absorb, and subsequently emit diffusely, radiations of certain wavelengths characteristic of their state of excitation. By passing modulated light beams of suitable wavelengths through plasma and measuring the effective beam absorption, the density of the neutral ions in various states of excitation has been found. The method permits observations on the variation of this density with time.

175. Preparations have been made for solar coronal and chromospheric plasma studies by means of far ultra-violet observations. This work has been accepted as part of the Royal Society's space research programme.

176. With a view to obtaining an understanding of the way in which disturbances can be propagated in plasma, experiments have been conducted on a variety of wave motions. These observations have proved in agreement with

predictions given by the theory which is used extensively in treating other problems in plasma physics. The experiments have included work on electro-acoustic waves (which are longitudinal density fluctuations of the ions and electrons together) and on transverse electro-magnetic waves in plasma carrying strong magnetic fields. In the latter case, at the lower frequencies Alfvén waves occur with both ions and electrons being set in motion, but as the frequency rises, eventually only the free electrons are affected. Theory predicts that there is an upper limit to the frequency at which such "whistler" waves can be propagated. Measurements in this essentially microwave region have confirmed the existence of such an upper limit and have agreed with other theoretical predictions.

Theoretical Studies

177. The microstructure of plasma consists of energetic particles of differing charge and mass gyrating in local magnetic fields with individual and collective interactions. Treating plasma as an ideal fluid of infinite conductivity in the presence of magnetic field, and ignoring this microstructure, leads to a well defined set of equations which can be analysed in great detail. This magneto-hydrodynamic approximation has been applied with some success but the nature of the microstructure generally calls for further refinements to the theory. The physicist is faced with the problem of deciding which of a whole range of phenomena can be safely ignored if the mathematicians' equations are to have any real significance. Among other possibilities finite conductivity has been considered as a source of the instabilities observed in hard-core pinch devices for which the simpler theory predicted stability.

178. Further calculations on fast linear pinches have been made, using the fully ionised plasma collapse programme mentioned in the Seventh Annual Report, paragraph 189. In these calculations the basic physical processes are understood, the main purpose being to provide accurate numerical data which can be used in computer calculations to interpret or to design experiments. Other computer programmes have now been written to explore physical situations where the basic processes are not well understood, so that it is worthwhile to investigate them by carrying out numerical experiments. One such programme describes the behaviour of a partially ionised gas in infinite cylindrical geometry. Another describes a fully ionised gas in two dimensions (radial and axial), and will be used to study the dynamics of a θ -pinch of finite length. All these programmes have been written in collaboration with physicists at the Max Planck Institut für Physik und Astrophysik, Munich.

International Collaboration

179. Teams from Culham Laboratory took part in two major international conferences in Europe during the year. The fifth international conference on ionisation phenomena in gases was held at Munich in late August followed directly by the International Atomic Energy Agency conference at Salzburg on plasma physics and controlled fusion research. Staff from the laboratory served on the paper selection committee and on the scientific secretariat for the Salzburg conference. After these conferences, scientists from laboratories in America, Asia and Europe visited the Culham Laboratory.

180. The laboratory also participated in meetings of the European Fusion Study Group and the International School of Physics held in Varenna. Informal meetings have been initiated with the Centre d'Etude Nucléaires at Fontenay-aux-Roses.

181. In the U.S.A., Culham staff have presented papers at several international conferences, and exchange visits with laboratories engaged in plasma physics and associated research have continued.

CHAPTER VIII

ISOTOPES AND IRRADIATION PROGRAMME

Production and Marketing of Isotopes and Labelled Compounds

182. The Authority's responsibilities for manufacturing and marketing radioisotopes and labelled compounds are fulfilled by the Radiochemical Centre, Amersham. The pattern of demand and of sales for the products of the centre is given in paragraph 260.

183. For the production of primary isotopes, advantage has been taken of the hollow Mark III fuel elements recently introduced into the reactors DIDO and PLUTO. New improved designs of irradiation rigs have enabled the Centre to make better use of the highest neutron fluxes in these reactors and consequently to reduce the chemical scale of processing and to increase both the quality and quantity of isotopes produced. Phosphorus-32 is now made regularly in these fuel elements and other isotope production processes are to be transferred progressively in 1962. A new rig for irradiating iridium in DIDO has greatly improved the specific activity of iridium-192, which is used extensively for radiography of welds in pipes or pressure vessels, and similar non-destructive testing. The intensity of these sources has been increased about five-fold, so allowing the radiographer to use shorter exposure time or to obtain higher definition.

184. Interest in those isotopes which can conveniently be made only in the cyclotron has continued to grow, and with the collaboration of the Medical Research Council Radiotherapeutic Research Unit at Hammersmith, the Department of Physics at the University of Birmingham and the Oak Ridge National Laboratory, the availability of these isotopes has been greatly improved. Their special properties make them of particular value in medical diagnosis, where accurate location of them in the body is important, and also in physical research by application of the Mössbauer phenomenon. During the year, processes for obtaining more than twenty isotopes with the cyclotron were thoroughly examined, and the following isotopes are now regularly available in useful amounts: sodium-22, cobalt-57, arsenic-74, strontium-85, bismuth-207, beryllium-7, manganese-54, iron-52, cadmium-109, zinc-65, and iodine-124.

185. The relatively long life (sixty days) and the favourable radiation energies of iodine-125 make it an interesting isotope for medical use in addition to the commonly used iodine-131. Hitherto only small quantities have been made

by cyclotron methods, but the reactor method based on the irradiation of xenon gas has been examined and conditions for optimum yield studied. Small batches of about 50 millicuries are now being made regularly and the scale is to be extended in 1962.

186. The demand for labelled compounds continues to grow steadily on a very broad front. For carbon-14 compounds particularly the emphasis is moving towards biochemical methods of preparation and generally to more exacting standards of purity. Studies have been made of the conditions under which the alga *chlorella* can be grown at high specific activities of carbon-14, and from this source labelled oleic, linoleic and linolenic acids became available for the first time during 1961. Carbon-14 is also proving to be a useful tool in the study of the chemistry of graphite and quantities of elementary carbon and pitch labelled with this isotope were prepared for the Culcheth Laboratory. Rapid progress was made with synthesising additional tritium compounds and the Centre's list of compounds of this isotope was extended to about 140 items. The possibility of making certain compounds at extremely high specific activity is being exploited, particularly for the drug "Synkavit", which is a possible chemo-therapeutic agent for some forms of cancer. This has been prepared at nearly the theoretical maximum activity, which is about a thousand times higher than usual for tracer use.

187. The use of isotopically labelled compounds in clinical diagnostic procedures continues to expand. As a result of intensive study of detailed culture conditions, production of the labelled vitamin B12 has been increased. It is now available with four alternative isotopic labellings over a range of specific activities; with cobalt-57, cobalt-58, cobalt-60 and tritium. The production of iodinated (iodine-131) human serum albumin has been much improved by close study of the experimental conditions, and a new production plant is being designed. Among other radioactive drugs useful as diagnostic agents and prepared regularly at Amersham last year, were "Hypaque"-I¹³¹, "Hippuran"-I¹³¹ and L-triiodothyronine-I¹³¹. The latter is of interest for testing thyroid function *in vitro*.

188. Techniques for making neutron sources based on alpha emitting radioisotopes and beryllium have been much improved to meet the requirements of advancing reactor technology. Careful studies of design, and most stringent testing procedures, have been necessary to make such sources stable and safe at higher operating temperatures. In particular, the neutron sources of HERO, which contain radiothorium, were given prolonged testing at 600°C, and those for ZENITH, using radium, were tested at 900°C. Two particularly powerful sources based on radiothorium have been supplied to the Central Electricity Generating Board for commissioning the Berkeley and Bradwell power stations. Neutron sources for several other research reactors are at present being designed, including one to an exceptionally exacting specification for the Dounreay submarine prototype.

189. In many uses of radioisotopes comparative measurements of radioactivity are sufficient but in some it is necessary to know the exact quantity of the nuclide used; the determination is often a matter of considerable difficulty. For the purposes of controlling production and distribution of radioisotope products, the Radiochemical Centre and the Wantage Research Laboratory have developed means of measuring absolutely a wide range of isotopes. Close

liaison has been established with the National Physical Laboratory at Teddington which is responsible for national and international comparisons. More than fifty nuclides are now regularly available from Amersham as accurately standardised solutions, and during 1961 some twenty countries availed themselves of this service. Improved techniques of measurement are being developed to meet the need for still higher accuracy. Anti-coincidence techniques have given promising results, and the Harwell Mercury computer is being used for calculating the results of multiple measurements.

190. A successful exhibition of labelled compounds for biochemical research was held in Moscow in August, 1961, at the Vth International Congress of Biochemistry, and there was also a display at theACHEMA Fair in Frankfurt. This year the Centre will exhibit at the Xth International Congress of Radiology and at the VIIIth International Congress of Microbiology, both in Montreal, in August. A series of monthly technical bulletins has been started to inform users of new products. The first part of a reference book for isotope users, entitled "The Radiochemical Manual", was published in February.* A completely new catalogue has been compiled, comprising some 2,000 items of radioactive chemicals and radiation sources, and will be ready for distribution in May, 1962.

Applications of Radioisotopes

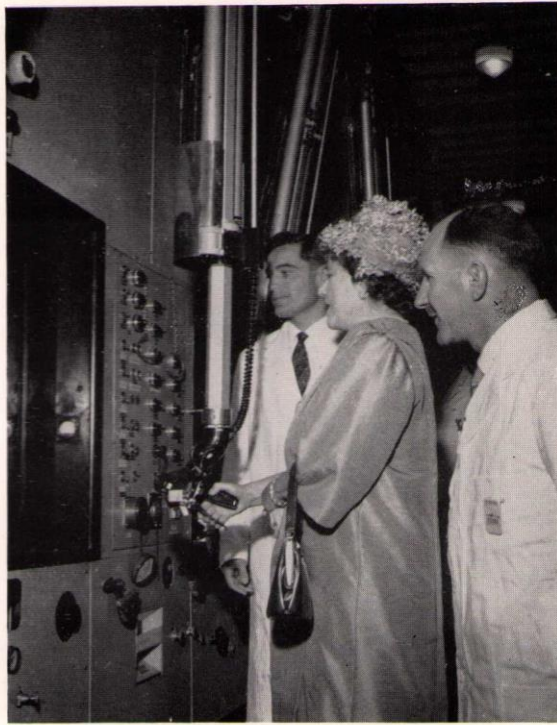
191. The function of the Authority's Wantage Research Laboratory is to do research into, and advise upon, the applications of radioisotopes. The demand upon the laboratory's services has continued at a high level, as is evidenced by the fact that over 100 representatives of industry visited the laboratory each month during the year. In addition, one-day courses and lectures were given to senior management in various industrial areas. These activities led to practical investigations by the laboratory both at enquirers' works and at Wantage. A typical example of an on-site investigation was the measurement of large water flow rates in 5-ft. square culverts at the C.E.G.B.'s Uskmouth generating station, in connection with acceptance tests on cooling-water pumps. The accuracy was estimated as better than ± 2 per cent.

192. A large-scale application of radioactive tracers, which is now well established, is their use for investigating the movement of coastal silt or of surface or underground water. In the Firth of Forth it was desired to study the movement of material which is dredged from the upper part of the estuary, and then deposited in a deep cut seaward of the Forth Bridge. Glass particles labelled with scandium-46 were used to trace the movements of the silt over a period of two months. After the first tide an upstream movement became evident and after six days traces of radioactive material were found in the dredging area. This result was similar to that found in the Thames estuary by pioneer experiments in 1955.

193. At Gibraltar water movements in a natural underground pool, semi-tidal and partly saline, were investigated using iodine-131. By measuring the dilution of the isotope, the capacity of the pool and its associated system was found, together with the throughput of tidal water and the flow of fresh water. The latter information will enable engineers to design methods for extracting potable water from the pool.

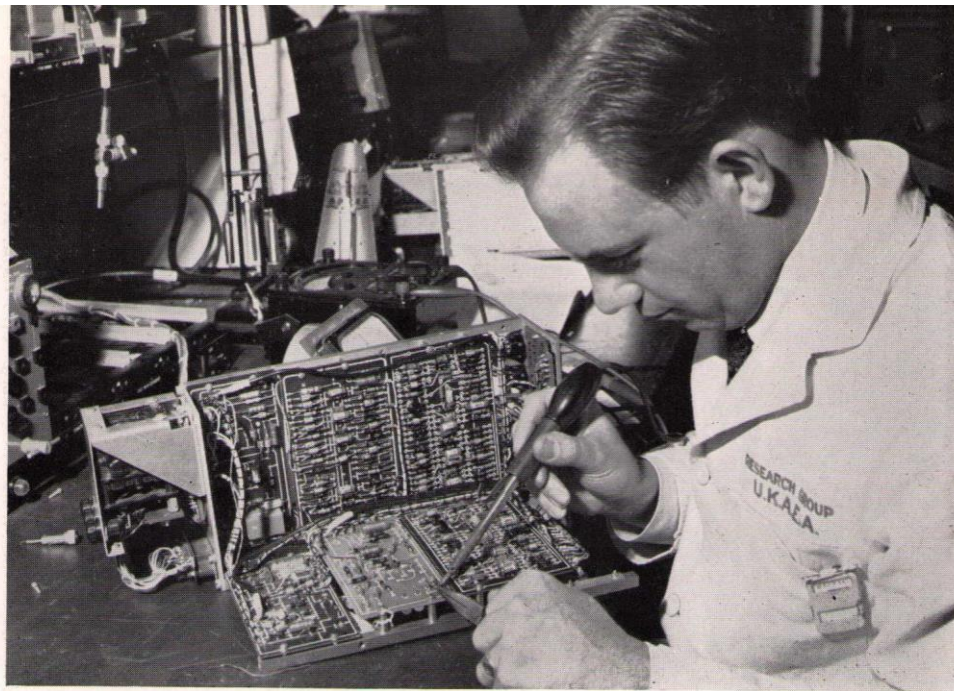
* The Radiochemical Manual, Part I, Physical Data. Available through H.M. Stationery Office and booksellers (price 15s.).

DOUNREAY. Her Majesty Queen Elizabeth the Queen Mother visited the Authority's Experimental Reactor Establishment at Dounreay, Scotland, in August. In December the Dounreay fast reactor reached a power level of 11 MW(H), more than double the power reached by any other fast reactor.



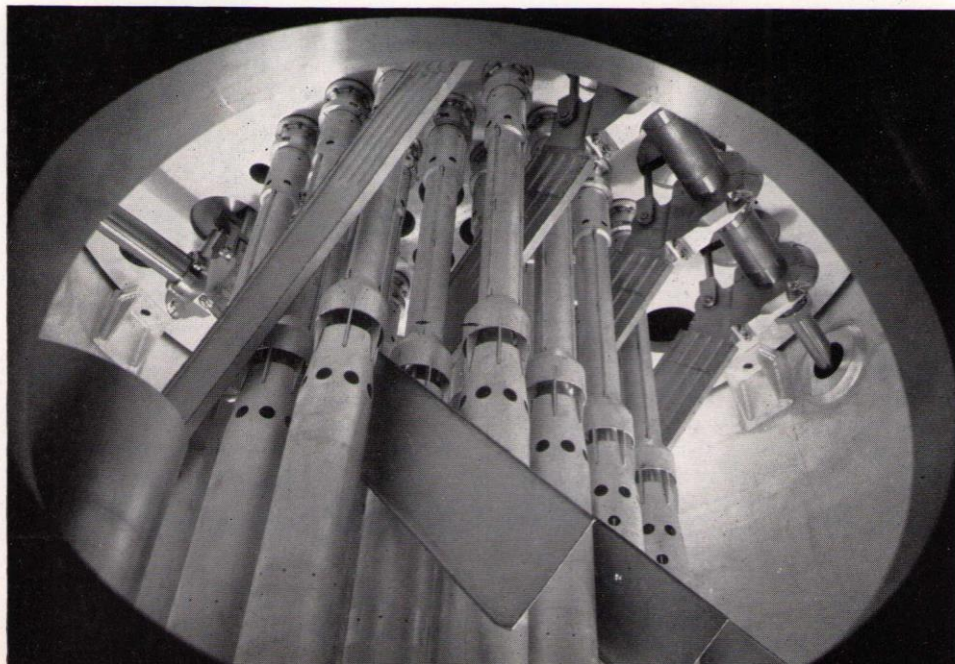
ADVANCED GAS-COOLED REACTOR. Construction of the advanced gas-cooled reactor at Windscale, Cumberland, was completed during the year. It is expected that electricity generated from A.G.R. stations will be as cheap as, and later cheaper than, electricity generated from conventional stations in the United Kingdom.

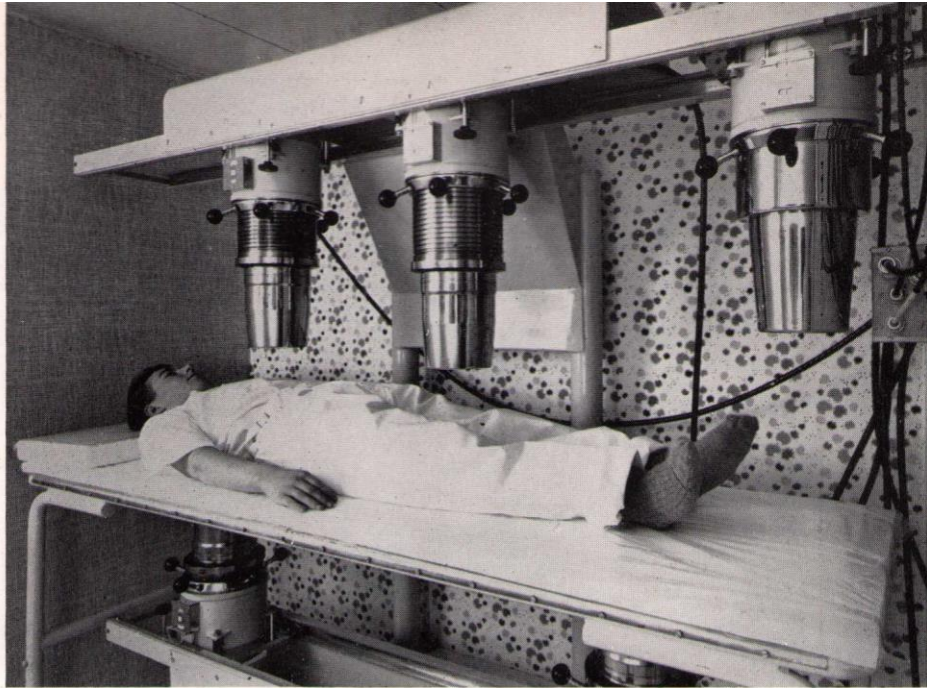




BRACKNELL. Prototype electronic and engineering equipment is manufactured at the Bracknell out-station of the Atomic Energy Research Establishment. An operator is shown changing a diode in a 10 mc/s transistorised " scaler " (an electronic circuit which records the number of nuclear particles detected in an experiment).

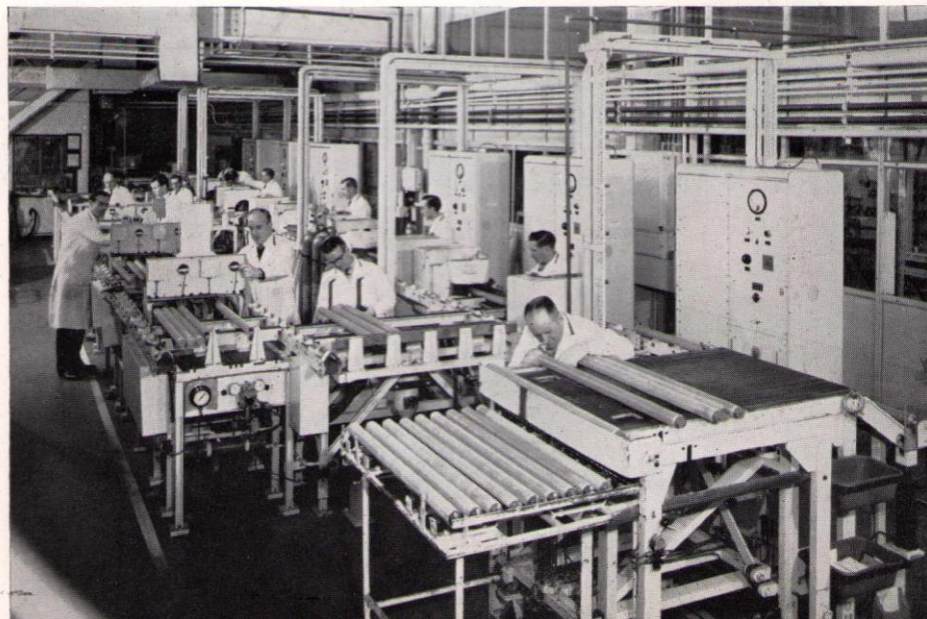
DAPHNE REACTOR. It is not often possible to see the " heart " of a reactor. This photograph of the core of Harwell's zero energy reactor DAPHNE was taken through the inspection port of the reactor vessel. It shows vertical fuel elements and " signal arm " control-members that move between them.

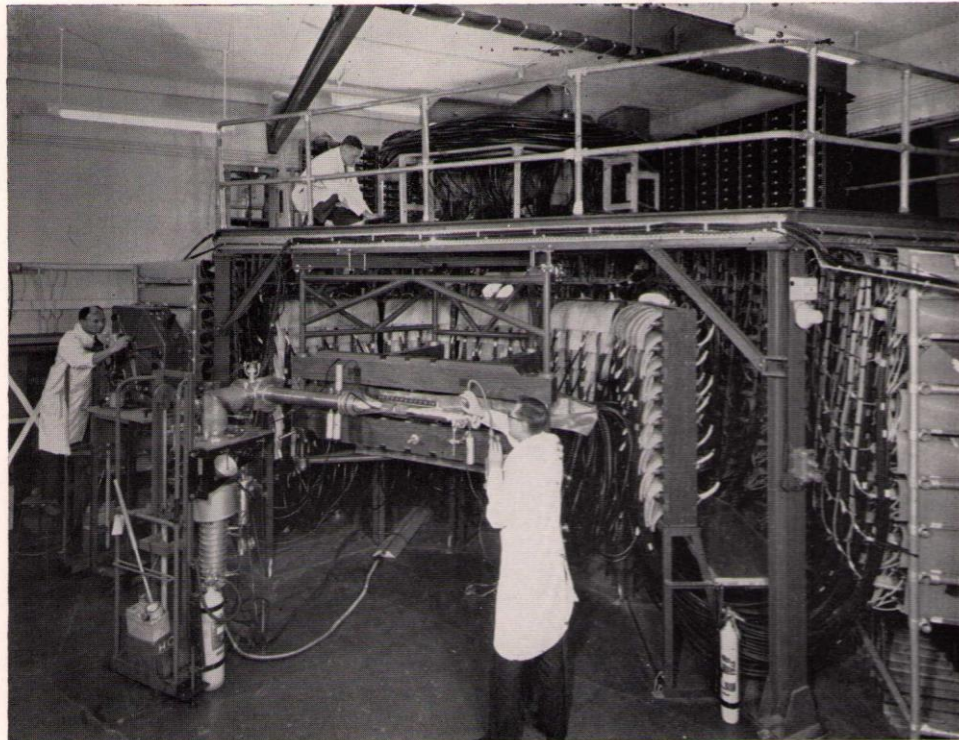




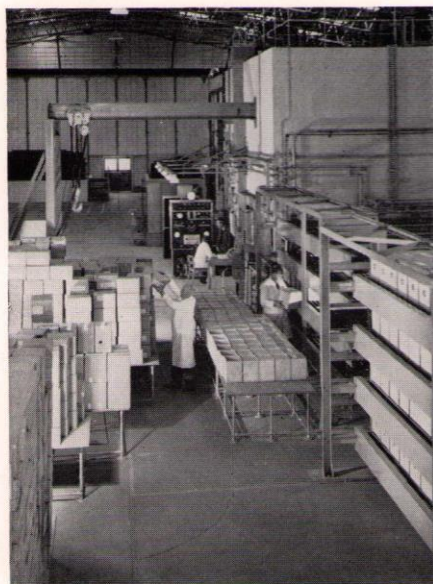
WHOLE-BODY MONITORS. An important health and safety event during the year was the commissioning of whole-body monitors at Windscale, Dounreay and Winfrith, as additions to the installation at Harwell. This is a valuable facility for research and, if accidental intake of isotopes is suspected, for diagnosis.

SPRINGFIELDS. The Springfields fuel element production plant has been greatly expanded in recent years. In addition to their commitments for the United Kingdom nuclear power programme, the Authority are under contract to supply the first fuel charge for the British built reactor at Latina in Italy.





PLASMA PHYSICS AND FUSION RESEARCH. A high voltage low inductance condenser bank used at the Atomic Weapons Research Establishment, Aldermaston, for research into thermonuclear fusion. This is part of the work (carried on also at Harwell and at Culham, where it will eventually be centred) in order to investigate the possibility of electricity generation from fusion reactions.



PACKAGE IRRADIATION PLANT. Radiation from a large cobalt-60 source is used at the Wantage package-irradiation plant to sterilise prepacked goods as a continuous process. Licensees of the Authority are now constructing the first two commercial plants of this kind to be built in the United Kingdom.

194. X-ray sources based on beta-emitting radioisotopes have been developed, covering the X-ray energy range 1 to 150 keV. The output of these sources is much lower than that of an X-ray tube but their compactness and portability give them an advantage in many applications. For example the ash content of unburnt coal can be measured at the washery by X-ray back-scattering using a tritium-zirconium source; accuracy is good and it is possible to compensate for the effect of variations in iron content of the ash. The method is being considered by the National Coal Board for routine use.

195. For the radiation treatment of certain malignant effusions in body cavities, colloids of yttrium-90 have been developed and are being used clinically to an increasing extent as an alternative to colloidal gold-198. Yttrium-90 emits more energetic β radiation than gold and there is no gamma radiation; the latter fact means that less shielding is needed and the material is easier to handle. This may well extend its use to the smaller hospitals.

196. Many of the physical and chemical properties of solid surfaces and metals are greatly affected not only by the presence of extremely small amounts of elements but also by the distribution of these elements in relation to microstructural features. Radioactive tracers can be used to measure the amounts of elements involved but techniques are needed for showing, at high resolution, the distribution of the radiotracers on a chemically reactive surface. An autoradiographic technique is being developed which gives this distribution with a resolution of about 1 micron and the distribution can be located in relation to microstructure with a similar precision. This resolution is sufficient for the study of a number of metallurgical and surface chemical problems. Methods are being investigated for improving radiation sensitivity and decreasing the effect caused by chemical reaction with the surface.

197. The addition of small amounts of a range of organic compounds to nickel electroplating baths produces a deposit which levels a rough base surface. Although levellers are used industrially on a large scale, little is known about their mode of action or the extent to which they are responsible for defects in deposits produced when using them. Experiments using as a leveller thiourea labelled with carbon-14 and sulphur-35 have shown that the carbon-containing and sulphur-containing materials produced by breakdown of the leveller are incorporated in the deposited nickel. The amounts incorporated depend on the rate of nickel deposition and the concentration of thiourea in the plating bath. Thiourea was chosen for the initial study of levelling using radioactive tracers because labelled thiourea was readily available. The results have shown the importance of the hydrodynamics at the solution-deposit interface and the effect of the leveller on plating efficiency. Further work using industrially important levelling additives is now in progress.

198. The commercial use made of the Wantage Research Laboratory's pilot plant for irradiating packages of materials with gamma-rays from cobalt-60 (the Package Irradiation Plant) has increased steadily and more than a thousand packages are irradiated each week. The army is using the plant for sterilising medical dressings intended for home and overseas use. More than fifteen industrial firms are using the plant regularly. Licensees of the Authority are now constructing the first two commercial plants of this kind to be built in the United Kingdom (see paragraph 264).

CHAPTER IX

SUPPORTING TECHNICAL DEVELOPMENTS

Introduction

199. In earlier chapters an account has been given of some of the Authority's scientific research. A large effort is also devoted to technical development in support of the major programmes and of scientific research, some of which is of general interest. A few examples have been selected for description in this chapter. The principal criteria for choosing topics have been either that they illustrate problems and methods peculiar to the atomic energy industry or that they concern devices or processes (some of which may be patented) that are likely to be useful in other industries or fields of work. The chapter also includes reports on the utilisation of some typical major experimental installations. These represent large investments both in capital and in operating and maintenance effort and maximum utilisation is important.

Reactor and Plant Engineering

Concrete Containment Buildings and Pressure Vessels

200. The greater use of concrete for containment buildings and pressure vessels has been considered by the Engineering Group. Some experience has already been gained; the HERO low-energy reactor at Windscale has been built within a low-pressure concrete containment building and results of leakage tests proved most satisfactory. For the Dragon reactor an outer containment building was designed in reinforced concrete and is partly built. This building will be maintained at a pressure a little below atmospheric and will contain any leak from the inner steel containment building; leakage of air into the concrete building will not exceed 0.75 per cent. of its volume in 24 hours at a pressure difference of 4-in. of water. Consideration is being given to the design of a containment building in pre-stressed concrete which would be suitable for a pressure tube reactor experiment. The building would be designed to carry a short term internal pressure of 10–20 lb/sq. in. without cracking and to have a leak rate of not more than 1.0 per cent. of its volume in twenty-four hours at 1 lb/sq. in. gauge.

201. Pre-stressed concrete pressure vessels are also being considered for various new types of reactors. Safety assessment, design criteria and methods, together with the economic and constructional aspects of such vessels, are being studied. The tenders for Oldbury nuclear power station, which includes a pre-stressed concrete vessel, were assessed by the Authority in conjunction with the Central Electricity Generating Board. In a vessel of this sort there would be a working pressure difference of the order of 350 lb/sq. in. and the vessel would have an internal steel lining attached directly to the pre-stressed concrete vessel. A similar pre-stressed concrete pressure vessel is being studied for a commercial advanced gas-cooled reactor in which the working pressure difference would be 400 lb/sq. in.

Reactor Technology

Inspection Methods for Reactor Pressure Vessels

202. A prototype 4.3 MeV linear accelerator has been used to radiograph butt welds in the thick steel plate of the pressure vessels on site at the Trawsfynydd nuclear power station. The experience has shown that high voltage

equipment of this type is suitable for site radiography of steel more than 3-in. thick; welds can be examined quickly and economically to an acceptable standard. Welded joints between nozzles and pressure vessel walls can be inspected by ultrasonic methods if the pipe is filled with water to allow transmission of the ultrasonic waves into the weld from the inside wall of the pipe. The feasibility of the method, and of techniques for mechanical scanning and recording to attain an economic rate of inspection, have been established. The practical application of the method is being examined by the C.E.G.B.

Welding Machine for Fuel Elements

203. The penalty of fuel element failure in reactor service is such that end-seal welds must be of the highest possible integrity; this necessitates the welding parameters being controlled to a high degree of accuracy. By using simple computer techniques and servo-mechanisms a welding machine incorporating such control has been designed and built, in collaboration with industry, at Springfields. A cycle counting timer is used to control weld speed, electrode movement, filler wire addition and welding current. These parameters are controlled to an accuracy of about 0.1 per cent. and are sequentially phased with a timed resolution of 0.2 secs. Any weld programme can be simply and quickly set up by operating a unit similar to a telephone switchboard. The machine is now under consideration for the production of high integrity end-seals for civil reactor fuel elements.

Handling and Disposal of Radioactive Material

Development of Remote-Handling Methods

204. Reference has been made in paragraph 53 to the new remote handling installations at Windscale for examining irradiated fuel. In one of the caves machine movements are remotely controlled by electric motors operated from control panels outside, so that no operating shafts pass through the shielding; in addition measured information from the machines is fed back to a paper record at the operating face. For example, in the fuel can metrology machine the irradiated fuel element is mounted so that both radial and axial measurements can be made of various aspects of distortion and stored electrically in a memory circuit; from this they can be recovered as required and automatically recorded on paper. In support of these facilities two new lines are being commissioned at Windscale which are in effect two small general machine shops, located behind lead walls 10-in. thick, in which the machines are remotely operated. One line will be used for machining irradiated fissile assemblies and the other for irradiated non-fissile assemblies.

Treatment and Disposal of Radioactive Waste

205. In work at Harwell on the treatment of radioactive wastes, two developments of centrifuges show promise. The first of these makes use of the centrifuge to reduce the bulk of the equipment needed to treat solutions containing radioactive materials. The centrifuge is used as an ion-exchange column by coating the bowl with an ion-exchange material; the solution under treatment is forced through the mass of material, which becomes densely packed under the centrifugal forces with the result that throughput is greatly increased over that possible with an ordinary column. The method leads to elimination of the large columns usually needed for this kind of process. The second line of

development is concerned with the treatment of slurries rather than solutions. These slurries arise from chemical processing of radioactive effluent and contain most of the radioactive materials originally present. They are treated to remove this material as sludges which should occupy as small a volume as possible because they have to be disposed of or stored. The new centrifuging technique gives a four- or five-fold greater reduction in volume, with the particular sludges being handled, than any method tried so far; it is also possible to control the operation remotely.

206. On 3rd January a new building was opened at Harwell for decontaminating equipment and handling all kinds of active solid (and some kinds of highly active liquid) waste in preparation for ultimate disposal. The centre deals with wastes and contaminated equipment from all the Authority's establishments in the south of England and also serves other laboratories, hospitals, and factories needing help. It is probably one of the most up-to-date plants of its kind.

Developments in Techniques and New Devices

Epoxide-Resin Laminated-Glass Vacuum Vessel

207. In collaboration with the National Institute for Research in Nuclear Science and a contractor an epoxide-resin glass laminate has been developed at Harwell for the vacuum vessel for the NIMROD accelerator. The development has involved investigating different resin mixes and different types of glass laminate to discover one suitable for the low pressure required; it has also been necessary to develop standard methods for testing the resin bonded sections. The epoxide surface finishes are also excellent for decontamination purposes in active areas. Development of the use of this material in collaboration with industry has made possible the fabrication of the unusually large vacuum-tight containment required in the NIMROD accelerator. This containment comprises inner and outer shells forming an annular ring 155-ft. in diameter, each shell being made up of eight sections. Some difficulties have been experienced in mixing and applying the resin coating but manufacture of the containment is now proceeding satisfactorily. A curing agent based on propanolamine di-isocyanate appears a promising method of still further facilitating manufacture of similar vessels.

High Voltage Surge Generator

208. In connection with the short duration flash-radiography work at Aldermaston, a new form of high speed, high voltage surge generator has been developed in which the outputs from a number of basic circuits are stacked in series. One type, which uses a single solid-dielectric switch and has a gain of 11, has produced output pulses of up to 1.2 MV with a time of rise of 10 nanoseconds. A second type uses ten switches and has produced pulses of 1.8 MV rising in 5 nanoseconds. The output impedance of the latter generator is 40 ohms and the output-pulse is produced between terminals 6 inches apart. To provide the very low inductance switching necessary for these generators, a new solid-dielectric switch has been developed. This can be used only once but a single switch will provide a rate of rise in current of up to 10^{14} amps per second. This can be increased by using a number in parallel. The switches have a breakdown voltage with a standard deviation of about 2 per cent. and their performance has been tested over a voltage range from 20 kV to 300 kV;

many switches can be triggered together with a simultaneity in the region of a nanosecond or less. A single switch has carried half a million ampères and there is every expectation that much higher current can be passed. The construction of the switches could be mechanised so that they could become cheap enough to be expendable at a rate of a few per second.

Neutron Tubes

209. There is a need for small neutron generators for many purposes, including reactivity measurements in reactors. The most important component of all such generators is the neutron tube, the development of which has been sponsored by the Authority. The tubes can be produced to give 14 MeV neutrons in pulses of which the duration and duty cycle can be varied between wide limits. A generator is being made available commercially in which fast neutron pulses can be produced with a 20 microsecond duration and a flux of 10^8 neutrons per pulse. Only a comparatively small amount of associated electronic equipment is necessary to operate the tube, and the massive and expensive shielding and extensive safety precautions necessary up to now in connection with the generation of neutrons are obviated. The neutron tube when switched off is completely inert and safe. This generator is also suitable for educational purposes as well as for research.

Developments in Manufacturing and Workshops Operations

Radiographic Inspection

210. The problems of radiographing radioactive materials have been studied at Dounreay. The main difficulty is that gamma rays can blacken film as effectively as X-rays. Following a series of experiments a new technique has been developed. The film is now protected from the radioactivity by a rotating lead disc in which is cut a number of collimating slits. The rotation of the disc causes the slits to scan the active specimen allowing the exposure to be made. The lead in the disc protects the film from most of the gamma rays except those emanating from the portion of the specimen exposed by the slits. This improves the discrimination, that is the ratio of X-rays to gamma rays reaching the film, by a factor of at least ten.

Planetary Swaging Machine

211. A prototype planetary swaging machine has been developed to make small quantities of thin walled stainless steel tubing for experimental work on fuel element canning. With this machine standard stock tubing of any gauge can be reduced to a wall thickness of 0.006 in. with excellent surface finish and to accurate dimensions. The machine can also be used to swage material to various contours, an operation that is impossible with ordinary methods of swaging. The machine is capable of producing work which could otherwise only be done by using a variable tube-drawing die and it is likely to find a number of industrial applications.

Electronics and Related Development

212. Development of electronic techniques is important to all aspects of the Authority's programme. This development covers the range from basic research into detector materials to the devising of complete instrument and control systems for reactors and other plant. For example, in a chemical plant for

processing irradiated fuel many of the measurements needed to check the contents of streams of process liquids can be done by radiometric methods (counting of nuclear particles and radiations). A fresh study at Harwell of the problems involved has been applied to the new chemical separation plant being built at Windscale and has resulted in a comprehensive instrument scheme, covering the whole plant, which combines measurements of radioactivity with more usual methods. Continuous alpha-particle, gamma-ray or neutron measurements are made at about 170 different points; each instrument employs identical electronic equipment and supplies information on process behaviour to the control centre.

213. At Winfrith a study of automatic control technology is being carried out. As part of this work methods have been developed for improving the reliability of control equipment using the principles of redundancy and comparison. Fully automatic control systems (employing transistors and A.C. servomechanisms) have been fitted to DIDO and BEPO. Theoretical work on automatic control has improved and extended the methods available for design and simulation of control systems for large power plants; this has involved developments in techniques of applied mathematics and has made extensive use of digital rather than analogue computation. In continuing the development of transistor and solid state reactor control instruments and safety circuits an almost complete range of instruments has been designed together with a protective system in which transistors and ferrite cores replace electro-mechanical relays. The electronic equipment and safety circuits of the DIMPLE reactor will use solid state devices almost exclusively.

The Authority's Research Reactors

Utilisation of Materials Testing Reactors

214. The Authority have four reactors whose main purpose is the testing of materials under irradiation; these are DIDO, PLUTO and BEPO at Harwell and D.M.T.R. at Dounreay. The operation of these four reactors costs about £2 million a year and employs about 250 staff (including about 60 qualified staff). The Authority therefore have devoted a great deal of attention to achieving a high utilisation of these important machines. Many of the difficulties in securing high utilisation arise simply from lack of space. For example, the average number of experiments in DIDO at any one time is about 45, all of which must be fitted into a cylinder of about 7-ft. in diameter. These difficulties are overcome by careful design of the rig and its associated instruments, which wherever possible are miniaturised, and by planning the sequence and arrangement of different experiments. Difficulties are also experienced because each experiment is designed to operate at a specified neutron flux and the experiments loaded into the reactor affect the intensity and distribution of the neutron flux in the core and in neighbouring experiments; these problems are dealt with by calculation and flux measurement but the coming into operation of DAPHNE (see paragraph 216) will make possible simpler and better methods of dealing with them. An overriding consideration in reactor operation, which may also set limits to utilisation, is the need to ensure that safety requirements are fully met at all times. It is not possible to express effective utilisation in any simple way but a steady improvement has been achieved through growing experience and by care in design and planning.

Release of Stored Energy in BEPO

215. In April, 1961, Wigner energy stored in the graphite moderator of BEPO was successfully released for the third time; the reactor had generated a total of 164,000 MWh of heat since the last release. This release was initiated by heating the inlet air, flowing at less than one tenth of the normal rate, and was completed well within 24 hours. All temperatures reached were within the limits predicted. To increase the interval between successive releases, and hence the reactor's economic efficiency, the operating temperature has been raised by heating the inlet cooling air continuously to 45°C by means of a heat exchanger installed in the inlet duct.

DAPHNE Reactor

216. To save valuable operating time in DIDO and PLUTO there was a need for a cheaper zero energy reactor in which preliminary measurements could be made of the effects of loading experimental equipment into the bigger reactors. Construction of a suitable reactor, called DAPHNE, began in February, 1961, and the reactor became critical on 20th February, 1962.

High Speed Computer

217. A need for much more powerful computing machines, especially in connection with detailed reactor studies, was foreseen some years ago and led Authority scientists to discuss future computing requirements in general with the universities and other research organisations. In the atmosphere of encouragement that ensued, an advanced design proposed by Manchester University was developed, in collaboration with the university, by Ferranti Limited into the machine now known as the Atlas computer. The Authority proposed to buy one of these machines for their own use and for use by other organisations, including universities. Subsequently, at the government's request, the management of the project was transferred to the N.I.R.N.S. The machine was ordered in 1961 and will be installed in a new laboratory of the Institute (the Atlas Computer Laboratory) adjacent to the Atomic Energy Research Establishment in 1964. In the interim, time on the I.B.M. Stretch computer, now being installed at Aldermaston (see paragraph 222), will be made available to all groups of the Authority and to the Institute.

CHAPTER X

NUCLEAR WEAPONS AND TEST DETECTION

Nuclear Weapons

218. The Authority remain responsible for the production of fissile material for weapons and for fulfilling the programme of nuclear warhead development authorised by Her Majesty's Government.

219. Close collaboration has continued with the United States of America under the Mutual Defence Agreement of July, 1958 (Cmnd. 537) and has been extended to co-operation in the American underground test series. This series included the firing, by a joint U.S.A./United Kingdom team, of a British device

at the Atomic Energy Commission's Nevada Test Site on 1st March, 1962. There has also been collaboration with the U.S.A. in studying the recent Russian nuclear tests.

220. The Authority are also working with the American departments concerned on certain scientific aspects of the preparation at Christmas Island for the proposed U.S.A. programme of atmospheric tests.

221. The facilities available in the Weapons Group for the British nuclear warhead programme are continually under review and are modified or extended as occasion demands. As an example, in recent years equipment has been developed in collaboration with industry for the environmental testing of warheads and their components to ensure that they will withstand the conditions of vibration, shock and extremes of temperature likely to be met with during their service life.

222. Arrangements have been made to hire a high capacity computer (Stretch) from International Business Machines Limited, and this is now being installed at Aldermaston to replace the existing 7090 computer which is to be transferred to the Reactor Group.

223. Some of the supporting research and development work at the Atomic Weapons Research Establishment has no security implications and can be published. As a result of work in such fields and in the civil aspects of Weapons Group work it has been possible to approve the publication of nearly 200 papers by staff during the year, either in open literature or at scientific conferences.

Test Detection

224. With the continued support of the Ministry of Defence, which has a central interest in the effectiveness of all measures for controlling and verifying any possible disarmament agreement, including a nuclear test ban, the Authority have been extending their work on test detection described in the Seventh Annual Report.

225. "Operation Seagull", mentioned in paragraph 199 of that report, was carried out early in 1961 in collaboration with the Admiralty. In this operation two similar tests were performed, one in the English Channel and one in a Scottish loch. A series of depth charges was detonated and the resulting seismic waves were recorded at various sites in the U.K. The records obtained in these experiments have demonstrated the possibility of measuring the depth at which a disturbance has occurred within the earth's crust. Since the epicentres of many earthquakes occur at much greater depths than those at which the detonation of nuclear devices is likely to be possible, measurements of the depth where seismic signals originate provide a means of distinguishing between, on the one hand, deep earthquakes, and on the other hand, shallow earthquakes or weapon tests (but not between these two). The method can be applied at distances up to 1,000 kilometres provided that the direct waves transmitted through the earth's crust can be identified and distinguished from the waves refracted at the Mohorovicic discontinuity (the Moho). This discontinuity is situated at a depth of about 25 to 50 kilometres and refraction of seismic waves occurs there because there is a sudden increase in the velocity of transmission of body waves at this boundary. The seismometer arrays now in use or being installed by the Authority are designed to identify these signal components by velocity filtering.

226. American seismologists are currently examining the application of this technique in an extensive programme which includes detailed investigation in fold mountain areas of recent geological origin where propagation paths are more diverse than in the European plain and similar areas. An opportunity for the Authority to participate in this investigation was presented by "Project Gnome" in the U.S.A. This project involved the explosion of a 5 kiloton nuclear device 1,200-ft. below ground level in a salt formation near Carlsbad, New Mexico, and was the first nuclear explosion of "Operation Plowshare", the U.S.A. programme on the peaceful uses of atomic energy. With the co-operation of the U.S.A. authorities, two linear arrays were established on Pole Mountain near Laramie, Wyoming, at a distance of about 1,000 kilometres from the Nevada Test Site and from Carlsbad. The Pole Mountain array has since continued in operation, to study focal depth measurements in the mountain area of the U.S.A. and also to study techniques for improving signal to noise ratio.

227. A criterion for distinguishing between the signals from the earthquakes and nuclear explosions is based on the fact that the first motion in the seismic wave from an explosion is outwards in all directions, whereas in earthquakes the first motion will be outwards in some directions from the source and inwards in others. It has been demonstrated by both "Seagull" and "Gnome" that it is possible by combining measurements on all instruments in an array to obtain a composite record which shows the waves more clearly and thus improves the registration of the first motion. In technical language, the cross correlation integral from summed outputs of groups of seismometers improves the identification of the onset of the first arrival.

228. First motion detection may also be improved by recording in deep bore holes. The amplitude of microseisms of the surface wave type decreases with depth and thus the "noise level" at the bottom of a deep hole is less than it is at the surface. A borehole seismograph has just been completed and is to be compared with surface arrays for the first motion detection.

229. A study of the possible use of surface waves for identifying some types of earthquakes began last year, supported by experimental work using long period seismometers of a conventional pattern. The large Russian nuclear explosions in the atmosphere over Novaya Zemlya were recorded in the course of these experiments.

230. The basic studies of the mechanism causing the shock, the transfer of energy to the ground, and of the propagation paths, have continued as part of the experimental programme.

CHAPTER XI

RAW MATERIALS

Uranium

231. During the year, uranium production in the United States of America rose to an all-time peak because of a long range domestic programme announced in 1956, but the uranium industry elsewhere continued to adapt itself to the lower level of demand, and production outside the U.S.A. dropped from some

27,000 tons of oxide in 1959 to less than 19,000 tons in 1961. Contraction has been most marked in South Africa, Canada and Australia, which have been affected mainly by the decision of the U.S.A. not to extend foreign contracts, but also by the lower requirements of the Authority. The major part of the readjustment has taken place within the framework of the stretch-out agreements reached between the U.S.A. and the United Kingdom on the one hand, with Canada and subsequently South Africa on the other (see Seventh Annual Report, paragraph 207). As a result of these agreements, and of the expiry of certain other contracts, eleven uranium producers have closed down during the year.

232. Two of these producers had close associations with the U.K.: Radium Hill in South Australia and Urgeiriça in northern Portugal. Production at Radium Hill was undertaken in 1954 in consequence of a contract signed with the Combined Development Agency in 1952; the seven year contract expired at the end of 1961 and the mine was then closed following the report of a Parliamentary Committee which found that there was no possibility of profitable production in the foreseeable future. The mine at Urgeiriça was operated by the Companhia Portuguesa de Radium Limitada on behalf of the C.D.A. This mine had a long history, having been worked for radium as early as 1912. The present company dates back to 1929 and was acquired by the U.K. in the course of pre-emptive operations against the Germans during the war. It was taken over by the C.D.A. in 1945 and became one of the pioneer uranium undertakings at a time when every ton of material was vital for the western defence effort.

233. Despite these painful readjustments in the mining industry, and all the measures which have been taken to reduce the burden of the Authority's current contractual obligations, the Authority are still committed to import uranium in excess of their current requirements. The already considerable stock is therefore still being increased and will not be used up until after 1970. In the current year over 3,000 tons of oxide had to be bought, the major suppliers still being South Africa, Canada and Mary Kathleen in Australia. Discussions also continued throughout the year about the purchase of the additional 12,000 tons of oxide from Canada, referred to in the exchange of letters which took place between the Authority and Eldorado Mining and Refining Limited in 1957 (see Seventh Annual Report, paragraph 211).

234. Two effects of the current uranium surplus should be mentioned. Firstly, purchases through the C.D.A., which was for many years the sole channel of U.K. supplies, are drawing to a close. The major step in this direction was taken, as reported last year, when the C.D.A. contracts with South Africa were replaced by separate U.S.A. and U.K. contracts. Only the Portuguese, Radium Hill and Rum Jungle supplies were still purchased through the C.D.A. during 1961, and in the next year only the Rum Jungle supplies will come through this channel. C.D.A. no longer finds it necessary to have any full-time staff.

235. Secondly, as a consequence of the stretch-out agreements and of the enforcement of ceiling delivery rates under current contracts, many uranium producers are now able to produce considerably more uranium than their contracts allow them to sell. These producers are able to meet their primary costs from their major contracts, and to offer any excess quantities for sale at

marginal cost. Prices low in the range \$4 to \$5 per lb. of oxide have therefore been quoted in some cases. The bulk of uranium production is still being exported at prices ranging from \$10 to \$12; but the United States Atomic Energy Commission have reported their average internal price to be under \$9.

Thorium

236. The prospect of any significant demand arising for thorium as a nuclear material has receded steadily over the last few years and by 1959 it had become clear there was no longer justification for retaining the Authority's buffer stocks of monazite and thorite. Disposals commenced therefore in 1959. By the end of 1961 about half the stock had been sold off and a contract for the disposal of the remainder was negotiated early in 1962.

Technical Services

237. Technical services on a reducing scale were provided for the Authority by the National Chemical Laboratory, the Geological Survey of Great Britain, the Warren Spring Laboratory of the Department of Scientific and Industrial Research, and the Mining Division of the Colonial Development Corporation. Measures were taken to bring to an end the assessment of the potential beryllium resources of Southern Rhodesia.

CHAPTER XII

COMMERCIAL OPERATIONS

Introduction

238. The Authority's commercial sales in the year amounted to over £20 million. Of this figure some £10 million was earned on sales of fuel elements for power reactors, £6 million from electricity sales, £2.5 million on graphite and £1.4 million on isotopes. There was also some income from consultancy services and from fees for the use of Authority owned patents and technological information.

Sale of Fuel Elements

239. There are now ten natural uranium magnox type stations under construction by electricity generating boards in the United Kingdom and abroad for which fuel elements are to be supplied by the Authority. Fuel manufacture is carried out at the new factory at Springfields, where during the year there were continuing improvements in manufacturing efficiency. Accumulating irradiation experience from Calder Hall also gives increasing confidence in the Authority's predictions of fuel element performance under prolonged irradiation.

(i) Power Reactors—U.K.

240. This year has seen the completion of delivery of the initial charges for the first two stations of the Central Electricity Generating Board's nuclear power programme, Bradwell and Berkeley. Supplies of fuel sold to the C.E.G.B. during the year totalled some 500 tonnes.

241. The first two contracts with the C.E.G.B. establishing the technical and commercial conditions for supplying fuel were signed in May, 1961.

242. There are special features which have had to be considered when settling the financial and contractual terms of these contracts with the electricity generating boards. The two boards, C.E.G.B. and the South of Scotland Electricity Board (S.S.E.B.), and the Authority are all public organisations which have a common interest in the success of the nuclear power programme. The Authority's approach was that, at least in the early years of the programme, they should not aim to make profits out of these sales, but only to recover their full costs (including the cost of developing the fuel elements).

243. Accordingly the fuel supply contracts have been negotiated to cover a period of years so that the Authority should be assured of the recovery of the heavy costs of their capital facilities and of a market for their uranium supplies. (Similar negotiations are in hand with the S.S.E.B.) The contracts deal both with the sale of the fuel to the board and its repurchase by the Authority after irradiation in the board's reactors. With the exception referred to in paragraphs 244 and 245 prices will be quoted annually a few months before the commencement of the financial year in which the deliveries will take place. The prices are calculated to recover full costs. The terms of the contracts are such that both the supplier and the user of fuel have a financial incentive to extract the maximum amount of useful heat from each tonne of fuel provided.

244. The Authority supported the adoption of a large nuclear power programme and accepted an obligation to help stabilise and keep to a minimum the capital costs of the early stations. Thus in 1956 they quoted firm prices, for the first charges for Bradwell, Berkeley and Hunterston, which were calculated to yield only a modest return on capital and did not include large allowances against contingencies even though there would be many uncertainties. The prices were subject to adjustment only to cover changes in design and in the level of labour and material costs.

245. The prices quoted were based on the tonnage of fuel elements which it was estimated in 1956 would be manufactured during the first few years of the programme. In the event the stretching out of the nuclear power programme by government decision and the delays in completing the early stations have resulted in fuel deliveries during 1960/61 and 1961/62 being substantially smaller than the 1956 estimates. This reduction in throughput has raised the unit cost of the initial charges for the first stations above the estimates on which the 1956 prices were based. In addition the earlier estimates of the capital costs of the new facilities required for fuel element production have proved in the event to be on the low side but this to some extent has been offset by the improvement in manufacturing efficiencies beyond the 1956 estimates. The Authority consider that the risk involved in quoting firm prices for these initial fuel charges in 1956 was one which it was proper to accept as part of their contribution towards getting the nuclear power programme under way.

246. It will be seen from the Notes on the balance sheet at 31st March, 1961, (see Appendix IV) that the Authority incurred a net trading loss of £1.9 million in 1960/61. This arose almost entirely from the sales to the C.E.G.B. of the initial charge for the number 1 reactors at Bradwell and Berkeley. A further

loss has been incurred during 1961/62 on the delivery of the remainder of the initial charges for these two stations, which is covered by the provision made in the accounts at 31st March, 1961 (see paragraph 23).

247. The Authority believe that the current arrangements for fixing prices for all subsequent fuel supplies to the electricity generating boards should avoid losses in the future.

(ii) *Power Reactors—Overseas*

248. In December, 1961, the Authority concluded a contract to supply 400 tonnes of natural uranium fuel elements for the Latina nuclear power station in Italy, which is in course of construction by The Nuclear Power Group for the Societa Italiana Meridionale Energia Atomica. Two-thirds of this quantity will form the initial charge for the reactor and the remainder will provide replacement fuel for nearly two years' operation. Delivery of the initial charge is to be made during 1962. This contract incorporates certain guarantees of fuel element workmanship and performance, but unlike the contracts for the supply of fuel to U.K. nuclear stations, it does not provide for the fuel to be bought back by the Authority after use.

249. The Authority are also to supply the fuel for the nuclear power station which the General Electric Company Limited are constructing at Tokai Mura for the Japan Atomic Power Company. Development work on the special fuel elements for this reactor, which instead of solid bars will contain hollow rods of uranium, made good progress during the year. It is expected that contract negotiations will be concluded during the financial year 1962/63, though the first deliveries of fuel will not be required until 1964.

250. The Authority have continued to support the efforts of reactor constructors to obtain further overseas contracts. As suppliers of nuclear fuel and reactor grade graphite they have associated themselves with tenders by industry for nuclear power stations abroad and have joined in preliminary discussions on fuel with several prospective buyers.

Other Sales

(i) *Fuel for Research Reactors*

251. There were further sales during the year of enriched uranium fuel elements for refuelling the Hifar materials testing reactor of the Australian Atomic Energy Commission and for the DR.3 materials testing reactor operated by the Danish Atomic Energy Commission. The Authority also received a contract for the supply of fuel elements for a similar reactor to be operated at Jülich by the German Land Nordrhein-Westfalen. Deliveries of fuel for this reactor will start in 1962/63.

(ii) *Miscellaneous Sales*

252. The Authority continued to lease natural uranium to several U.K. universities which have installed sub-critical assemblies for teaching purposes.

253. Other miscellaneous sales included special uranium elements for experimental use by the nuclear power consortia and other companies, uranium oxide and non-fissile materials such as beryllium, vanadium and niobium. Miscellaneous services undertaken for industry included analysis of nuclear materials.

254. Considerable efforts were made to encourage the use in industry of depleted uranium. This is uranium in which the proportion of the fissile isotope-235 has been reduced to below the natural level of 0.7 per cent. and is one of the main by-products of the Authority's uranium processing. It is already used, for example, as an alloying constituent in steel, in the manufacture of radiation shields and aircraft balance weights, as a pigment for ceramics, and as a catalyst in chemical reactions.

255. The Authority also undertook on behalf of the French Commissariat à l'Energie Atomique the reprocessing of a batch of irradiated fuel elements from the E.L.2 research reactor at Saclay.

256. During the year the Authority agreed with the General Council of British Shipping a form of indemnity to cover the carriage of fissile materials and irradiated fuel in British ships on the Authority's behalf. This indemnity, the terms of which are broadly in line with the provisions of the Organisation for Economic Co-operation and Development Convention on Third Party Liability in the Field of Nuclear Energy, 1960, (see Seventh Annual Report, paragraph 298 (iii)) is intended to meet the reasonable requirements of shipowners until the entry into force of this and other conventions removes the need for it.

(iii) *Electricity*

257. The by-product electricity from Calder Hall and Chapelcross is sold to the C.E.G.B. and the S.S.E.B. for supply through the grid. As stated in paragraph 43, the development of operating techniques, and modifications to the turbo-alternators at both stations, have increased the amount of electricity for sale.

(iv) *Graphite*

258. Over 6,000 tons of nuclear grade graphite were delivered during the year for the power programme. Deliveries were completed for the Trawsfynydd station and began for the Dungeness station. In addition, over 1,000 tons of graphite were supplied for the power station being constructed at Latina in Italy. A small quantity of graphite, some 200 tons, was supplied to the Dragon project and to other customers for research purposes.

259. In order to be assured of the necessary capacity for high grade graphite production for the nuclear power programme, the Authority entered into contracts in 1956 and 1957 providing for the purchase of the minimum quantities then thought to be necessary. Both technical and programme changes have since reduced the requirements, and these contracts will therefore involve some loss in the next few years, which will be shared between the Authority and the C.E.G.B. Provision to cover the Authority's share of these future losses on graphite trading was made in the balance sheet for 1960/61 (see paragraph 23).

(v) *Radioisotopes*

260. The general trend of demand for the products of the Radiochemical Centre in 1961 followed the pattern of previous years. The use of the irradiation service based on the research reactors at Harwell declined somewhat, as was to be expected with the increasing provision of similar facilities in Europe and elsewhere, and there were no large sales of cobalt-60 for industrial purposes, as no plants were commissioned in this year. Apart from these two factors,

the sales of all other types of radioisotopes, labelled compounds and radiation sources increased by about 20 per cent. over the previous year. The proportion exported was a little over 50 per cent. and the principal markets were the United States of America, Canada, Federal Germany, France, and Japan. Forty-two thousand consignments of radioactive materials were despatched from Amersham and Harwell.

261. In 1960/61, after charging depreciation and an appropriate levy towards research costs, sales of isotopes yielded a return on capital of just over 7 per cent.

262. The agreement with the C.E.G.B. (see Seventh Annual Report, paragraph 217) for the processing and marketing of radioactive materials, which are to be produced in the board's reactors, has now been signed.

Royalties, Patents and Licensing

263. The government's White Papers on nuclear power (Cmd. 9389 and Cmd. 1083) did not lay down any policy for recovering the costs of development, but government financed bodies normally seek to recover as much as possible of their costs of development where it leads to commercial exploitation. The Authority have adopted the principle that, once the stage of preliminary research and feasibility study has been passed and a reactor system has been adopted for major development with a view to commercial exploitation, they should aim, as far as conditions permit, to recover such major development costs by means of royalties on nuclear power stations constructed for commercial use, and development expenditure on fuel in the prices at which fuel for them is sold. The Authority have concentrated their major developments on a narrow front and, in their planned progression towards competitive nuclear power, they have selected those systems which careful preliminary research and development work have shown to have a real prospect of achieving economic benefits for the nation and of being adopted for commercial application by the electricity generating boards.

264. In addition to major development of reactor systems the Authority's research and development lead to many inventions of commercial value. These are protected by patents both in the U.K. and overseas, and licences are issued where appropriate on commercial terms. Some of the licences are for patents and know-how which can be applied to general industrial engineering. Among such agreements negotiated during the period were those for the manufacture of package irradiation plants, based on the Authority's plant at Wantage, in which radiation from a large cobalt-60 source (up to 500,000 curies) is used to sterilise prepacked goods as a continuous process (see paragraph 198). Licensees of the Authority are now constructing the first two commercial plants of this kind to be built in the U.K. and they have high hopes of selling irradiation plant overseas. One of the first commercial plants to operate outside the U.K. was built in Australia with the Authority's assistance, and uses 600,000 curies of cobalt-60, supplied by the Radiochemical Centre, Amersham, to kill the anthrax bacillus found in goat hair used for the manufacture of carpets.

265. An agreement has also been concluded with a company for the manufacture under licence of the first compact and inexpensive neutron generator to become generally available in the U.K. This neutron generator can be used to produce very short-lived isotopes and should be of value to research workers and teachers.

266. Although payment of royalties on C.E.G.B. nuclear power stations is not due to begin until 1964, the Authority's royalty income from other sources during the year amounted to £115,000.

267. The Seventh Annual Report, paragraph 232, referred to negotiations with foreign organisations for the licensing of the manufacture of natural uranium fuel elements under Authority patents. These negotiations have not yet resulted in a licence.

Consultancy

268. The Authority are consultants for the construction of nuclear power stations to electricity generating boards in the U.K., i.e., C.E.G.B. and S.S.E.B., and to the two overseas customers for whom British designed nuclear power stations are being constructed; Agip Nucleare for the station at Latina in Italy and the Japan Atomic Power Company for the Tokai Mura station. Charges for the consultancy services provided during the year amounted to £400,000.

Collaboration

(i) With Industry

269. The Authority have continued their close collaborative work with the consortia of companies which construct nuclear power stations both at home and abroad. As in earlier years the association has been two-fold: the consortia are the Authority's licensees for gas-cooled, graphite-moderated reactors and as such are kept informed of progress and development work on this system by the Authority. The consortia and the Authority also collaborate in joint development work both on the gas-cooled, graphite-moderated reactors and on more advanced reactor systems. During 1961 an agreement was signed with the consortia for collaboration on a development programme supporting the steam generating, heavy-water-moderated reactor system (S.G.H.W.). A joint appraisal has also been carried out by the Authority and the consortia of water and organic cooled and moderated reactor systems. The Authority and the consortia are also examining the possibilities of collaboration in the field of fast reactors. In these agreements the Authority's rights are protected so that subsequent commercial exploitation of these reactor systems can result in benefits to public funds by way of royalties.

270. The Authority's licence and access agreements with two British companies relating to the design and manufacture of chemical plants have continued to operate. These agreements make available to the companies the Authority's experience in the production of uranium metal from ore and in the reprocessing of irradiated nuclear fuels.

271. The Authority participate in two schemes involving access to computer programmes. One scheme covers programmes of general academic interest and is open to other users of similar facilities. The other scheme is of particular application to the design of nuclear power stations and is available only to the Authority's reactor licensees.

(ii) With Consulting Engineers

272. An agreement is being negotiated with four British consulting engineering firms interested in nuclear power station work. It is proposed that in return for certain charges the Authority would keep the firms informed of, and advise

them on, developments in nuclear technology relevant to their business. Where the firms are engaged in nuclear power station projects overseas the agreement would provide for the Authority to give supporting consultancy on the nuclear side of the work.

(iii) *With the Admiralty*

273. Agreements in connection with the submarine programme, between the Authority and the Admiralty and between the Authority and the Admiralty's contractors, have now reached the final stages of negotiation. These agreements define the areas within which the Authority's services are to be made available and also contain provisions relating to financial matters, security, control and exchange of information and the disposition of emergent patents, inventions and designs.

Attachment Agreements

274. Staff from government departments, from industry and from overseas have been attached to Harwell and to the Wantage Research Laboratories during the year; and from the electricity generating boards, as well as from industry, to the Authority's design offices and laboratories. Members of the future operational staff of the nuclear power stations under construction by British consortia in Italy and Japan also received training at Calder during the year.

CHAPTER XIII

HEALTH AND SAFETY

Health and Safety of the Authority's Staff

275. About 20,000 Authority employees are classified as radiation workers. The maximum permissible whole-body dose (3 rems in 13 weeks) was exceeded by a small margin on eight occasions in 1961; this compared with nine occasions in 1960, fourteen in 1959 and twenty-five in 1958. In all cases arrangements were made to reduce subsequent exposure and to ensure that long-term dose limits were not exceeded.

276. A wide variety of non-radioactive materials is also handled by the Authority's staff. Some of these are highly toxic but, in the year under review, there were no cases of illness from this cause.

277. In the field of conventional industrial safety, the accident frequency rate (i.e., the number of lost-time accidents per 100,000 man-hours worked) was 1.02, and the mean duration 156 hours.

278. In March, 1962, settlement was reached of a claim made against the Authority concerning a deceased employee who had developed myeloid leukaemia while employed for three years at the Authority's establishment at Windscale. The claim alleged that this disease, and cataracts which later developed, were due to exposure to ionising radiations in the course of his work.

279. Careful records of exposure of personnel to radiation are maintained at all the Authority's establishments and it is clear from these that the exposure in this case was below the maximum permissible level recommended by the Medical Research Council.

280. The Authority's medical consultants felt that the cataracts were of the common type and not due to radiation. They also concluded that it was unlikely in the extreme that the leukaemia could have been caused by the slight exposure to radiation incurred. The plaintiff's medical advisers concluded otherwise.

281. The complexity of the medical issues involved was such that the burden of legal proof on either side would have been very heavy. The Authority, therefore, without making any admission of liability and without prejudice to any future claims, decided to negotiate a settlement, and terms were agreed.

Protection of the Public

282. The Authority are responsible every year for many thousands of consignments of radioactive materials. During the year there have been no incidents involving any hazard from radioactivity to the public or to employees of transport undertakings. The Authority have for many years had their own rules for transport operations. This experience has been made available for the development of national and international regulations, both statutory and otherwise. It was also reflected in the International Atomic Energy Agency regulations published in May, 1961, which are being followed as a model.

283. Three minor incidents involving the release of radioactivity beyond the confines of the Authority's establishments occurred during the year. These are described in the following paragraphs. In no case was there any hazard to the public, although it was necessary to impose minor and temporary local restrictions. In each case a thorough investigation was carried out.

284. On 19/20th June, 1961, a plant defect at Windscale led to the discharge of a quantity of radioactivity on to the beach, between the high and low water marks. It was thought desirable, as a precautionary measure, to restrict access to this part of the beach for several days until the full significance of the release could be assessed. There was no injury or risk to any member of the public and the restrictions were removed shortly afterwards.

285. On 1st August, 1961, the effluent pipeline from Harwell to the river Thames at Sutton Courtenay burst, flooding a road and the lower part of a nearby house. The effluent being discharged at the time was not radioactive, but the monitoring team detected deposits of sediment which were slightly radioactive and steps were taken at once to clean this up. The flooding caused the road to be closed for a short period.

286. In October, 1961, a jacket worn by a member of the staff at Harwell became contaminated with strontium-90. As this jacket was worn on the bus by which he travelled from work, it was necessary to monitor the bus and other passengers to whom contamination might have been spread. As a result of the incident, two members of the Authority's staff received radiation doses in excess of the maximum permissible level for external exposure to localised areas of the skin. The level of possible contamination was so low that no member of the public could have suffered any harm.

Collaboration with Government Departments

287. The Authority have continued to provide advice and assistance to government departments. In particular, the Safeguards Division of the Authority Health and Safety Branch has continued to carry out work on behalf of the Chief Inspector of Nuclear Installations, Ministry of Power, and to advise the Admiralty and the Ministry of Transport on the safety aspects of nuclear propulsion of ships.

288. The Sealed Sources Regulations made by the Minister of Labour under the Factories Act came into full operation on 1st February, 1962. These provide for the protection of persons handling sealed radiation sources or X-ray and similar apparatus in industrial premises and apply to those of the Authority's premises which are classified as factories. In preparing the regulations the Ministry of Labour consulted organisations, including the Authority, with special knowledge and experience in the radiological protection field. No significant changes in the Authority's existing control procedures were necessary to comply with the requirements of the regulations.

International Co-operation

289. The Authority have continued to support the work of the International Atomic Energy Agency. During the year Authority staff have taken part in most of the Agency's scientific conferences and symposia concerned with health and safety. These have included the Panel on Basic Safety Standards; a joint Legal/Scientific Panel on Radioactive Waste Disposal into the Sea, which met in September, 1961, to give consideration to some of the scientific problems identified at a meeting of lawyers in January, 1961; and a joint Conference on Reactor Site Selection held in Vienna with the International Standards Organisation in October, 1961.

290. In May, 1961, the European Nuclear Energy Agency organised an international symposium at Karlsruhe on criticality control in the design and operation of chemical and metallurgical plant. This was of particular interest as being the first public discussion on an international scale of this subject of basic importance. Authority representatives played a full part in the planning and proceedings.

291. Close contacts have been developed with those responsible for health and safety policy and practice in the United States Atomic Energy Commission. In June, 1961, the Director of the A.E.C.'s Division of Biology and Medicine, accompanied by the Directors of Radiation Standards and of Operational Safety, visited the Authority for discussions on matters of mutual interest, and a return visit was paid in October. Similarly fruitful personal contacts have been established on questions of reactor and plant safety and on the practical problems involved in emergency planning and control.

292. Other valuable bilateral exchanges on health and safety subjects have been continued and developed, particularly with France, Canada and the Euratom Commission.

Research and Investigations

293. Health and safety are important factors in the design, development and research work carried out by the Authority. The account given below of some of the projects undertaken or in progress during the year predominantly for health and safety reasons is necessarily selective.

Fallout

294. Increased studies of fallout were made during and after the series of Russian test explosions. The concentration of fission product activity in air at the sampling station near the Atomic Energy Research Establishment, Harwell, rose from 0.02 micromicrocuries per kilogram to a maximum of about 15. This level was still far below that having a direct significance to health. Nevertheless, deposition of radioactivity on grazing land occurred throughout the country and led to a rise in the radioactivity in milk. A number of results of analyses of milk from areas round Authority establishments were provided to the Agricultural Research Council, which conducted a country-wide survey on behalf of the government.

Radiological Protection

295. Some of the Authority's research work in the radiological protection field has been carried out by those responsible for the provision of health and safety services at works and establishments. This has particular advantages in the field of applied or operational research.

296. Investigations relating to the monitoring of neutrons of various energies and of beta and gamma rays have been carried out during the year. Consideration was given to the monitoring both of low level, long-term exposures and of the sudden, high exposures which might result from a criticality accident. The routine measurement of doses to personnel from fast neutrons requires the tedious counting, using a suitable microscope, of photographic tracks in a special emulsion. A feasibility study has shown that it may be possible to identify and count these tracks automatically and development work has started. The Authority have also collaborated with the Radiological Protection Service in the development of a new and improved film badge and work is in hand to develop automatic equipment for measuring and interpreting the films from these badges. Automatic computation has proved valuable in interpreting the results from a number of gamma ray spectrometers used to identify species of radioactive materials without recourse to complex chemical procedures.

297. Improved methods of estimating traces of plutonium in the body have been studied. These include the development of more sensitive analytical techniques for plutonium excreted from the body and studies of the possibility of detecting the low energy radiation from plutonium by direct measurement with a special whole-body monitor.

298. An important health and safety event during the year was the commissioning of whole body monitors at Windscale, Dounreay and Winfrith, as additions to the installation already in service at Harwell. The whole body monitor represents a valuable facility for use in research; for establishing that accumulation of artificial radioisotopes in the body is at safe levels; and, in the event of suspected accidental intake of radioisotopes, for diagnosing the quantity, nature and location in the body.

299. Following the publication in 1960 of the Adrian Report on Radiological Hazards to Patients, work has continued on methods of reducing the X-ray dose to patients during diagnostic investigation. The Authority are collaborating with the appropriate committee of the International Commission on Radiological Units and Measurements in this connection.

300. An important programme of work has continued on the chemistry of chelates (i.e., chemical agents which may be of use in facilitating the excretion of radionuclides from the body).

Waste Disposal

301. A radiobiology team at Windscale has carried out studies of the mechanism of uptake in fresh-water and marine life of important fission products and of radioactive products of the corrosion of fuel element materials.

Reactor and Plant Safety

302. Experimental and theoretical work undertaken during the year has increased knowledge of the criticality characteristics of systems incorporating fissile materials. This work is important in ensuring the safety of plant and of transport containers and storage arrangements involving fissile material. It is also devoted towards ensuring that over elaborate and unnecessarily expensive precautions are avoided.

303. Work on the behaviour of radioiodine in air has been greatly enlarged and extended. Some aspects of this work are described in paragraphs 143 to 145. A programme has been launched involving:

- (a) identification of the isotopes released in gaseous or aerosol form from overheated fuel elements;
- (b) development of filtering and adsorbing media to arrest these isotopes; and
- (c) construction of a test rig simulating the layout and volume relationships of a power reactor to assist in the development of practical containment and clean-up systems for future reactors, particularly the advanced gas-cooled reactor.

304. The continued development of gas-cooled reactor systems has required a parallel research effort on graphite behaviour. This is influenced by coolant temperatures, which are higher in the latest magnox stations and more advanced gas-graphite systems; and, in the case of the high temperature, gas-cooled reactor, helium has replaced carbon dioxide as the coolant. Particular emphasis is being placed on the microstructure of graphite; the effect of impurities in the graphite and in the coolant; and the effects of radiation on the various chemical reactions in which graphite may take part.

The Evaluation of Reactor Sites

305. During the year a new method for the evaluation of reactor sites in relation to the local population distribution was worked out and presented to the Nuclear Safety Advisory Committee, which was appointed by the Minister of Power and the Secretary of State for Scotland, under the chairmanship of Lord Fleck. The new method enables sites to be assessed according to the expected degree of exposure to radioactivity of the actual numbers of people living at various distances from the reactor in the remote event of an accidental release of fission products. A comparison of the merits of various sites is thus possible. This does not of itself provide a more liberal siting policy, but it avoids certain anomalies found in the former method. When, in the judgment of the licensing authorities, some relaxation from the present conservative policy is permissible, it will be possible, using the new method, to measure sites against any desired standard.

CHAPTER XIV

INFORMATION SERVICES

306. Requests for information about the Authority's work continue to grow in number both at home and overseas.

Press

307. More than 150 journalists and broadcasters from the United Kingdom and overseas took part in a two-day visit to the Atomic Energy Research Establishment, Harwell, in June.

308. In October a group of journalists from Australia, India, Pakistan, Brazil, Germany, Japan, the Netherlands, Spain and Sweden toured several Authority establishments and industrial undertakings.

309. In the same month a visit for local and technical press to Calder Hall was arranged to mark the fifth anniversary of the station.

310. In January, technical journalists went to the A.E.R.E., Harwell, to report on the inauguration of the new building for decontamination and disposal of solid wastes.

311. A two-day course for journalists was held at the Harwell Reactor School in February.

312. Television and radio broadcasts during the year included a one-hour programme on the peaceful uses of atomic energy, transmitted by Southern Television, in which the Chairman of the Authority participated. Authority film material was supplied to a number of television companies at home and abroad.

313. The resumption of atmospheric nuclear weapon testings by the Union of Soviet Socialist Republics in the autumn resulted in many requests to the Press Office for background information. Visits to the health physics laboratories at Harwell were arranged for journalists and a press briefing on fallout measurement techniques was held in London in October.

Exhibitions

314. The travelling exhibition "Atoms at Work" visited Exeter (January), Rugby (February) and the Science Museum, London (March). Film shows, lectures and organised visits by schools and technical colleges were arranged at each location. The London exhibition was opened by Mr. Denzil Freeth, M.P., Parliamentary Secretary for Science.

315. The Authority provided exhibits for the annual meeting of the British Association for the Advancement of Science at Norwich in August. A mobile exhibit was loaned to the Association for a tour of museums in the midlands area. The Authority also exhibited at the Second Engineering Materials and Design Exhibition at Earl's Court, London, in November; at the annual meeting of the Science Masters' Association at Imperial College, London, in January; and at the Institute of Physics and Physical Society exhibition in London in the same month. The Authority continued to loan models and display material to learned societies, universities, schools, museums and other organisations at home and overseas.

316. The Authority exhibited at ACHEMA, the West German Triennial Chemical Engineering Exhibition and Congress in Frankfurt in June, 1961; and at the 5th International Congress of Biochemistry in Moscow in August.

Films

317. Six new films were completed during the year:—"Nuclear Power Reactors" (survey of reactor systems); "Britain's Nuclear Power Programme" (progress report); "Fuel for Nuclear Power" (fuel element production); "Explaining the Atom" (basic principles, power generation and radioisotopes); "VERA" (research reactor at Aldermaston); "Operation Orpheus" (experimental work on the detection of underground explosions).

318. An earlier film, "Steel for Nuclear Power", gained a special mention at the 6th International Exhibition of the Scientific-Didactic Film at Padua.

319. Nearly 1,000 issues of films to home users were made from the library during the year. The Central Office of Information and the British Council have continued to distribute Authority films overseas. There are now over 500 prints in 74 countries.

Publications

320. Some 70 new publications were produced during the year. They included "Atom 1961", an illustrated summary of the Authority's Seventh Annual Report; revised editions in English, Spanish and German of "The Nuclear Energy Industry of the United Kingdom"; a new edition of "Careers in the U.K.A.E.A."; and a revised edition of "Calder Hall", a guide to the nuclear power station. Most of the current information brochures and pamphlets were reprinted during the year and, in addition, two new series of publications, in support of the Authority's sales programmes for radioisotopes and reactor fuel elements, were inaugurated. A range of Authority publications was printed in Russian, in support of the Authority exhibit at the Moscow Biochemical Conference in August; in German, for the ACHEMA Conference at Frankfurt, in June; in Japanese, in preparation for the Osaka Trade Fair in April, 1962; and in Italian, for the Milan International Samples Fair, also in April, 1962. The circulation of "Atom", the Authority's monthly information bulletin, rose from 15,500 to over 18,000 copies, of which 3,400 were sent overseas.

Information Centre

321. The Information Centre and Isotope Information Bureau at 11, Charles II Street, London, dealt with 5,000 enquiries during the year, of which more than half concerned radioisotopes.

Photographs

322. Over 800 new negatives were added to the Photographic Library and 400 new prints from outside sources. Enquiries for photographs from press and public averaged 95 a week.

The Authority's Schools

Isotope School

323. The policy of the Isotope School has continued to be that courses will be given for which a need is apparent and that courses shall not duplicate the work of universities and technical colleges. Accordingly, two new courses

were given, on industrial radiation processing and on radioisotopes in non-destructive testing, but there were only two basic general courses. The period included three medical courses and three short (one week) courses on radiological protection. Other courses were given on radioisotope methods in chemistry and on autoradiography for biologists. There was also an advanced course in physics and measurements, and a general course with special reference to radiobiochemistry. For the third time, the school held a course, for the World Health Organisation, on public health aspects of radiation protection. The number of students attending the school during the year was 325 of whom 115 were from overseas. During the eleven years of its existence, a total of 2,846 students, of whom 1,052 were from overseas, have attended 130 courses.

Harwell Reactor School

324. During the year the Reactor School held two standard courses and two for senior technical executives, together with two radiation protection courses. New courses included one for senior engineering staff of universities and one for members of the press. In place of the control and instrumentation courses of previous years, a new course was held on instrumentation of reactors. Another new course was for science masters, held in the Easter vacation; this was designed to help those teaching science to keep up-to-date with recent developments at Harwell in the nuclear physics and reactor fields.

325. There was an increase in the number of courses held for Authority staff only. The reactor engineering induction course has been held six times. Further series of courses, designed for reactor engineer control officers and for technical and non-technical classes, have been started.

326. That part of the standard course held at the colleges of advanced technology has been extended by three weeks, the other ten weeks taking place at Harwell, and in the new Reactor School premises at the Atomic Energy Establishment, Winfrith.

327. A total of 338 students attended the Reactor School during the year, of whom 289 were British and 49 were foreign. Of the British total, 113 were Authority staff. Since the school began, 2,062 British and 657 foreign students have attended courses there.

Calder Operation School

328. During the year five standard courses for professional engineers and physicists were held at the Calder Operation School. Thirty-four of the 98 students came from overseas. Over 600 students have now attended this course. In addition three short reactor practise courses for technician grade operators were attended by 21 students; and four special two-week courses were attended by 39 Authority professional engineers and physicists. A summer school in August, 1961, for science teachers and technical college lecturers proved a successful experiment. A new type of course is being planned which will deal with all the reactor systems under development in this country. This course is designed to appeal particularly to executives from overseas.

Libraries

329. The Authority's libraries, in addition to serving the Authority's own staff, continued to lend material to, and to answer questions from, external

organisations. During the year over 10,000 items were lent and over 600 external enquiries were answered, principally from British industrial firms and universities.

Visitors

330. During the year over 60,000 people visited the Authority's establishments.

CHAPTER XV

INTERNATIONAL RELATIONS

International Atomic Energy Agency

331. The Authority continued to release members of their staff for service as consultants, and on panels and working parties convened by the Agency, as part of their general support of its work. The topics discussed during the year, at the meetings of this kind which Authority experts attended, have included the disposal of radioactive waste into the sea and fresh water, basic health and safety standards, the application of radioisotopes in hydrology, agricultural research and industry, the costing of nuclear power, and international co-operation in the compilation of nuclear data. Authority staff also attended a number of meetings convened by the I.A.E.A. jointly with the Food and Agriculture Organisation (F.A.O.) of the United Nations and the World Health Organisation (W.H.O.), and a conference held jointly with the International Standards Organisation (I.S.O.). They also assisted at training courses in radioisotope techniques organised in the Netherlands by the I.A.E.A. and F.A.O. A member of the Authority's staff spent three weeks in Japan in April, 1961, on an I.A.E.A. technical assistance mission, to advise on waste disposal techniques.

332. Authority representatives also attended ten scientific conferences and symposia held by the Agency during the course of the year. The subjects included nuclear electronics, plasma physics and power reactor experiments.

333. Early in the year Sir William Penney succeeded Sir John Cockcroft as a member of the I.A.E.A. Scientific Advisory Committee.

334. The Chairman of the Authority led the United Kingdom delegation to the Fifth Annual General Conference of the Agency, held in Vienna in September and October, 1961.

335. During the year holders of I.A.E.A. Fellowships continued to be accepted for attachments at the Authority's establishments and for training at the Authority's schools.

European Nuclear Energy Agency

336. In June Professor L. Nicolaidis, Chairman (until December, 1961) of the European Nuclear Energy Agency Steering Committee, and Mr. P. Huet, Director of E.N.E.A., visited a number of Authority establishments, including Harwell and the Wantage Research Laboratory.

(i) *Dragon High Temperature Gas-Cooled Reactor Project.* During the period under review Sir William Penney was Chairman of the Dragon Board of Management and Dr. Micheal Hignatsberger of Austria was Chairman of the General Purposes Committee. Progress at Winfrith on both the engineering and research and development sides, by the joint team consisting of staff drawn from the Authority and from the other European signatories, was good: the main pressure vessel was delivered to the reactor site in March, 1962, just two years after the construction work began. The present Dragon agreement will come to an end in March, 1964, but by then the reactor will have operated for only a short time. Negotiations are already under way to prolong the life of the joint project so that the signatories to the agreement will obtain greater benefit from it.

(ii) *Halden Reactor.* The joint programme for the experimental operation of the Norwegian boiling water reactor at Halden by E.N.E.A. member countries has made satisfactory progress during the year. The programme of experiments with the first fuel charge has been completed and the interpretation and publication of the results of this work are in hand. Following a period of modification of the experimental equipment, a similar series of experiments will be conducted with a second fuel charge of enriched uranium. Norwegian proposals for a future international research programme, after the conclusion of the present Halden agreement in December, 1962, are being studied.

(iii) *E.N.E.A. Study Groups and Committees.* The Authority have continued to participate in the work of the Study Group on Nuclear Ship Propulsion, the Health and Safety Sub-Committee and the European-American Nuclear Data Committee. Members of the Authority's staff have also taken part in the work of the Study Group on Food Irradiation and the group of experts set up to study the possibilities of heavy water production by use of geothermal steam in Iceland.

(iv) *Miscellaneous.* Dr. F. A. Vick, Director of the Research Group, represented the Authority at the meeting of a top level group of nuclear experts from European countries, the United States of America, Canada and Euratom, which was convened by E.N.E.A. in Paris in October, 1961, to examine possible new fields for international collaboration in advanced nuclear research. An authority team attended a symposium held by E.N.E.A. at Karlsruhe, Federal Germany, in May, 1961, on the subject of criticality control in chemical and metallurgical plant.

Euratom

337. Storms in the channel isolated the U.K. and prevented the Euratom party from crossing for the third meeting of the U.K.-Euratom Continuing Committee for Co-operation which was to have been held in London in November. The meeting—which is held at ministerial level—was later arranged to take place in April, 1962.

338. The U.K.-Euratom Joint Working Group met twice during the year, in July and February. At the July meeting the discussions ranged over a wide variety of topics of common interest. A meeting between Euratom and Authority representatives to discuss problems encountered in the design of fast zero energy facilities was held at Winfrith in November. At the meeting in February consideration was given to the possibility of the Authority working with the BR.2

reactor at Mol, Belgium. During the year members of the Authority's staff assisted in the commissioning of this reactor. Help was also given with the safety assessment of the BR.3 reactor.

339. Authority representatives read papers at a Euratom symposium, on the medical supervision of workers exposed to ionizing radiations, held in Italy in May, 1961. In April a Euratom team visited the U.K. for discussions with Authority staff on the public relations aspects of health, safety and waste disposal. Other Euratom visitors to Authority establishments during the year have discussed irradiated fuel examination facilities and health and safety problems. Two members of the Euratom staff began attachments of six months at Harwell in November, 1961.

340. On 5th March, 1962, Her Majesty's Government applied formally to open negotiations with the object of acceding to the treaty establishing the European Atomic Energy Community (Euratom).

European Organisation for Nuclear Research (CERN)

341. Mr. J. B. Adams, Director of the Research Group's Culham Laboratory, was succeeded as Director-General of CERN by Professor V. F. Weisskopf on 1st August, 1961. Four members of the Authority's staff presented papers at a conference held by CERN in September, 1961, on fission and spallation phenomena and their application to cosmic rays.

Central Treaty Organisation (CENTO)

342. During the year Dr. M. L. Smith of the Research Group succeeded Mr. H. A. C. McKay as Director of the CENTO Institute of Nuclear Science at Tehran. With the development of national institutes in the individual CENTO countries, the work of the CENTO Institute is now directed more towards research, and the provision of advice and assistance, than to teaching and the organisation of training courses as in the past. Sir William Slater and Mr. B. S. Smith were appointed U.K. members of the CENTO Scientific Council in succession to Sir John Cockcroft. The Pakistan Atomic Energy Commission and the CENTO Institute were together responsible for the organisation of a symposium at Lahore in January, 1962, on the role of science in the development of natural resources.

Co-operation with Other International Organisations

343. The Authority have continued to send representatives to the symposia organised by the European Atomic Energy Society and during 1961 they acted as hosts to two symposia: one on public relations and the other on safety, control and instrumentation of zero and sub-critical reactors. In March, Sir William Penney replaced Sir John Cockcroft as the U.K. representative on the Scientific Advisory Committee of the United Nations. The Authority have continued to send members of their staff to attend meetings convened by the specialised agencies of the United Nations Organisation.

The Commonwealth Countries

344. (i) *Canada*. The annual meeting to review collaboration between the Authority and Atomic Energy of Canada Limited was held in November, at Chalk River, under the chairmanship of Mr. J. Lorne Gray, the President of A.E.C.L. The Authority team was led by the Chairman of the Authority and included Sir William Cook and Group representatives. Discussions at the three

day meeting covered all aspects of the programme of co-operation including, in particular, reactor physics and fuel development. The power reactor programmes of the two countries were also reviewed. Co-operation between the two organisations has recently been increasing in basic and applied research, reactor technology and other fields. The opportunity was accordingly taken to place on record the arrangements under which the co-operation is effected. This was done in the form of letters exchanged during the conference between the Chairman of the Authority and Mr. Lorne Gray.

(ii) *Australia*. In September an extension of the Authority's arrangements with the Australian Atomic Energy Commission was agreed, providing for increased co-operation in fields in which both organisations have active programmes. Professor Baxter, Chairman of the Commission, visited the U.K. in October for discussions and for a tour of the Authority's establishments. In the same month Sir Claude Pelly visited Australia. Sir William Cook went to Australia in March to see something of the Commission's programme of work at Lucas Heights and elsewhere.

(iii) *Pakistan*. Discussions were held in London in June, 1961, with Dr. Usmani, the Chairman of the Pakistan Atomic Energy Commission, about ways and means of increasing co-operation between the Authority and the Commission. Letters were exchanged in September between the Authority's and the Commission's respective Chairmen which made provision for exchanges of unclassified reports, for visits by scientific staff and for assistance to be given by the Authority in the training of scientists and the provision of radioisotopes and research materials. The implementation of these agreed arrangements was discussed by the Authority's and the Commission's Chairmen at the beginning of March, when the latter visited London, and again later in that month when the Chairman of the Authority spent a few days in Pakistan at Dr. Usmani's invitation to see something of the work being carried out by the Commission.

(iv) *India*. The Indian Government are now considering the tenders submitted to them in response to their invitation relating to a 300 MW nuclear power station which they propose to construct at Tarapur. Two of the British consortia tendered. Discussions have taken place during the year between the Authority and the Indian Department of Atomic Energy on consultancy services and fuel supplies which could be provided by the Authority for this project, and the possibility of the Authority granting licences for the manufacture of fuel elements.

United States of America

345. Discussions between the Chairman of the Authority and Dr. Seaborg, Chairman of the U.S. Atomic Energy Commission, took place in London in September and in Washington in November. A survey of exchanges was also made when an American team visited the U.K. in June. Numerous meetings and visits on specialist topics, both civil and military, have taken place at the working level between representatives of the two organisations during the year. On the civil side, these included a conference in the U.S.A. in October on plutonium recycling; and conferences in September on feed materials and in December on advanced gas-cooled reactor systems, both in the U.K. One of the U.S. Commissioners, Dr. Robert E. Wilson, visited Authority establishments in July and August and the Chairman of the Authority, Sir William Penney and Sir John Cockcroft, all visited the U.S.A. during the year.

Union of Soviet Socialist Republics

346. A collaboration agreement between the Authority and the U.S.S.R. State Committee of the Council of Ministers for the Utilisation of Atomic Energy was signed in London in May, 1961. A Soviet team led by Professor Emelyanov, then Chairman of the Committee, visited London to conclude the negotiations and to sign the agreement, which covers exchange of visits, exchange of unclassified reports and assistance in the provision of nuclear equipment and radioisotopes. Proposals for a programme of visits were also agreed. The first two such visits took place during the year. A Soviet team visited the U.K. in July for discussions on solid state physics and an Authority team, led by Sir William Cook, visited the U.S.S.R. in September for discussions on reactor physics and fast reactors.

Japan

347. The Chairman of the Authority visited Japan for discussions with the Japanese atomic energy authorities. During his stay he visited the Osaka Trade Fair, the nuclear power station which is under construction by British industry at Tokai Mura, and various installations of the Japanese Atomic Energy Research Institute.

France

348. Co-operation between the Authority and the French Commissariat à l'Energie Atomique on a variety of technical subjects continued to be close and fruitful. A further meeting between Authority representatives and those of the Commissariat was held in June, 1961, in Paris to review the progress of exchanges between the two countries. The Authority team was led by Sir William Penney, who spent the two days before the meeting visiting some of the Commissariat's research centres and production plants.

Sweden

349. At the invitation of the Swedish organisation AB Atomenergi the Chairman of the Authority visited Sweden in May, 1961, for discussions on future co-operation. Other visits in both directions were then agreed, including one by an Authority team led by Sir William Cook, which had discussions in Sweden in December on heavy water reactor systems. Later in the month Dr. Brynielsson, Chairman of AB Atomenergi, visited the U.K. on a return visit at the invitation of the Authority. During his visit it was agreed that the exchange of information between the Authority and AB Atomenergi in relation to heavy-water-moderated reactor systems should be increased.

Greece

350. In March, Admiral Spanides, Chairman of the Greek Atomic Energy Commission, came to the U.K. for discussions and to see something of the Authority's work. During his visit he and the Chairman of the Authority exchanged letters providing for co-operation in the peaceful uses of atomic energy by collaboration in a number of fields of common interest as well as by exchanges of staff and basic research information. The Authority have undertaken to assist the Commission in the use of isotopes and by providing information, when requested, on nuclear power station construction.

Spain

351. The contacts between the Authority and the Junta de Energia Nuclear, which were formalised in the 1960 intergovernmental agreement between Her Majesty's Government and the Spanish Government on the peaceful uses of atomic energy, have led to a number of further visits and to arrangements for Junta staff to be attached to Authority establishments.

Denmark

352. Professor Niels Bohr, Chairman of the Danish Atomic Energy Commission, and Mr. Hans Koch, Chairman of its Executive Council, came by invitation to the U.K. in June, 1961, to see something of the Authority's work. Regular visits by Authority staff to the Commission's Risø establishment have taken place in connection with the irradiation programme which is being undertaken there on behalf of the Authority in the DR.3 reactor.

Poland

353. At the invitation of Mr. W. Billig, the Polish Government Commissioner for Atomic Energy, Sir John Cockcroft visited Warsaw in September and saw research and development work being undertaken by the Commission.

Brazil

354. Only one country, Brazil, has announced specific plans during the last twelve months for the introduction of nuclear power. These plans are for a 300 MW nuclear power station which is to have a single gas-cooled, graphite-moderated reactor, fuelled with natural uranium. Eight companies, including the three British consortia, have now been selected by the Brazilian Government to be invited to tender in due course.

Visitors to Authority Establishments

355. Distinguished visitors to Authority establishments during the year included Professor Felice Ippolito, Secretary-General of the Italian Comitato Nazionale per l'Energia Nucleare; Mr. Masanosuke Ikeda, then Japanese Minister of State in charge of Atomic Energy Matters; Professor Kaneshige, one of the Japanese Atomic Energy Commissioners; a group of Japanese M.P's; Dr. Gunnar Randers, Director of the Norwegian Institutt for Atomenergi; and Dr. U. W. Hochstrasser, Swiss Federal Delegate for Atomic Energy Matters.

CHAPTER XVI

THE AUTHORITY'S STAFF

Senior Staff

356. The Boards of Management of the five Groups, the other officers in charge of establishments, the Principal Officers in the London Office, the Management Committee of the Authority Health and Safety Branch and the advisers to the Authority are listed in Appendix II.

General Manpower Position

357. In the course of the year there was a small increase in the number of non-industrial staff from 20,234 to 20,543, while the number of industrial

employees fell from 20,606 to 20,017. There was thus little change in the total. From the review of the Authority's forward civil research and development programme (see paragraphs 60 and 61) and the known trends in the weapons and production fields, it seems probable that total manpower will remain roughly steady for the time being.

358. However, the stabilisation of total numbers will by no means imply rigidity of programmes. In a large and lively research and development organisation, the emphasis on the many individual aspects of the work inevitably changes from time to time. As particular projects come to fruition, staff take on fresh problems associated with new projects. With the development of the Authority's work, there is increasing scope for a very wide range of scientific disciplines. To some extent the balance of effort can be altered by varying the proportions of the different categories of new recruits as wastage occurs. But in the main, the need will be to deploy the existing staff effectively. From the staff themselves this calls for ready adaptation to different kinds of work appropriate to their various qualifications; and one of the aims of the Authority's training arrangements, which are described below, is to assist their staff in taking advantage of the continuing and widening scope for rewarding work and the associated opportunities for successful careers in many fields.

359. It is a healthy feature of a large research and development organisation that a proportion of staff should move to take posts elsewhere, to be replaced by younger staff. Nevertheless a substantial proportion of the staff will remain with the Authority throughout their careers, especially as there is available within the organisation a great variety of work over the whole spectrum from basic research to operational work of various kinds. Moreover, it is on staff who have made their careers with the Authority that reliance must in the main be placed for the future succession to managerial posts. Thus recruitment of non-industrial staff has recently been chiefly confined to younger people, especially those just leaving school or completing a first or research degree at university, and this will be the future general policy.

360. During the year, recruitment of non-industrial staff was generally satisfactory although the Authority, like other employers, did not secure as many qualified scientists and engineers from the universities as were required. It may be that there is not yet a full appreciation of the wide range of interesting work which will continue to be available in the Authority for both scientific and engineering graduates of many disciplines, and steps are being taken to ensure that this is more widely recognised.

361. For the fourth successive year the Authority combined with the Civil Service Commission in a campaign for recruiting British graduates in North America, and the signs are that the number of recruits from this source is likely to increase.

362. Recruitment of industrial employees was also generally satisfactory, although there were some local difficulties affecting certain types of industrial labour.

Reduction in Capital Programme

363. The level of work on capital projects in the Authority has so far been geared to the building up of the various establishments. The virtual completion of this process and the general stabilisation of the present level of effort inevitably

mean that the rate of capital construction must fall to a significantly lower level within the next few years. In November, 1961, the Authority announced that the non-industrial staff of the Engineering Group was expected to fall from the current strength of just over 1,900 to about 1,500 by 1964, the reduction being amongst staff primarily concerned with the design and construction of major new works. The object is to secure an organisation of appropriate size capable of dealing effectively with the future reduced, but still very considerable, programme of design and construction of a wide variety of projects. It is expected that the reduction will be substantially achieved by restrictions on recruitment throughout the Authority and by the redeployment of staff surplus to the Engineering Group to fill vacancies which arise—mainly through wastage—during the next two or three years.

Staff and Industrial Relations

364. The reduction of the strength of Engineering Group has been the subject of consultation with the Staff Side of the Authority Whitley Council. Appreciation has been expressed on behalf of the staff at the fact that it has been possible to give nearly a year's notice of the beginning of the reduction in work load, and also at the intention to plan on an Authority-wide basis to deal with the consequential problems with the stated aim of avoiding redundancy.

365. As usual, much business has been transacted both formally and informally between the Official and Staff Sides of the Authority Whitley Council for non-industrial staff as well as on the local Whitley Committees. The joint negotiating and consultative machinery for industrial employees also continued to work well at both central and local levels during the year.

Work Study

366. As part of the Authority's continuing effort to secure the highest level of productivity and the maximum degree of efficiency in the operation of their plants, the subject of work study received a great deal of attention during the year. A special sub-committee of the National Joint Industrial Council was set up under the chairmanship of the Member for Production and Engineering to consider issues arising from the application of work study in the Authority. A number of method study schemes have been put in hand, mainly in production areas, and a start has been made on formulating the principles to govern the introduction of full work study techniques where appropriate.

Benevolent Funds

367. The Benevolent Fund for non-industrial staff, administered by a committee including representatives of both the Official Side and the Staff Side of the Authority Whitley Council, has been used to give financial aid in some eighty new cases of need, in addition to continuing assistance to widows and dependent children of former Authority employees. Local benevolent funds continued to give assistance to industrial employees.

Joint Health and Safety Committees

368. The Joint Committee on Health and Safety (which consists of representatives of the non-industrial and industrial employees and of the management under the chairmanship of the Director of Health and Safety) met three times

during the year. Among the subjects considered, protective clothing was of particular interest to members. The local joint sub-committees set up at the major establishments in 1958 continued to meet regularly.

Superannuation

369. The first valuation report on the Principal Non-Industrial Superannuation Scheme was received during June, 1961. This shows that the finances of the scheme are satisfactory.

Training

370. The pattern of the Authority's arrangements for training their staff is now well established. External training ranges from full-time university degree courses, or "sandwich" courses leading to the Diplomas in Technology, to short-term conferences or symposia in specialised subjects. The bulk of the external training falls between these two extremes and usually takes the form of time off to attend classes at a local technical college on one day a week. Those who benefit from day release are chiefly young people straight from school, and junior staff who wish to improve their academic qualifications. Most of the external training is in the scientific or technical disciplines and is related to the Authority's needs, while at the same time contributing towards an increased national output of trained scientists and technicians. Administrative staff are similarly encouraged to attend appropriate courses to increase their knowledge of the techniques in their work. An increased number of industrial employees attended part-time courses at technical colleges for which financial assistance and time off work were granted. Opportunities were also given to young people to take part in Outward Bound and other courses, the aims of which are to develop character and initiative, as a result of which two gold and two silver Duke of Edinburgh's awards were obtained.

371. The variety and scope of internal training at Authority establishments has continued to be very wide. Courses range from senior level management conferences to special courses in radiation health and safety, and practical instruction in working techniques. The courses are carefully designed to meet the special interests of different categories of staff and are continually developed or augmented to take account of changing needs.

372. The recruitment of apprentices showed an increase over previous years; 44 student apprentices and 204 craft apprentices were enrolled during the year.

Housing, Hostels and Canteens

373. With the completion of the construction of most Authority establishments, their needs for housing, hostels and canteens have largely been met and there are only a few outstanding projects.

APPENDIX I

MEMBERSHIP OF ATOMIC ENERGY AUTHORITY AS AT 1st APRIL, 1962

Chairman

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

Deputy Chairman

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

Full-time Members

Sir William Cook, C.B., F.R.S.
(Member for Reactors)

Sir Alan Hitchman, K.C.B.
(Member for Finance and Administration)

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

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

Part-time Members

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

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

Sir James Chadwick, F.R.S.

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

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

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

Secretary

Mr. D. E. H. Peirson

APPENDIX II

ATOMIC ENERGY AUTHORITY SENIOR STAFF AS AT 1st APRIL, 1962

LONDON

R. W. Burkitt	Principal Officer, Commercial Policy
E. J. S. Clarke, T.D.	Principal Officer (Supplies and Stores)
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)

ENGINEERING GROUP

Headquarters, Risley

H. V. Disney, C.B.E.	..	..	Managing Director
C. Buck	..	..	Director, Chemical Plant Design
D. S. Mitchell	..	..	Director, Personnel and Administration
J. Tatlock, M.B.E.	..	..	Director, Fuel Element Design and Inspection
C. J. Turner, C.B.E.	..	..	Director, Engineering Design
T. L. Viney	..	..	Director, Works and Buildings

Southern Works Organisation, Tadley

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

PRODUCTION GROUP

Headquarters, Risley

J. C. C. Stewart, C.B.E.	..	..	Managing Director
Dr. J. M. Hill	..	..	Deputy Managing Director
S. F. Hines, O.B.E.	..	..	Production Director
Dr. N. L. Franklin	..	..	Nuclear Fuel Director
—			Technical Director
Dr. A. B. McIntosh	..	..	Liaison Director
D. S. Mitchell	..	..	Personnel and Administration Director
P. A. Bundy	..	..	Finance Director
W. R. A. Taylor, O.B.E.	..	..	General Manager, Capenhurst Works
G. R. Howells, M.B.E.	..	..	General Manager, Chapelcross Works
Dr. H. Rogan	..	..	General Manager, Springfields Works
T. Tuohy	..	..	General Manager, Windscale and Calder Works

REACTOR GROUP

Headquarters, Risley

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

Atomic Energy Establishment, Winfrith

D. W. Fry	..	..	Director
-----------	----	----	----------

Dounreay Experimental Reactor Establishment

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

REACTOR GROUP LABORATORIES

J. Harper	..	..	Head of Reactor Fuel Element Laboratories, Springfields
F. I. Hurley	..	..	Head of Reactor Engineering Laboratories, Risley
J. M. Hutcheon	..	..	Head of Reactor Materials Laboratories, Culcheth
K. Saddington	..	..	Head of Reactor Development Laboratories, Windscale

RESEARCH GROUP

Atomic Energy Research Establishment, Harwell

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

Culham Laboratory

Dr. J. B. Adams, C.M.G.	..	..	Director
-------------------------	----	----	----------

Radiochemical Centre, Amersham

Dr. W. P. Grove	..	..	Director
-----------------	----	----	----------

WEAPONS GROUP

Atomic Weapons Research Establishment, Aldermaston

Dr. N. Levin	..	..	Director
E. F. Newley, C.B.E.	..	..	Deputy Director
J. E. Adamson	..	..	Group Secretary
W. J. Challens, O.B.E.	..	..	Chief of Warhead Development
J. M. High	..	..	Head of Engineering Services
G. L. Hopkin, O.B.E.	..	..	Chief of Materials
Dr. H. R. Hulme	..	..	Chief of Nuclear Research
I. Maddock, O.B.E.	..	..	Head of Field Experiments

Foulness Establishment

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

Woolwich Common

G. A. Bailey	..	..	Superintendent
--------------	----	----	----------------

Orfordness Establishment

H. S. Weeks	..	..	Group Leader
-------------	----	----	--------------

AUTHORITY HEALTH AND SAFETY BRANCH

Dr. A. S. McLean	..	..	Director
F. R. Farmer	..	..	Head of Safeguards Division, Risley
Dr. W. G. Marley, O.B.E.	..	..	Head of Radiological Protection Division, Harwell
I. G. K. Williams	..	..	Head of Administrative Division, London

ADVISERS TO THE AUTHORITY

Mr. Anton Gray, O.B.E.	..	..	Senior Mining Adviser
Mr. G. H. Nowell-Withers, C.B.E.	..	..	Chairman of the Advisory Committee of the Authority's Non-Industrial and Industrial Superannuation Schemes and Adviser on Pensions and Taxation Matters.

APPENDIX III

THE AUTHORITY'S REACTORS AS AT 31st MARCH, 1962

Research and Experimental Reactors

NAME	LOCATION	DATE OF START-UP	PEAK NEUTRON FLUX THERMAL n/cm^2 sec.	MAXIMUM HEAT OUTPUT	MODERATOR	COOLANT	FUEL	PURPOSE
1. GLEEP ..	Harwell	1947	0.167×10^9	3 kW	Graphite	Air	Natural uranium	Routine graphite and uranium quality testing, research with oscillator, biological irradiations.
2. BEPO ..	Harwell	1948	2×10^{12}	6 MW	Graphite	Air	Natural uranium	Nuclear reactor material studies, isotope production, neutron physics, radiation chemistry.
3. LIDO ..	Harwell	1956	10^{12}	100 kW	Light water	Light water	Enriched uranium-aluminium alloy	Thermal reactor studies including shielding.
4. Dido ..	Harwell	1956	2×10^{14}	13 MW	Heavy water	Heavy water	Highly enriched uranium-aluminium alloy	Nuclear reactor material studies, isotope production, neutron physics, radiation chemistry.
5. PLUTO ..	Harwell	1957	1.8×10^{14}	10 MW	Heavy water	Heavy water	Highly enriched uranium-aluminium alloy	Nuclear reactor material studies, isotope production, neutron physics, radiation chemistry.
6. D.M.T.R.	Dounreay	1958	1.2×10^{14}	10 MW	Heavy water	Heavy water	Uranium ²³⁵	Studies on nuclear reactor materials.

7. HORACE ..	Aldermaston	1958	about 10 ⁸	10 Watts	Light water	Light water	Uranium 235	To obtain basic nuclear information on HERALD.
8. Fast Reactor	Downreay	1959	—	60 MW	None	Sodium potassium alloy	Enriched uranium; plutonium	Development of fast reactor technology (reactor physics, fuel elements and coolant handling).
9. ZENITH ..	Winfrith	1959	10 ⁸	100 Watts	Graphite	None; Nitrogen used as heating gas	Ceramic elements containing highly enriched uranium oxide	Reactor physics investigations for high temperature gas-cooled systems. (Max. temp. 800°C in core, 400°C in reflector.)
10. NERO ..	Winfrith	1960	3×10^8	Less than 100 Watts	Graphite	None	Enriched uranium	Investigations for advanced graphite-moderated reactors and pile oscillator studies.
11. HERALD ..	Aldermaston	1960	5×10^{13}	5 MW	Light water	Light water	Uranium 235	Neutron physics, radiochemical and nuclear reactor materials studies.
12. VERA ..	Aldermaston	1961	—	100 Watts	None	None	Highly enriched uranium	Experimental studies of fast reactor systems.
13. NESTOR ..	Winfrith	1961	10 ¹¹	10 kW	Light water	Light water	Enriched uranium-aluminium alloy	Sources of neutrons for sub-critical assemblies giving thermal fluxes of 10 ⁸ in the assemblies.
14. DIMPLE ..	Winfrith	1962	3×10^8	Less than 100 Watts	Light water, heavy water or organic liquid or mixtures	None	Uranium or plutonium	Testing a wide range of lattices at uniform temperatures up to about 80°C.

Research and Experimental Reactors (contd.)

NAME	LOCATION	DATE OF START-UP	PEAK NEUTRON FLUX THERMAL n/cm^2 sec.	MAXIMUM HEAT OUTPUT	MODERATOR	COOLANT	FUEL	PURPOSE
15. HERO ..	Windscale	1962	—	A few Watts	Graphite	Carbon dioxide used as heating gas	Enriched uranium oxide	Reactor physics studies for the advanced gas-cooled reactor system.
16. DAPHNE ..	Harwell	1962	2×10^9	Up to 100 Watts	Heavy water	Heavy water	Enriched uranium-aluminium alloy	To simulate Dido and Pluto and to provide basic physics information in support of these reactors.

80

Research and Experimental Reactors under construction

17. AGR ..	Windscale	1962	1.6×10^{13}	100 MW (28 MW(E) net)	Graphite	Carbon dioxide	Enriched uranium oxide	To study the advanced gas-cooled power reactor system and to test fuel elements for the system.
18. HECTOR ..	Winfrith	1963	3×10^8	Up to 100 Watts	Graphite	Carbon dioxide used as heating gas	Permanent fuel: enriched uranium-aluminium alloy. Central core: variable	Oscillator reactor; reactivity measurements on materials and fuel elements.
19. ZEBRA ..	Winfrith	1962	5×10^9	100 Watts	None	None	Uranium 235; plutonium	A flexible system intended primarily to investigate the physics of large, fast reactors.

Plutonium/Power Producing Reactors (in production)

20-23. Calder (2 stations) ("A" and "B") (4 reactors)	Calderbridge	Station "A" 1956 Station "B" 1958	—	225 MW (heat) per reactor (45 MW(E) net)	Graphite	Carbon dioxide	Natural uranium	Plutonium, power production, and experimental work in aid of the U.K. nuclear power programme.
24-27. Chapel- cross (4 reactors)	Annan	1958 (1st reactor) 1959 (reactors 2, 3 and 4)	—	225 MW (heat) per reactor (45 MW (E) net)	Graphite	Carbon dioxide	Natural uranium	Plutonium, power production, and experimental work in aid of the U.K. nuclear power programme.

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

APPENDIX IV

BALANCE SHEET OF THE UNITED KINGDOM ATOMIC ENERGY AUTHORITY AS AT 31 MARCH 1961

FOREWORD

1. The seventh Balance Sheet of the United Kingdom Atomic Energy Authority, as at 31 March 1961, 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 1961 is withheld from publication in the interests of national security. Some details of the Net Cost of Operations are shown at Balance Sheet Note 7.

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

3. In addition to the records to meet the requirements of Parliamentary accounting the Authority maintain a commercial system of accounting appropriate to their requirements, including the division between capital and revenue, to facilitate management control and commercial operation. Transactions on revenue account are treated as follows:—

- (a) The cost of normal operations in the Production Group, including expenditure on development and design, is regarded as recoverable in the price of products.
- (b) Expenditure, less recoveries, of the Development and Engineering Group, which undertakes research, development, engineering and consultancy work, is regarded as a charge to be borne by H.M. Exchequer.
- (c) The whole of the cost of the operation of the Research Group, less the proceeds of sales of radioactive substances and other income, is regarded as the cost of general research in the atomic energy field to be borne by H.M. Exchequer.
- (d) The costs incurred by the Weapons Group for work done under production and research contracts from Defence Departments are recovered. The cost of other research and development work undertaken by the Group is regarded as a charge to be borne by H.M. Exchequer.

4. The charge for interest on capital has been calculated as if the capital required by the Authority were raised at ruling rates of interest year by year. The rates applied for capital borrowed during 1960–61 resulted in weighted averages of 6·08 per cent. on fixed capital and 5·37 per cent. on working capital.

29 November 1961.

UNITED KINGDOM ATOMIC

BALANCE SHEET AS AT

31 March 1960			£	£
£				
432,986,012	I. CAPITAL ACCOUNT			
	Balance at 1 April 1960	481,453,513		
85,455,971	Net advances from Office of the Minister for			
21,614,138	Science	85,881,891		
	Interest on capital	24,814,124		
540,056,121		592,149,528		
58,602,608	Deduct—			
	Net Cost of Operations for the year	68,647,251		
481,453,513	Capital Account at 31 March 1961		523,502,277	
	II. RESERVE FOR LOSSES (in lieu of insurance) (see Note 6)			
	Balance at 1 April 1960	6,640,047		
	Add—			
	Amount charged to operating costs in the year ..	2,700,000		
		9,340,047		
	Deduct—			
	Charged in the year	84,414		
6,640,047			9,255,633	
23,000,116	III. CURRENT LIABILITIES AND PROVISIONS			
—	Trade creditors and accrued liabilities	17,365,255		
	Provision for future losses (see Notes 3 and 4) ..	5,000,000		
949,808	Provisions for superannuation and special main- tenance	668,018		
			23,033,273	
512,043,484			555,791,183	
13,583,910	IV. PRINCIPAL NON-INDUSTRIAL SUPERANNUATION SCHEME			
	Balance at 31 March 1961	17,391,123		
2,610,609	V. PROTECTED PERSONS SUPERANNUATION SCHEME			
	Balance at 31 March 1961	3,196,565		
1,225,136	VI. INDUSTRIAL SUPERANNUATION SCHEME			
	Balance at 31 March 1961	1,436,816		
£529,463,139	Notes forming part of this Balance Sheet are appended. (See page 86)		£577,815,687	

ENERGY AUTHORITY

31 MARCH 1961

31 March 1960 £		As valued at 1 August 1954 plus additions at cost £	Depre- ciation £	£
	I. FIXED ASSETS, at cost or estimated cost less depreciation			
592,911	Freehold land	594,708	—	594,708
104,779,588	Buildings, ancillary installations, housing and hostels	136,688,504	25,058,677	111,629,827
130,454,671	Plant and machinery, motor vehicles, loose apparatus, tools and equip- ment	187,513,280	51,817,247	135,696,033
3,340,876	Furniture, fittings and office machinery	4,695,835	1,346,429	3,349,406
246,230	Capital assistance—assets with assisted contractors	526,722	265,145	261,577
239,414,276		£330,019,049	78,487,498	251,531,551
30,308,918	Assets in course of construction			27,009,550
269,723,194				278,541,101
	II. SPECIAL DEVELOPMENT AND DEFERRED REVENUE EXPENDITURE, less amounts written off			
498,285	Initial production expenses		82,417	
1,065,027	Research and development expenditure in aid of design		1,500,149	1,582,566
	III. LOANS, ADVANCES AND INVESTMENTS			
17,680,482	Loans and advances for the production of uranium, including accrued interest		15,556,971	
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 £11,928)		14,871	15,571,842
	IV. CURRENT ASSETS			
79,773,840	Stocks of raw materials and stores (see Note 2)		95,653,651	
131,781,541	Work in progress (see Note 2)		151,969,878	
9,914,978	Debtors, deposits and payments in advance		10,707,502	
1,591,266	Balances with Paymaster-General, with bankers and cash in hand		1,764,643	260,095,674
512,043,484				555,791,183
	V. PRINCIPAL NON-INDUSTRIAL SUPERANNUATION SCHEME FUND			
13,542,562	Amount due from H.M. Exchequer (see Note 8)		17,340,426	
41,348	Insurance policies		50,697	17,391,123
	VI. PROTECTED PERSONS SUPERANNUATION SCHEME FUND			
2,610,609	Amount due from H.M. Exchequer (see Note 9)			3,196,565
	VII. INDUSTRIAL SUPERANNUATION SCHEME FUND			
1,225,101	Amount due from H.M. Exchequer (see Note 10)		1,436,781	
35	Insurance policies		35	1,436,816
£529,463,139				£577,815,687

Roger Makins, Chairman.

E. A. Hitchman, Member.

NOTES

These notes form part of the Balance Sheet as at 31 March 1961.

1. Capital expenditure authorised, but not provided for in these Accounts, amounted to £46m. of which £20m. had been committed contractually.
2. Stocks and work in progress are valued at the lower of cost or realisable value.
3. The Authority have extensive commitments for the purchase under long-term contracts of:—
 - (a) Uranium concentrates in excess of current prices. The major part of these purchases is for supplies to the Defence Departments and the Generating Boards, from whom the Authority are required to recover their costs; losses will be incurred on the small part used for certain supplies to other customers and stocks to be used for these supplies are written down to realisable value.
 - (b) Graphite, on which a substantial loss will arise. Provision has been made in these Accounts for the estimated amount.
4. Provision has been made for losses which may be incurred on sales of fuel elements, at prices based on quotations made in 1956, for the initial charges of the first three civil power stations ordered.
5. The Authority have contingent liabilities under contracts for the repurchase of irradiated fuel elements from the civil power stations.
6. 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.
7. The Net Cost of Operations amounting to £68·6m. includes £5·1m. for grants to the National Institute for Research in Nuclear Science; £1·1m. for grants to international projects; £3·0m. for interest on excess stocks of certain materials which, with Treasury agreement, is not recovered in selling prices; and £1·9m. for net loss, including interest, on trading in fuel elements, graphite, isotopes, &c., in which the total turnover was £17·5m. It also includes the provision of £5m. for future losses shown under Current Liabilities and Provisions in the Balance Sheet; and a further provision to write down the cost of material, allocated for overseas fuel element business, to realisable value.
8. The amount shown as due from H.M. Exchequer to the Principal Non-Industrial Superannuation Scheme is made up as follows:—

	£
Excess of contributions and other receipts over benefits and other outgoings for the period 1 August 1954 to 31 March 1961	15,612,662
Interest on funds treated as deposited with H.M. Exchequer	1,727,764
	<u>£17,340,426</u>

The first actuarial valuation of the Scheme was undertaken as at 31 March 1960 and the outturn showed a surplus of £3·89m.

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

	£
Transfer values in respect of industrial civil servants transferred to the Authority	1,094,511
Excess of contributions and other receipts over benefits and other outgoings for the period 1 August 1954 to 31 March 1961	1,652,695
Interest on funds treated as deposited with H.M. Exchequer	449,359
	<u>£3,196,565</u>

The first actuarial valuation of the Scheme is being undertaken as at 31 March 1961.

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

	£
Excess of contributions and other receipts over benefits and other outgoings for the period 1 August 1954 to 31 March 1961	1,359,032
Interest on funds treated as deposited with H.M. Exchequer	77,749
	<u>£1,436,781</u>

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

I have examined the foregoing Balance Sheet. I have obtained all the information and explanations that I have required, and, subject to the observations in my Report, 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 1961.

E. G. Compton,
Comptroller and Auditor General.

APPENDIX V

SUMMARY OF ESTIMATES 1961/62 AND 1962/63

	1961/62	1962/63
	£	£
EXPENDITURE		
Salaries and Wages, etc.	43,257,000	43,185,000
Travel and Subsistence, Rent, Rates and other Administrative Expenses	5,259,000	5,248,000
Stores, Materials and Services for Establishments (Net)* . .	21,614,000	5,321,000
Advance Payments for Uranium and Graphite purchases . .	8,506,010	16,510,000
Research, Development and Design Contracts with Industry, Universities, etc.	4,531,000	4,881,000
Capital Expenditure on Lands, Buildings, Plant and Machinery, etc.	23,770,000	22,787,000
Capital Assistance to Contractors	37,000	103,000
Staff Housing Loans and Guarantees	94,000	130,000
Contributions towards the International Atomic Energy Projects Dragon and Halden	2,142,000	3,168,000
Grants to the National Institute for Research in Nuclear Science	6,211,000	6,790,000
GROSS TOTAL	<u>£115,421,010</u>	<u>108,123,000</u>
DEDUCT RECEIPTS		
Sales of Fuel Elements, etc.	27,003,000	30,143,000
Agency Services and Receipts under Research Agreements . .	3,198,000	3,059,000
Receipts from Contractors for Stores Issued on Repayment Terms	1,986,000	1,927,000
Canteen, Hostels and Housing Receipts	1,956,000	2,044,000
Superannuation—Employers' Contributions	2,033,000	1,971,000
Miscellaneous Receipts	1,174,000	1,104,000
TOTAL RECEIPTS	<u>£37,350,000</u>	<u>40,248,000</u>
NET EXPENDITURE	<u>£78,071,010</u>	<u>67,875,000</u>

* Net of receipts not disclosed for security reasons.

Printed and published by
HER MAJESTY'S STATIONERY OFFICE

To be purchased from
York House, Kingsway, London w.c.2
423 Oxford Street, London w.1
13A Castle Street, Edinburgh 2
109 St. Mary Street, Cardiff
39 King Street, Manchester 2
50 Fairfax Street, Bristol 1
35 Smallbrook, Ringway, Birmingham 5
80 Chichester Street, Belfast 1
or through any bookseller

Printed in England