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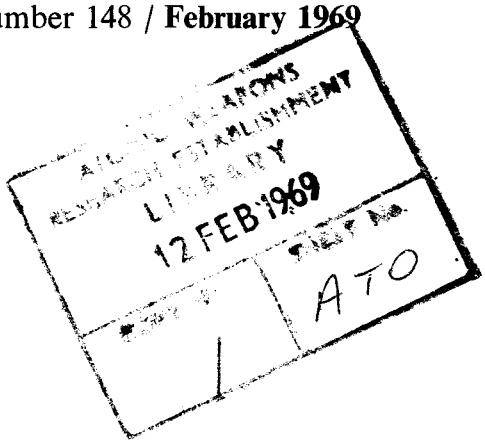

MONTHLY INFORMATION BULLETIN OF

THE UNITED KINGDOM ATOMIC ENERGY AUTHORITY

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Two new A.E.A. members

The following press release was issued by the Ministry of Technology.

The Minister of Technology, Mr. Anthony Wedgwood Benn, has appointed Dr. Norman Franklin and Dr. Hans Kronberger as Members of the United Kingdom Atomic Energy Authority for a period of five years from 1st January, 1969.

Dr. Franklin is made Member for Production, a post which since October 1967 has been covered by the Chairman, Dr. John Hill.

Dr. Kronberger is made Member for Reactor Development, replacing Mr. James Stewart who has been appointed Deputy Chairman and Chief Executive of BEE Ltd. the first of the new nuclear design and construction companies.

Biographical notes

Dr. Norman Laurence Franklin, O.B.E., was born on 1st September, 1924, at Leeds and educated at Batley Grammar School and Leeds University where he was awarded a First Class Honours degree in Chemical Engineering in 1945, an M.Sc. (Distinction) in 1948 and a Doctorate of Philosophy degree in 1952.

Dr. Franklin joined the Authority in 1955 in the Technical Policy Branch at Risley: a year later at the age of 32, he was appointed Manager of the Chemical Process Section. In February 1958 he was appointed Assistant Director, Technical Plans, and in September 1959 he became Senior Reactor and Chemical Plants Manager in the Production Group at Risley. Six months later he was appointed Deputy Technical Director and within a year Technical Director and a member of the Production Group's Board of Management. In 1963 he became Assistant Managing Director for Nuclear Fuels in the Production Group with continuing responsibility for the commercial activities of the Group in the nuclear field and for the work of the Production Group's Technical Directorate.

In August 1964 he was appointed Deputy Managing Director of the Production Group: since January 1968 Dr. Franklin has been concerned primarily

with the reorganisation of the nuclear industry.

Dr. Hans Kronberger, C.B.E., F.R.S., was born in 1920. He took an honours degree in physics at King's College, Newcastle-upon-Tyne and a Ph.D. at Birmingham University. He went to Harwell in 1946, shortly after the Establishment was formed. In 1951 he joined the Capenhurst Laboratories and subsequently became Head of Laboratories where he was primarily responsible for the development of diffusion plants for the separation of the uranium isotopes. He was appointed Chief Physicist at Risley in 1956. Dr. Kronberger became Director of Research and Development, Industrial Group, in February 1958, and in July 1959 became Director, Research and Development, Development and Engineering Group, Risley.

In 1960 he was appointed Deputy Managing Director of the Development and Engineering Group and in August 1964 he became the Scientist-in-Chief, Reactor Group, broadly responsible for formulating and supervising the research and development programme of the Group.

In 1965 he was elected to Fellowship of the Royal Society for his major contribution to the applications of physical science to all aspects of development of nuclear power for the United Kingdom programme.

New reactor group

A NEW company to be called The Nuclear Power Group Limited will be set up to design and construct nuclear reactors and power stations at home and abroad as one of the two companies foreshadowed by the Minister of Technology in his statement of the 17th July, 1968.

The new company's share capital will be held in the following proportions: U.K.A.E.A. 20%; Reyrolle Parsons Ltd. 20%; Sir Robert McAlpine & Sons Ltd. 15%; Clarke Chapman & Company Ltd. 10%; John Thompson Ltd. 10%; Industrial Reorganisation Corporation 10%; Head Wrightson & Co. Ltd. 5%; Strachan and Henshaw Ltd. 5%; Whessoe Ltd. 5%.

The Chairman will be Sir Edwin McAlpine and the Deputy Chairmen Mr. J. B. Woodeson and Mr. J. Bennett. The Managing Director will be Mr. S. A. Ghalib.

The Industrial Reorganisation Corporation intends to dispose of its shareholding in due course.

It is the intention of the Atomic Energy Authority to license each of the nuclear design and construction companies for the commercial exploitation of all British reactor systems. Negotiations will now be undertaken with the new TNPG with a view to placing with that Company by the Authority of contracts for the completion of the prototype Fast Reactor and for certain other design work connected with the F.R. system.

Dr. N. L. Franklin

Dr. H. Kronberger

New Years Honours

THE QUEEN has awarded New Year Honours to the following U.K.A.E.A. staff:—

C.M.G.
Mr. C. A. Rennie, until 30.6.68 Chief Executive, DRAGON High Temperature Reactor Project, European Nuclear Energy Agency, Winfrith.

C.B.E.
Mr. T. Tuohy, Managing Director, Production Group, Risley.

O.B.E.
Mr. J. M. Hutcheon, Head, Reactor Materials Laboratory, Culcheth. Reactor Group.

M.B.E.
Miss M. A. Anderson, Chief Executive Officer, Aldermaston.

Mr. T. C. Lightfoot, Engineer I, Springfields Works, Production Group.

B.E.M.
Mr. W. E. Rushby, Skilled Craftsman, Harwell.

Safety and siting

AN INTERNATIONAL Symposium on Safety and Siting, organised by BNES, will be held at the Institution of Civil Engineers, Great George Street, Westminster, London, S.W.1, on Friday, 28th March, 1969. The objects of the symposium are:—

To increase the awareness of designers, rather than safety specialists, of current trends in safety philosophy and siting criteria.

To provide an opportunity for stating the UK siting policy, and for discussion of the implications of the new policy on design and operation of nuclear power plant.

To illustrate the use of probability analysis in reactor safety assessments, primarily by studies of current UK designs.

To provide an opportunity to present assessments of the suitability of current and more novel systems for urban siting.

Those wishing to attend this Symposium should apply as soon as possible for registration forms to: The Secretary, British Nuclear Energy Society, 1-7, Great George Street, London, S.W.1.

Chile buys British research reactor

The Chilean Government made the following announcement on Saturday, 21st December:—

"The Government of Chile have decided to buy in Britain an atomic reactor which will allow the country to be fully incorporated into nuclear science and technology, and to be placed among the best equipped countries of this Continent in this matter.

"This acquisition has been recommended by the Chilean Nuclear Energy Commission, which will be operating the reactor. The reactor will be a part of the National Centre of Nuclear Research, the building of which is under construction.

"Both the reactor and the building in which it will be housed will be financed through a British credit.

"Also, within the framework of the Treaty on Nuclear Co-operation recently signed with Great Britain, there will be a donation of additional equipment which will allow for the full development of our activities in nuclear physics and chemics, production of radioisotopes, and will also support scientific teaching and research in Chilean Universities."

The Chilean Government are buying the reactor from Fairey Engineering Ltd., of Stockport, Cheshire. The reactor is of the HERALD "swimming pool" type and will be designed and built for the Chilean Nuclear Energy Commission for installation at a new atomic research centre near Santiago. It will be used for basic research and training scientists for Chile's future nuclear power station programme. Associated with the reactor will be a smaller non-critical training facility and a graphite stack. Total value of this export order is more than £600,000.

A HERALD research reactor is in operation at the Atomic Weapons Research Establishment at Aldermaston, Berkshire, where it is used by all Groups of the United Kingdom Atomic Energy Authority for materials-testing and neutron physics experiments. The Authority have licensed Fairey Engineering to sell research reactors abroad. Under this agreement Fairey Engineering

have access to the Authority's experience in operating the HERALD reactor at Aldermaston.

The Chilean version of the HERALD has been slightly modified in the light of the latest technology and of the particular requirements of the C.N.E.C. It is equipped with a seismic detector which in the event of an earthquake tremor would close the reactor down. Design work will start at Stockport early in 1969. A number of Chilean technicians will be working at Stockport on the project throughout the design stages.

This is the third nuclear research facility to be sold abroad by Fairey Engineering in the past three years. In 1966 the Swiss Nuclear Research Centre at Würenlingen bought a zero-energy sub-critical assembly, and in 1967 Rumania bought a HELEN research reactor.

Financing of the Chilean project has been arranged by the Overseas Development Ministry and the Export Credits Guarantee Department.

Technical description :

HERALD (Highly Enriched Reactor ALDermaston) is a thermal heterogeneous swimming-pool research reactor using ordinary light water, both as a moderator and as a coolant.

The model for Chile has two separate pools with a common shielding. One pool will house the 5 MW core, while the second will be available for future developments of the C.N.E.C. The interconnecting sluice gate is provided to facilitate the transfer of fuel elements and experimental rigs from the HERALD core to storage racks which may be sited within the transfer pond. The second pool can also be used to dismantle the rigs which have been irradiated. A hot cell is to be provided to assist in the handling of experiments and irradiation material.

The design of the fuel elements is a compromise between reactor physics, cooling and manufacturing requirements. The main physics requirement is that the reactor core should be under-moderated so that the reactor power coefficient is negative. The fuel element is the usual aluminium MTR plate type, consisting of 15 fuel plates which are held between side plates by roll-swaging. Top and bottom end boxes are welded to the element; the top box is used for lifting the element and incorporates a filter to prevent blockage of the coolant channels; the bottom box is cylindrical and supports the element on the lattice plate. The fuel plates are aluminium clad alloy 15 mm. thick separated by coolant channels 30 mm. wide. The outer fuel plates have half the uranium content of the centre plates. Each fuel element contains 165g of uranium 235 at 80 per cent enrichment. The fuel plates are slightly curved. The fuel elements are designed for close packing on a square lattice pitch of 7.5 cm.

The control of the core reactivity is for 5 MW operation invested in six absorbers which are of a flat plate form; they are positioned in two banks on either side of the core centre line.

The complete control rod assemblies working as three pairs are suspended from a steel gantry spanning the main pool.

The core will be immersed in water at a depth of 9.5 metres, with 1.5 metres of water surrounding the core for shielding purposes. The top of the core to water surface distance is 7.6 metres.

Conference on nuclear fusion reactors

THE MAJOR effort on nuclear fusion research has been on the physics problem of achieving adequate containment of a high temperature plasma. Recently a number of groups have been giving some attention to the problems of the design of a power producing nuclear fusion reactor—assuming that the containment problem will be satisfactorily overcome. These preliminary studies have already shown that there are many problems outside the current activities of the major fusion research laboratories which would benefit from a wider discussion.

An International Conference sponsored by the British Nuclear Energy Society, on these topics will be held at the Culham Laboratory at the invitation of the UKAEA from 17th-19th September, 1969 (inclusive).

Intending participants should write to: Mr. J. H. C. Maple, Conference Secretary, Culham Laboratory, Abingdon, Berkshire.

Fuel services for Italy

"COMBUSTIBILI NUCLEARI," an Italian company owned jointly by the United Kingdom Atomic Energy Authority and SOMIREN (ENI Group) has been awarded a contract by ENEL, the Italian State Electricity Board, for the supply of 80 tonnes of fuel elements for the Latina nuclear power station. The supply will be spread over a period of about three years and will satisfy about half the annual requirement of the reactor.

The fuel will be manufactured in a factory that is being constructed at Rotondella, near Taranto in the south-east of Italy. The factory will be completed in the first months of 1969 and production is planned to commence in May 1969.

New business in Italy

In addition to the above the Production Group of the United Kingdom Atomic Energy Authority has recently secured two other major items of nuclear fuel service business in Italy. The first contract complements that with Combustibili Nucleari and secures the other half of the supply of fuel elements for the Latina nuclear power station for at least the next three years.

A second contract has been signed between the Authority and ENEL for reprocessing about 40 tonnes of irradiated fuel elements from the Garigliano nuclear power station. This quantity covers all the fuel to be discharged from the reactor up to 1970. The fuel will be carried from Anzio to Barrow in the same ship that carries irradiated fuel from the Latina reactor.

Background notes

Combustibili Nucleari

The present contract is the first to be awarded to "Combustibili Nucleari," a company established in Italy for the supply of services relating to fuel for nuclear reactors.

Recent U.K.A.E.A. business

The above contracts bring the total of export fuel service business won by the Production Group of U.K.A.E.A. during 1968 to over £10m.

Other major contracts signed within recent months have been for the reprocessing of irradiated fuel elements from the Tokai Mura reactor of JAPC in Japan, for reprocessing of the fuel from the Beznau reactor of NOK in Switzerland, for sale of plutonium to Belgo-Nucléaire in Belgium and for conversion of uranium ore concentrate to uranium hexafluoride for AEG in Germany. Many smaller orders have also been secured and overall prospects for further business appear to be good.

Latina nuclear power station

The Latina nuclear power station of ENEL having an output of 200 MW(e), incorporates a gas-cooled, graphite moderated reactor, and was built by the Nuclear Power Plant Company of the U.K. (now a partner in TNPG) in conjunction with AGIP Nucleare. The station started operation in December 1963 and has been fuelled throughout its life with fuel elements supplied by U.K.A.E.A., Production Group. It has operated with consistently good performance having achieved a cumulative load factor of over 83%.

Garigliano

The Garigliano nuclear power station of ENEL has a 150 MW(e) boiling water reactor. It is situated on the Garigliano river between Rome and Naples and has been in operation since 1963.

30th December, 1968

High temperature chemical technology

HARWELL is now able to apply its expertise in high temperature chemical technology to research and development on processes of interest to industries in the U.K. outside the nuclear power field. This follows the issue by the Minister of Technology of a Requirement under the Science and Technology Act 1965.

High temperature research at Harwell involving applied chemistry, chemical engineering and applied metallurgy has made major contributions to the improvement and cheapening of processes for the production of nuclear materials to exacting requirements. Such processes have involved diverse techniques, including the application of fluidised, vibrated and stirred beds to solid-solid and solid-gas reactions, the use of molten salts as reaction media and the application of powder metallurgy in novel ways. Re-

search and development in these and allied fields can now be carried out for industry generally; discussions and negotiations with particular industrial firms have shown both that there is a substantial demand for this kind of work and that it is in the national interest to turn the Harwell expertise towards these wider problems. Initially the new programme of work will concentrate on processes and techniques of importance to a range of industries involved in the production, refining and fabrication of metals and refractory compounds.

In particular, work originally undertaken for the nuclear programme on the design of economical continuous chemical reactors will be devoted to processes for the production of metal powders by the reduction of oxides and halides. Allied work at Aldermaston is aimed at producing oxide feed materials for metal and alloy powder production using a novel gel-precipitation technique. Sintering of powders in controlled atmospheres, originally developed for application to ceramic fuel fabrication, will be developed as a method of fabricating very fine metal powders into strong high-density components. Other work will include studies of reactions between molten metals and slags, and the development of techniques for the on-line control of high temperature processes. Discussions with industry are resulting in proposals both for joint programmes and for sponsored work.

The nature of work to be undertaken will continue to be decided in consultation with industry and with the Ministry of Technology. When fully operational the programme will employ an annual effort equivalent to about 22 professional man-years at an annual cash cost of about £175,000 p.a. The effort required will be found by transferring staff gradually from the nuclear programme as the industrial demand for the work grows.

Enquiries concerning the project should be addressed to Dr. R. G. Sowden, Applied Chemistry Division, Building 429, A.E.R.E., Harwell, Didcot, Berkshire.

High temperature equipment available to the new research programme

Techniques and equipment available to the High Temperature Chemical Technology Centre at Harwell, Culham and Aldermaston, include the following:—

Transpiration techniques, Knudsen cells and mass spectrometers for vaporisation studies to 2300°C.

Thermal analysis apparatus for phase studies up to 2500°C including recording microbalances, DTA equipment and dilatometers.

X-ray diffraction equipment for use up to 2500°C.

Galvanic cells for fluorine and oxygen activity determination up to 1300°C.

Gas equilibration techniques for oxygen activity measurement up to 2200°C.

Equipment for thermal diffusivity measurements up to 1500°C.

Chemical and electrochemical techniques for carbon activity determination in gases and liquid metals.

Micro-reactors for simulation of agitation in chemical plant; horizontal stirred-bed, fluidized-bed, vertically moving-bed reactors, vibrated tray reactors and atomised suspension contactors for work on gas-solid reactions up to 2200°C.

Induction and resistance furnaces for use to 3000°C.

Equipment for studying molten slag/metal/gas reactions in levitated drops at temperatures up to 2000°C.

Plasma arc and high energy electron beam equipment. Techniques for plasma diagnostics including measurement of electron temperature and density, cross sections for molecular dissociation and ionisation and transport co-efficients.

In addition, a wide range of analytical techniques is available in the Harwell Analytical Sciences Division.

8th January, 1969

Fast reactor physics

A three-day conference on The Physics of Fast Reactor Operation and Design, will be held at the Institution of Civil Engineers, Great George Street, Westminster, London, S.W.1, from 24th-26th June, 1969 inclusive.

Those wishing to attend this conference should apply as soon as possible for registration forms to: The Secretary, BNES, 1-7, Great George Street, London, S.W.1.

IN PARLIAMENT

300 GeV accelerator

5th December, 1968

MR. FORTESCUE asked the Secretary of State for Education and Science what representations he has received requesting the Government to reconsider their policy with regard to the 300 GeV nuclear accelerator planned by C.E.R.N.; and what reply he has sent.

The Minister of State, Department of Education and Science (Mrs. Shirley Williams): Apart from the Parliamentary representations with which the hon. Gentleman is familiar, I have received representations from the hon. Member for Eastleigh (Mr. David Price), the Secretary of the Association of Scientific, Technical and Managerial Staffs and a number of individual nuclear physicists. In addition, the Chairman of the C.S.P., while not asking the Government to reconsider their decision, did express his deep regret that the Government had found it necessary to decide against participation. The views expressed and my replies are covered by the discussions on the 300 GeV accelerator in the Consolidated Fund Bill debate on 24th July.

Mr. Fortescue: While thanking the Minister for that reply, may I ask whether she has given further consideration to the recommendation of the Nuclear Physics Board, that not only should we participate in this project, but that our participation could be paid for by reducing expenditure on existing obsolescent accelerators.

Mrs. Williams: We have given some consideration to the matter. As the hon. Gentleman will be aware the Nuclear Physics Board bases its proposals on the assumption that the site would be in Britain and there are strong indications that the site would not be in this country.

Uranium survey

9th December, 1968

MR. GWYNFOR EVANS asked the Secretary of State for Education and Science, what surveys he proposes to make in Wales to discover the location of uranium; and what are the results of previous surveys.

Mrs. Shirley Williams: The Institute of Geological Sciences (on behalf of the U.K.A.E.A.) is conducting a survey for uranium in the United Kingdom. This is likely to include certain areas in Wales. Uranium-bearing shales were located near Dolgelly by the former Atomic Energy Division of the Geological Survey (now Institute of Geological Sciences) 14 years ago, but were not at that time regarded as economically worthwhile.

Reorganisation

10th December, 1968

MR. GREGORY asked the Prime Minister if he is satisfied with the co-ordination of the work of the Minister of Power and the Minister of Technology on the reorganisation of the nuclear engineering industry, in seeking to ensure the best use of industrial resources for domestic use and for exports; and if he will make a statement.

The Prime Minister: Yes. The prime responsibility for the reorganisation of the nuclear industry rests with my right hon. Friend the Minister of Technology, but he works in close cooperation with my right hon. Friend the Minister of Power on these matters.

Sizewell 'B'

10th December, 1968

SIR H. HARRISON asked the Minister of Power what is the starting date and what are the estimated completion dates, for the building of the second nuclear power station at Sizewell, and the estimated date when the station will generate electricity for the public.

Mr. Mason: I am still considering the Central Electricity Generating Board's application for consent for this station.

Sir H. Harrison: Is the right hon. Gentleman aware that when the original station was built, it was designed to have a second one there and that this is rather expected, provided it is a sound financial proposition?

Mr. Mason: I have two requests before me for stations, but I have not yet decided where they will be built and what type of fuel will fire them.

Seaton Carew

10th December, 1968

MR. WOOF asked the Minister of Power why he based his decision to approve a nuclear station at Seaton Carew on a comparison with a coal-fired station, the capital cost of which

continued on page 52

Planning for future enrichment plants

This paper, by C. Allday, D. G. Avery and R. B. Kehoe, of Production Group, UKAEA, was presented at a symposium, Nuclear Fuel Utilisation, *organised by the Federazione Delle Associazioni Scientifiche e Techniche, in Milan from 12th-14th December, 1968.*

Synopsis

The United Kingdom and European requirements for enrichment and the plans for meeting them are discussed. Particular aspects of the problem of optimising the installation of plant and its subsequent operation are considered, with particular reference to differentiation between the diffusion, nozzle and centrifuge separation processes.

Introduction

During the last three years, the U.K. diffusion plant at Capenhurst has been undergoing modification to make it suitable for meeting the low enriched fuel requirements for the British A.G.R. programme. By mid-1970 the plant will have adequate capacity to meet the expected domestic British requirements until about 1974. Thereafter, rapid increases in separation capacity will be required for the fuelling of nuclear stations which are expected to be commissioned in 1975 and beyond. Decisions on such further expansion must be made some four or five years in advance of the requirement and, therefore, are imminent.

Methods for the optimisation of plant construction and operation used in the U.K. were discussed in the context of diffusion plant in a paper presented to the Turin conference on enrichment in October 1968 (Ref. 1). These methods are not, however, specific to the diffusion process and are applicable whatever method is chosen for isotope separation. The papers reported at Turin on the nozzle process (Ref. 2) and on the ultracentrifuge (Ref. 3) all confirmed the conclusion based on our own development work that alternatives to the diffusion

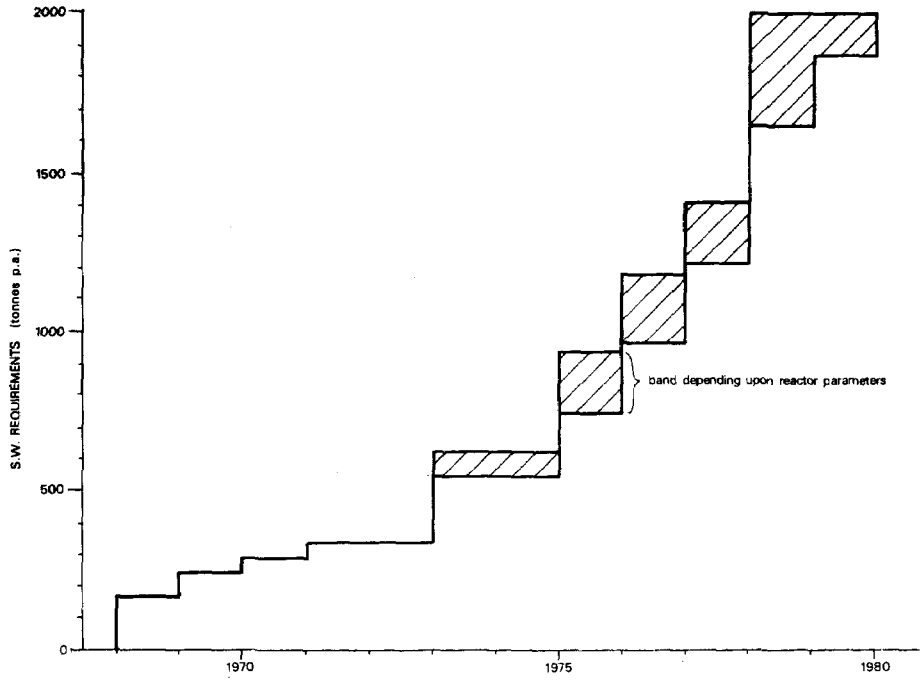

Fig. 1. *Estimated U.K. requirements for separative work (assuming all natural uranium feed).*

process must be considered for new plants in the mid-1970's.

This paper describes progress with the British programme for the provision of enrichment and discusses in a European context some of the problems which will be faced in determining the future expansion of enrichment capacity.

U.K. enrichment requirements

The expected growth of separative work requirements in the U.K. is shown in Fig. 1. The requirements during the next five years are determined by the programme to 1975 announced by the Government, but thereafter the rate of growth and the type of reactors to be installed become less certain.

Production at Capenhurst re-started in 1967, but development work aimed at improving efficiency for low enrichment production had been in progress since 1960. This work led to a decision in 1965 to modify, at a cost of £14m, the largest stages of the plant. These modifications will enable the separative work output of these stages to be increased substantially. The rebuilt stages will be introduced into the operating cascade progressively over the period 1969-70 and the resulting available capacity will approximately match the U.K. requirements shown in Fig. 1 until 1974. The subsequent requirements are seen to increase rapidly to around 800 tes S.W. in 1975, and 2000 tes S.W. in 1980 on natural feed.

European enrichment requirements

Figure 2 shows the comparable requirements for demand in the European countries, grouped for convenience into those within the E.E.C., and within the E.F.T.A. countries excluding the U.K. There have, of course, been many estimates of these requirements, and in the figure we have tried to reflect the concensus of the various views. If we assume

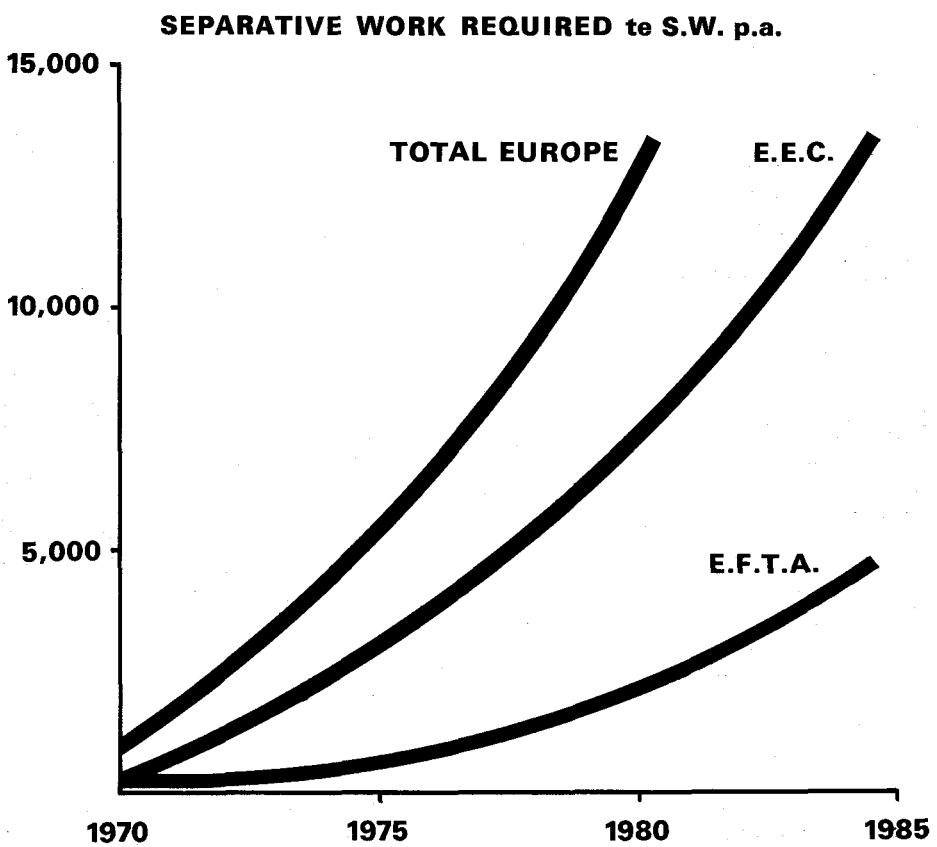

Fig. 2. *European separative work requirements.*

that some part of the early requirements will be met by purchase or toll enrichment from the U.S.A., then it will be seen that the pattern of European demand is similar to that of the requirements for new capacity in the U.K., but that the total European requirement (E.E.C. + E.F.T.A. + U.K.) is around six times that of the U.K. alone by 1980.

Planning the production of enrichment

The preceding paragraphs have outlined the requirements in the U.K. and in Europe in terms of separative work capacity. However, what is required is enriched uranium and not merely separative work. It is necessary when planning to provide for a reactor fuelling programme, to take into account likely trends in uranium price and in future enrichment plant costs as well as the capacity and flexibility of existing plant.

This optimisation problem has previously been considered in some detail (Ref. 1). A point of some importance is that with satisfactory plant flexibility it is possible to work with high or low waste concentrations. Thus a period of high uranium demand can be met by working at a high waste concentration. There will, of course, be a corresponding high rate of feed and therefore of uranium usage, but the partially stripped waste can be re-fed to the plant in a period when the product demand is low. This does not imply any inefficiency in the use of uranium and using the optimisation techniques which we have developed, we find that this type of operation should be regarded as normal in the provision of product from a growing enrichment capacity servicing an expanding nuclear programme. It is also important as an insurance against possible delays in the introduction of new capacity especially if this involves a new process. Thus, given access even to a relatively small plant, enriched uranium demands can be maintained for periods of perhaps 12 months, albeit at a high initial cost for the uranium feed, but without excessive long term economic penalty.

Such an optimisation should provide an installation programme for new plant involving minimum total discounted cost over a period. There is now in addition, the possibility of choice between at least three enrichment processes, and the most effective means of comparison is to optimise for each process separately and then to determine which route gives the lowest discounted cost. The paragraphs below consider further some of the more important factors which are relevant to the choice between processes.

Planning horizon

Different planning horizons are relevant to different phases of the whole activity. The overall strategy of plant installation must be decided upon against a long term horizon in order to plan development and design work. Thus it may be necessary to begin development on a new plant whose installation date is ten years away. At the investment phase, because of construction times, decisions must be taken several years before plant is commissioned, but because reactor construction times tend to be even greater, the degree of uncertainty in requirements for U235 will probably not be large. However, the optimum installation at a given time may still be a function of long term requirements. Thus, it would not, for example, be economic to develop and intall a few new large diffusion stages if there were no expanding requirement for this type of stage to justify its development cost.

Fuel cycle integration

The enrichment plant can receive feed from the chemical reprocessing of irradiated reactor fuel as well as natural hex and depleted hex produced earlier as waste. Also, the output is fed to fuel fabrication facilities which may at one extreme be a simple, one enrichment line, or at the other extreme, a complex of plants simultaneously requiring different enrichments for different reactors. This is a complicated scheduling problem in which stockholding must be kept to a minimum. It has been studied in detail (Ref. 4) elsewhere, and is a consideration which must be included in the planning of enrichment plant strategies.

Diffusion plant considerations

An important consideration in planning based on use of the diffusion process is the ultimate capacity required. This is because the final cascade will be

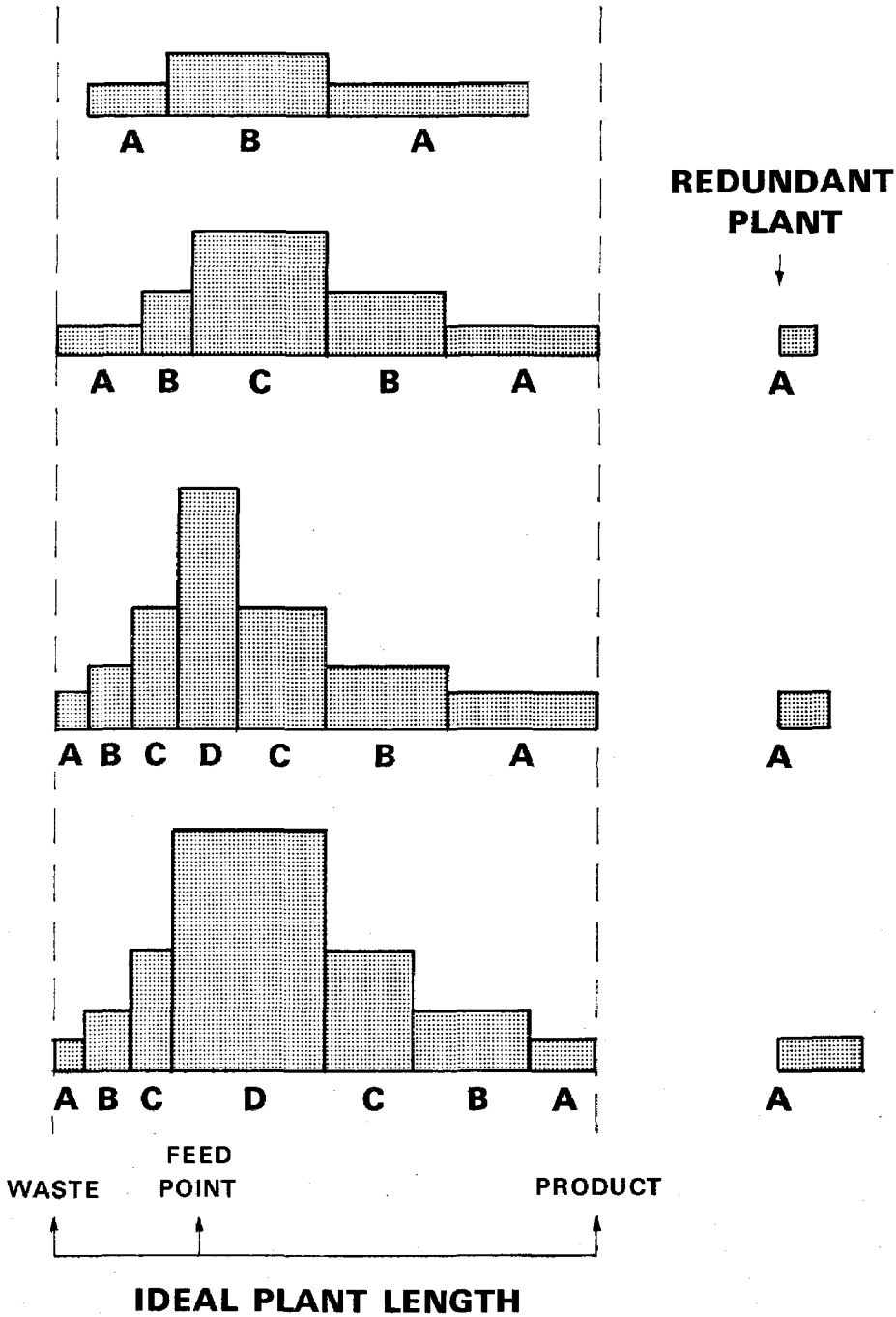

Fig. 3. *Illustrating how diffusion plant capacity can be increased. The height of each block represents the power of the individual diffusion plant stages and the width is proportional to the number of stages of each type. The total area of the blocks is, therefore, proportional to the capacity of the whole plant.*

achieved by inserting larger and larger stages into the feed point of the cascade and at the same time, rejecting some or all of the smallest stages at the product and waste ends of the cascade. (See Fig. 3). For the cascade to retain its approximation to ideal shape, it is necessary to make an early decision on the assumptions of long term growth pattern and hence of the eventual ultimate plant size. The subsequent procedure for proceeding through plant size optimisation at intermediate stages is discussed in Ref. 1.

However, decisions on the stage sizes and their rates of installation are only part of the problem. A diffusion plant itself might cost £60-70/kg. S.W. p.a., but the associated power requirements will themselves involve a further capital cost of about 40% of this figure. If the final size of the diffusion plant is, say, 3,000 tes S.W. p.a., the total power requirement would be of the order of 1,200 MW and the siting of the whole complex will be affected by decisions on the source of power. If a separate nuclear power station is envisaged, then the customary safety considerations for the power station will apply, coupled with availability of cooling water and site engineering considerations. If the diffusion plant is to be driven from an existing electricity supply system, then the capacity of that system and its stability under fault conditions will be of importance in addition to the obvious consideration of power cost.

An early decision, reflecting on decisions about power supply, is required at the design stage to determine the capability of the diffusion plant to accept interruptions in the power supply. If a sufficient reduction in electricity tariff can be negotiated from a utility in return for a defined degree of interruptability to ease the utility's peak load problem, it would be worthwhile designing the plant so that these interruptions could be accepted without risk of damage to plant components.

The inherent flexibilty of diffusion plant is important. The plant can work with different and even multiple feeds, products and wastes without excessive losses of efficiency. Thus a plant with a capacity of 1000 tonnes S.W. p.a., optimised for natural feed, 0.3% waste and 3% product could, for example, produce approximately as follows using natural feed:

Product		
Enrichment	*Quantity (tonnes p.a.)*	*Waste concentration*
2%	570	0.3%
3%	290	0.3%
4%	190	0.3%
3%	230	0.2%
3%	350	0.4%

Ultra-centrifuge considerations

In the case of the ultra-centrifuge it is not the ultimate size of the plant but the rate of installation which would appear to be a controlling factor. Ultra-centrifuges are likely to be installed in banks of single cascades. Thus, if the output of one such cascade were, say, one tonne of separative work per year, then to achieve an output potential of 1000 te SW/year over a space of 10 years would require installation of two cascades per week which in turn would be likely to involve manufacture of several hundreds of individual centrifuge machines per week. Clearly, such a plant would not be started up in large blocks as would a corresponding diffusion plant; capacity would expand progressively and uniformly with little scope for change of rate. However, providing requirements build up with reasonable uniformity or do not pass through a peak, it should be possible to match installed centrifuge capacity to demand.

It is not yet clear from published technology whether centrifuge cascades can offer as much flexibility as diffusion plant in terms of enriched uranium output as a function of uranium feed rate and waste concentration. In principle, however, it is clearly possible to construct at the outset cascades designed to run at high waste concentrations to give a large enriched uranium output in relation to their separative work capacity. Such cascades could later be modified to work at lower waste concentrations. Equally, cascades could be constructed to accept various concentrations of feed, i.e. partially stripped uranium from earlier overdriving or slightly enriched uranium from irradiated fuel processing. However, to achieve the same flexibility as is offered by a diffusion plant appears to necessitate either some degree of complication in

cascade design involving extra capital cost or increased stockpiling with associated interest charges. Clearly much detailed optimisation work would be required.

It would appear on present evidence that the capital costs per unit of separative work output would be much the same for centrifuges as for diffusion plants, but because the energy consumption is an order of magnitude less, the questions of power supply are of much less significance although the requirement for a completely firm supply is probably greater.

Another interesting difference between the diffusion and centrifuge processes is in the effect of scale on costs. As the recent U.S.A.E.C. publication (Ref. 5) illustrates, there are significant cost advantages in building a single big diffusion plant as opposed to several smaller ones. In the case of the centrifuge, however, whilst there could well be economies of scale through concentration of machine manufacture, it is not immediately obvious that there will be comparable economies in the enrichment plants themselves. In the European context, therefore, whilst a single European diffusion plant seems desirable if maximum economy is to be achieved, the same may not be true for centrifuge plants.

Similarly the problem of obsolescence of small diffusion plant stages as plant expansion proceeds does not arise with centrifuge plant. There is, however, another aspect which is in some respects similar. As a newer technology, centrifuge development can be expected to proceed fairly rapidly and if the centrifuge process is adopted, it will be a difficult planning judgment to decide upon the extent of investment in designs which are likely soon to become obsolescent.

Nozzle separation process

The problems associated with the planning of a nozzle-jet separation plant are not as yet as clear as those for the other processes. However, it appears to have much in common with a diffusion plant. Plant shape could be important, and the problems of stage obsolescence during expansion must, therefore, be considered. It would seem that strong arguments exist for building a large single unit as for the diffusion plant, since the efficient use of electrical power in the compressors and compressor drives can be more readily achieved in larger units.

Since the process, as at present conceived, requires even more power than the diffusion plant, considerations of siting in relation to power supply become of major importance. It may be easier to design plants based on this process which can accept interruptions in power supply to take advantage of tariff reductions on this account.

On the other hand, it is not clear whether the process offers the same flexibility in enrichment output as a diffusion plant and similar problems in respect of development improvements must be faced as for centrifuges.

Conclusions

Based on the above optimisation techniques and noting the above technical factors, the choice, on grounds of least cost, can be made between processes. The comparison must, of course, take full account also of development costs, licensing fees and royalties as necessary and also of any limitations which may be imposed by local engineering and manpower problems.

It is clear from the problems which have been discussed that an overall optimisation on a European basis might lead to different conclusions than if the individual countries or groups of countries proceed separately. The total combination of resources and markets, and the larger scale of production required will all influence the relative status of these alternative processes. The presence within the total European grouping of two existing diffusion plants could also have an important bearing in providing already a basis on which to meet early demands and which could serve as an " insurance " during the early stages of starting new projects.

Finally, it will be recognised that it is not possible for the present paper to reach conclusions on overall comparisons between the various enrichment processes without disclosure of detailed capital and operating costs and technical assessment data. However, it has been attempted to identify and discuss some aspects of the overall optimisation which should be considered either in a national or a European context. Apart from quantifiable econo-

mics, technical assessment and judgement of the capabilities of the various processes will also inevitably be involved.

In presenting this paper, Mr. C. Allday, Commercial Director, Production Group, UKAEA, made the following statement:

It will be clear from what I have said that we in the UK are now faced with some major decisions. We must provide for increased supplies of enrichment for our own programme by about 1974. Our work on the centrifuge method of enrichment which was re-started in about 1960 has shown that this method offers prospects of producing enrichment at equivalent or lower costs than our diffusion process. In addition, the centrifuge process offers the prospect of greater convenience in that increments of capacity can be more easily added progressively. On the other hand, the diffusion process is, for us, well established, and we can be completely confident about our cost predictions for extensions of capacity. In addition, as we pointed out in the paper, a given diffusion plant cascade has very considerable flexibility in operation and we are not yet certain whether this can be achieved with a centrifuge cascade, and if not, whether it offsets the advantage of the latter in being able to add increments of capacity.

It is clear that precise timing of our expansion programme can be varied. The optimum timing will depend on (a) quantity of enrichment required, (b) economic advantage of the new capacity compared with the old, and (c) planning horizon used. There can be clear advantages from an early start on new plant, provided that its overall economy is superior to the old.

We shall therefore be making an early decision on when our new capital investment should be made and clearly this is now also influenced by the international discussions on co-operation in the enrichment area which have recently been announced. There are many advantages in such co-operation, although it has to be recognised that international ventures of this sort must almost inevitably cause some delays.

It is against this background that we have considered our position in relation to supplying enrichment to overseas customers. Our position can be summarised as follows. We expect to have surplus separative work capacity from 1974 on. We do not yet know for certain how this will be provided but it will probably be by centrifuge. If so, machines will be made either unilaterally by us in the UK, or collaboratively in Europe. The plant itself may be at Capenhurst operated by us, or may be a collaboratively operated plant situated at Capenhurst or elsewhere in Europe. In these circumstances it is clearly difficult for us to honour our undertakings to quote a detailed price-scale by the end of this year. Indeed it would probably be damaging to the prospects for the international co-operation we all seek, for us to do so. However, on the assumption that surplus capacity will be available at Capenhurst, we are willing to discuss with individual prospective customers supply of enrichment along with associated conversion services. We are confident that attractive overall terms can be agreed.

Finally, I hope it will be recognised that it is not possible to present in this paper conclusions on overall comparisons between the various enrichment processes without disclosing detailed capital and operating costs and technical assessment data. However, I hope the paper is of some interest to all those who are interested in fostering the idea of a European enrichment plant complex.

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Concrete pressure vessels

A SYMPOSIUM on Model Techniques for Prestressed Concrete Pressure Vessels is being organised by the British Nuclear Energy Society from 10th-11th July, 1969.

Further details of the symposium will be published in the March issue of ATOM.

Growth potential for isotope applications in environmental and ocean sciences

This paper, by D. B. Smith, leader of the Geophysical Tracers Group, Isotope Research Division, A.E.R.E., Wantage Research Laboratory, was presented to the International Conference on the Constructive Uses of Atomic Energy, at Washington from 10th-14th November, 1968. The organisers of the conference were the American Atomic Industrial Forum and the American Nuclear Society.

Introduction

The object of this paper is to review the growth potential for isotope applications in the environmental field during the next decade. This includes application to hydrology, oceanography and meteorology defined in their widest terms.

Methods of looking into the future are necessarily imprecise and often more subjective than is desirable. A general technique is to review the work of the past decade, see how this has developed and try to project it into the future. The result of such a projection done at the present time should then be modified to take account of the continuing change of emphasis in the policy governing scientific research from the pursuit of research as an end in itself to the evaluation of research in terms of its direct social or economic benefit.

Growth can come both from the improvement and increased application of existing techniques and from the introduction of new techniques. The application of isotopes to environmental studies is already well established and so the former consideration is by far the more important. This may not sound exciting to many scientists but it is at this stage that real economic benefit can be gained from research. Suprisingly, this is often the stage at which the scientist loses interest and the results of his research can therefore take much longer to be exploited than they should.

Increased application of isotope techniques to environmental disciplines, if indeed they are as advantageous as we believe, will come through initiation by the environmental scientist rather than from the isotope technologist. It is essential that isotopes are not viewed in isolation but that isotope techniques take their place with established methods to form an additional tool for environmental studies.

This brief review of growth potential for isotope applications in hydrology, oceanography and meteorology presumes a considerable background knowledge of isotope techniques and environmental science on the part of the reader.

Applications to hydrology

The last decade has seen a great increase in hydrological research, partly stimulated by the International Hydrological Decade. The role of isotopes in this research has steadily increased and through close collaboration which has built up between hydrologists and isotope technologists, many isotope techniques are already being regularly applied in hydrology.

Naturally occurring radioactive isotopes

The most important naturally occurring isotope used in hydrological studies is tritium. The concentration in rainfall resulting from cosmic ray production of tritium was about 5 tritium units (TU)*. Since 1954, this has risen in the northern hemisphere due to thermonuclear testing to a peak of several thousand TU's in 1963 and has subsequently fallen with a "half-life" of just over a year. In addition, each year has seen an annual cycle with a maximum in late spring when tritium is transferred from the stratosphere to the troposphere. This vast input of tracer to surface water and thence to ground water has provided much raw material for hydrological investigations.

In the past decade, investigations have been carried out into ground water recharge, aquifer characteristics such as

* 1 tritium unit (TU) = 1 tritium atom per 10^{18} hydrogen atoms and produces 7.2 disintegrations per minute per litre of water.

flow velocity and storage capacity, pollution and measurement of water movement in the unsaturated zone.

The future of natural tritium applications is particularly difficult to assess since the large-scale production is not controlled, or even influenced, by hydrological interests. The reducing tritium levels, which make both measurement and interpretation more difficult, will probably continue. In spite of this, the high tritium levels of the early 1960's are still present in many ground water systems and with selective application, many more major investigations should be carried out in the next decade.

Two outstanding problems require further study. One is the stratification of ground water in different aquifers. Data interpretation in the past has often had to be made from pumped samples which consist of water from different horizons. This can produce most misleading results and much more knowledge is required about stratification. Even with such knowledge, future investigations may require samples from specified depths, an expensive and often restrictive operation. The second problem is the hold-up of tritium in the aerated zone above the water table. Fissure flow of water is often assumed whereas field measurements are showing a greater degree of displacement flow by downward transfer from granule to granule. This results in a long delay before tritium reaches a deep water table and with the present state of knowledge can lead to erroneous interpretation of ground water tritium data.

Other applications of naturally occurring tracers centre on carbon-14 which occurs in ground water as dissolved bicarbonate, partly composed of carbon from the atmosphere. "Dating" of waters with an age range from 1,000 to 20,000 years is becoming established. Demand for these measurements will increase, although the method is restricted to old waters. Used in conjunction with tritium, it can help to identify mixtures of very old and modern water. Will there be hydrological applications for the recent factor-of-two increase in the carbon-14 in rainfall?

Other naturally occurring isotopes have been suggested for ground water investigations. One is silicon-32 (half-life 600 yr) which could provide a tracer for waters of intermediate age between the tens of years covered by tritium and the thousands covered by carbon-14. The very low natural concentration and problems of loss in transit through an aquifer preclude wide application in the future, although silicon should be considered, in spite of its limitations, for problems to which there is no alternative solution.

Stable isotope applications

The variation of the stable isotope ratios of deuterium and oxygen-18 provides information which can be used in hydrological and meteorological applications. The variation arises from preferential precipitation of the heavier isotopes and preferential evaporation of lighter isotopes. Hence ground waters of different origins (either geographical, thermal or chronological) have different isotope ratios from which ground water interconnection, mixing and pollution can be studied. Other applications include study of ice profiles, variations in climatic history and surface water evaporation studies.

Stable isotope measurements are becoming well established as a method of obtaining additional information in hydrological investigations. Although application is limited to areas where natural variations occur, it is likely to be more widely applied in the next decade.

Radioactive tracer applications

These cover many aspects of hydrology and although their use is well known, their potential is by no means fully exploited.

Tritium is the obvious tracer for ground water studies but it is difficult or impossible to measure in situ. A search for alternative soluble chemical tracers which can be labelled with a γ-emitting isotope and which are not adsorbed in the ground has led to the use of iodine-131, bromine-82 and complex forms of tracer such as chromium EDTA (Cr^{51}) and potassium cobalticyanide (Co^{60}).

Applications have progressed from qualitative tracing of ground water to quantitative methods of borehole pumping to yield aquifer parameters such as effective porosity, permeability, thickness and ground water velocity.

Tracer methods have been developed and applied for the accurate measurement of river flow where they have advantages over conventional salt or dye dilution techniques in the ease and sensitivity of tracer measurement and in being unaffected by pollution.

The use of radioactive tracers in ground water investigations is sure to be a growth area in the next decade. In countries where water is at a premium, such as Israel, they have already been widely applied. The better understanding of radioactive hazards and the wider public acceptance of radioactivity which has occurred in the last decade will assist in the increased use of tracer techniques. If the natural tritium level continues to decrease, low level tritium measurement laboratories will have more effort available to undertake tracer investigations at concentrations of a few hundred tritium units. This will provide a very powerful tracer which avoids health problems and can be used economically on a very large scale. It should be realized that tracer tritium application precludes further natural tritium investigations in the same locality, but this is not necessarily very restrictive. As an example, a catchment with a mean annual surface run-off of 1 m^3/sec. at a concentration of 100 TU would discharge 10 curies of tritium per year. Hence a tracer experiment using several curies of tritium on the catchment is unlikely to completely nullify natural tritium results even within the restricted area of the catchment.

Recurrent problems of importance include reservoir bed or dam leakage, canal leakage, river recharge to ground water and the time distribution of run-off from a catchment (for flood studies). These are all problems which have already used radioisotopes, but to which more effort should be devoted in the future.

Instrumental techniques

Nuclear instruments are finding increased use in hydrology. Probably the most widely used at present is the portable neutron soil moisture gauge which is already used routinely and in the next decade could become the accepted method of moisture measurement in a wide range of applications, including civil engineering, agricultural research and irrigation projects.

Gamma-ray absorption measurements are used to determine the density of soils and the water content of snow pack, although fixed instruments for the latter application are mainly confined to sites where public access is limited.

Instruments using small amounts of radioactive tracer are being used and developed for measuring ground water velocity and direction in shallow perforated or unlined boreholes. They are quick and inexpensive to use, but have the disadvantage that they make a local measurement in an area where natural flow conditions are liable to be altered by the borehole. Another instrument also uses tracer to measure the vertical water velocity in a borehole, from which areas of entry or loss of water can be located. All these instruments are likely to remain research tools for some time, but their use is certain to widen beyond the few groups currently using them.

Borehole logging techniques

Borehole exploration techniques, using nuclear methods, have been very highly developed for oil well application and have only been used to a very limited extent in water exploitation.

The methods and applications include:—

(a) Natural gamma-ray logging—stratigraphical correlation, estimation of clay particularly in stratified quaternary deposits.

(b) Gamma-gamma logging—strata density from which information can be obtained on porosity.

(c) Neutron logging—several methods for estimating the water content of strata.

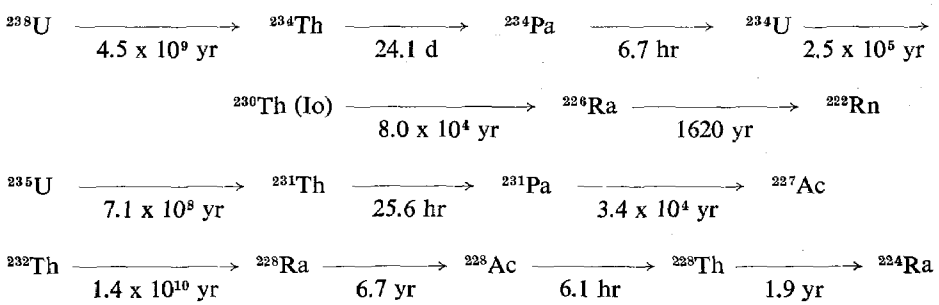
(d) Neutron-gamma logging—this has been used to locate a water-brine interface in a cased borehole.

Proven equipment exists and commercial teams operate in the oil industry. Application to hydrology is only a matter of time and is governed by considerations of cost and benefit.

Applications in oceanography

Oceanographic research involves a very wide range of disciplines and has a multitude of objectives. It is a rapidly expanding field with the general object

Table 1



of economic savings in such diverse fields as ocean transport, mineral exploitation and food production.

During the last ten years, the 'doubling time' for the U.S. expenditure on studies relating to the ocean has been just over three years. It is unreasonable to expect this rate of expansion to continue during the next ten years, but there are certainly 'growth' prospects during this period, particularly in view of the increasing interest in exploitation of the continental shelf. It is also possible that some of the present research investigations will move into the development and exploitation phase and will attract more commercial support for oceanic investigations.

The role of isotope techniques is one of support to the oceanographers, engineers, geologists and geographers and in this capacity, their application covers a wide field, varying from primordial dating to current meters and power sources.

Applications of naturally occurring isotopes

The oceanographic applications of naturally occurring isotopes are principally concerned with the 'dating' of events, such as sedimentation of coastal land and water level changes and with the mixing of ocean waters.

Primordial isotopes of the uranium and thorium series have been used for dating marine sediments for some 20 years. Table 1 shows the relevant parts of the two series.

The first technique to be applied to sediments was based on the precipitation of thorium-230 (ionium) and its inclusion in the sediment where it decays with a half life of 80,000 years. The age of the deposit can be inferred from the rate of reduction of ionium with depth in the sediment. The method has to assume that there is a constant rate of deposition of ionium and that no migration of the isotope occurs after deposition. Field results do not entirely support these assumptions, and this has led to more refined dating methods depending on the simultaneous deposition of two isotopes such as thorium-230 and thorium-232. A further development uses the ratio of protoactinium-231 and thorium-230 to obtain dates back to about 2.10^5 years.

These geochronological techniques have already been widely applied and have shown ocean sediment accretion rates from a few millimetres to a few centimetres per thousand years. However, there are many more problems to be studied, and if expansion continues at the same rate (based on the number of published papers, 1945-1967), then an increase of some 50% above the present level is to be expected in the next 10 years. A greater expansion may be anticipated in view of the current interest in oceanography and would be stimulated if the subject became of more commercial rather than academic interest. Possibly chronological techniques can cast more light on interesting deposits such as manganese or phosphate nodules. Although dating techniques other than those proposed in the literature may be developed, it is more likely that the method will progress by development, refinement and better understanding of problems associated with the present methods.

A number of cosmic or man-made radioactive tracers have been produced in the atmosphere and applied in ocean-

ographic studies. Tritium is potentially an excellent tracer for studying short-term phenomena, although the input from the atmosphere to the oceans in the last 15 years has been very complex and not very well determined. Nevertheless, it has been used to examine surface water mixing and to estimate the residence time of water above the thermocline. It is a measure of the interest in tritium as an ocean tracer that the tritium concentration of 640 ocean samples had been reported to I.A.E.A. by 1966 and subsequently published. The declining input of natural tritium to the oceans indicates a corresponding decline in applications in the next decade. Should high atmospheric levels again be established, it is likely that the scientist will be less pre-occupied with the problems of measurement of low level tritium and more able to produce valuable oceanographic results from the method.

Carbon-14 has been fairly widely applied in the marine environment. It is of interest that of 3,000 measurements reported in *Radiocarbon* (1967), some 6% relate to oceanographic or coastal topics. These include coastal studies of beach development and sea level changes, sediment and coral dating, vertical ocean mixing across the thermocline, slow, deep-water currents and carbon dioxide ocean-atmosphere exchange. The application of carbon-14 is likely to continue to expand and possibly the recent doubling of the natural level in the biosphere will stimulate its use as a tracer for relatively short-term phenomena.

Applications of radioactive tracers

One of the major uses of radioactive isotopes in oceanography has been their application to coastal silt, sand or pebble movement studies. Although the applications have often been sponsored by commercial engineering interests and the " environmental " aspect of the work was of secondary interest, they have already yielded much basic information which is likely to be of considerable value in providing a better understanding of sea and ocean bed movement.

One of the problems requiring further investigation is the validity of the chosen tracer for quantitative measurements. Tracer for silt or sand can be a γ-emitting isotope either incorporated in ground-glass or absorbed on the surface of the natural material. Although both methods can be used quantitatively in sand measurements, silt presents a greater problem. The wide range of particle sizes and the variety of mineral content can result in surface labelling being far from proportional to mass, as required for quantitative tracing. On the other hand, the behaviour of an artificial tracer such as glass in silt requires careful investigation to establish whether its different surface properties affect its reliability as a tracer.

A second problem is that quantitative measurements require a knowledge of the depth distribution of the tracer as well as its areal distribution. When the thickness of deposition is small, surface measurements can be quantitative and evidence of distribution in depth may be obtained from γ-ray energy degradation using spectrum analysis. For reliable estimates of total tracer, these methods at present have to be supplemented with direct sampling by a diver or coring device. Both techniques are limited in accuracy and scope.

In spite of these limitations, coastal sand and silt tracing is a very important tracer application. Some 19 countries have used the technique and of these, 4 have used it fairly extensively. The next decade will see a considerable expansion of applied investigations with close collaboration between engineer and scientist. Emphasis is likely to be on the evaluation of existing and proposed spoil grounds into which dredged material is to be deposited. The premise that " nothing succeeds like success " applies and a number of investigations have already shown their commercial value. Studies are likely to extend further off-shore to outer port approaches, now of increasing commercial interest with the advent of deep draught tankers. Information on the shallow part of the continental shelf will be required with particular interest in data on bed transport by sand waves.

Coastal and estuarine water movement has been fairly extensively investigated using radioactive tracers often in connection with sewage or chemical waste disposal. Probably the most extensive application is in Denmark where a well equipped team investigates coastal water movement on a routine basis. An expansion of interest in other maritime coun-

tries to even a fraction of that employed in Denmark would produce a large "growth" in this application. Such growth is likely because of the increasing commercial importance, and public awareness, of waste disposal and control.

Radioactive tracer techniques have been somewhat neglected in deep ocean water studies although there has been some work with naturally occurring ^{14}C, ^{226}Ra and fall-out products. Early investigations using mixed fission products showed the tracer technique had possibilities. A major problem of deep ocean water tracer work is the location and assay (in three dimensions) of the tracer which is likely to spread as a thin horizontal layer. Expensive development work is inevitable before the method can realize its full potential.

Oceanographic nuclear instrumentation

Isotope or nuclear techniques have been applied in current measuring instruments, in the analysis of bottom sediment or ocean water and in small power sources.

Isotope current meters (DWICA I and II) have been developed to measure currents near the ocean bed. The principle of operation is to measure the time and direction of drift of a small injection of radioactive solution by surrounding the injection point with a circle of scintillation detectors. One instrument, designed to operate to 2,000 m depth will measure currents as low as 0.1 cm/sec. The future development of the instrument is already planned. It will be converted to a bottom-anchored, cableless, free-fall instrument which will enable it to measure the current profile of a site rather than the near-bed currents to which it is at present restricted. The extent of further development will depend on financial support for an instrument that is fairly expensive to build and to operate in the ocean. Such support is again largely dependent on the commercial or defence interest in the measurement of slow oceanic currents.

Several nuclear analytical techniques which have been highly developed for geophysical exploration by the oil companies are gradually being adapted for application to oceanographic problems.

These include natural γ-ray measurements, which can be used to measure uranium concentrations and possibly to locate other minerals associated with uranium (e.g., phosphorite), neutron activation using a submersible neutron generator and selective γ-γ logging to identify high atomic number materials on the sea bed. An instrument using γ-backscatter techniques can measure sediment density profiles in fairly soft deposits over a depth of 11 feet.

Analysis of dissolved oxygen in water has been carried out by a "radio-release" system whereby the dissolved oxygen present in the water causes the dissolution of an otherwise insoluble radioactive tracer (Tl^{204} or I^{131}) which can then be measured. The method has been used in sea water.

The use of analytical techniques for *in situ* measurement in the ocean or on the ocean bed must be one of the areas in which nuclear methods have most to offer. Techniques such as X-ray fluorescence analysis, neutron activation analysis, prompt γ-emission from (n,γ) reactions and neutron die-away methods are potentially applicable. Alternative sampling methods are laborious and expensive and any increase of the number of measurements which can be made in a given amount of ship-time is economically desirable. Present applications only represent a very small fraction of the potential and there is need for more research to develop the techniques for commercial exploitation.

An entirely different field of isotope application is the use of radioisotopes as heat and power sources. The present power range of isotope sources (milliwatts to several tens of watts) will increase by the use of larger sources and higher electrical conversion efficiency. As the cost per unit of power decreases, future applications will extend beyond the present use as power sources for remotely sited buoys, communications and meteorological stations.

Applications in meteorology

Meteorological applications vary from the global to the micro scale and up to the present time, radioactive tracers have contributed extensively to the understanding of atmospheric behaviour.

Global investigations

Some of the most interesting isotope applications are concerned with strato-

spheric air behaviour. Tritium and other "fall-out" tracers have shown the extent to which the stratosphere is isolated from the troposphere and have given an idea of the magnitude of the exchange between them. The more detailed mechanism of the interchange is still obscure but could be investigated by large scale radioactive tracer investigations. The degree of mixing between the north and south hemispheres is clearly seen in the slow rise of the tritium levels in the southern hemisphere. A more detailed picture has been produced by the injection of specific tracers such as rhodium-102 at very high altitude (in excess of 40km), tungsten-185 at medium altitude (up to 20 km) and plutonium-238 (at 40 to 60 km).

Although the tracer results generally support the Dobson-Brewer circulation model up to the lower stratosphere and indicate more complex circulation above this, much more information is required before stratospheric circulation is fully explored. An important item for future stratospheric research is that tracer measurements should be coupled with a much more extensive sampling cover. Conclusions from existing data are frequently hampered by the restricted sampling. Since sampling is difficult and very expensive, complete cover from a scientific viewpoint may be prohibitive but in several instances the balance seems to have swung too far in the direction of economy.

The residence time of a variety of tracers in the stratosphere and troposphere has been provided from nuclear debris. For instance, tritium appears to have a half residence time in the stratosphere of nearly $1\frac{1}{2}$ years with a corresponding value of a year for particulate material. The tropospheric half residence time of nuclear debris is about 30 days. The rate of exchange of both carbon dioxide and water between the atmosphere and the ocean merits further study. There is a need for further data of this type related to specific atmospheric pollutants.

The vertical mixing rate of tropospheric air and the associated transport of water vapour and energy is basic data required by the meteorologist. Some information has been provided by using radon-222 which is released at land surfaces and transported throughout the troposphere and to some extent, beyond. More information is required both on ground level turbulent mixing and on large scale convective mixing. These could both be studied with tracers such as tritium (as tritiated water), krypton-85 or other gaseous isotopes. Such applications would not be difficult at or near ground level but would present problems which increased with altitude.

Hydrometeorology

The structure of a hurricane was examined by Östlund. The variation of the tritium content of water in various parts of the hurricane enabled an estimate to be made of the relative contribution of atmospheric water vapour, oceanic water and, in the eye of the storm, of stratospheric air. This type of investigation requires extension and refinement and could be used in conjunction with stable isotope measurements to obtain finer detail of the water behaviour in a storm. Could it be applied to the investigation of whole anticyclones where the energy and movement are much less intense and tracer variations will be less marked?

Similar investigations have been carried out on hailstones, using the variations of deuterium content of the concentric rings of the hailstone to trace its life history. Tritium measurements have shown the hailstones to consist of similar water to normal rainfall. Further work is required to relate tritium, deuterium and oxygen-18 measurements to structural features of the hailstones and to interpret the results in accordance with other physical and meteorological data observed in the same storm.

Other isotope techniques relating to precipitation include the study of the short lived radioactive isotopes sodium-24, silicon-31, sulphur-38 and several chlorine isotopes, produced in the troposphere by cosmic radiation. The ratio of the concentration of these in rain may offer a technique for once again investigating the history of the rain droplets in the cloud.

Evapotranspiration is an important water balance factor in both hydrology and meteorology. Direct quantitative measurements are very difficult but it would appear to be worthwhile to in-

crease research into the problem using tritium, deuterium and oxygen-18 as tracers.

Atmospheric pollution

Recent predictions of disastrous biological effects if atmospheric pollution is allowed to increase without restriction in the next two decades have brought this subject to prominence and indicate the requirement for an expansion of applied research effort in the very near future.

Radioactive isotopes are already widely used in this context. Aerosol behaviour is being studied by measuring the decay products of natural radon on atmospheric aerosols and by labelling artificial aerosols with radioactive tracers. Detailed study of natural precipitation processes (e.g. by rain or snow-fall) are required to evaluate the mechanisms of atmospheric cleansing. Any investigation of this type, in irreproducible environmental conditions whose physical characteristics must be separately recorded, involves a large and time consuming programme to collect statistically significant information.

General investigation of atmospheric pollution requires large-scale studies of trace elements in which activation analysis can be of value. Specific investigations of particular sources of pollution have involved tracer studies such as the diffusion of plumes from chimneys. Allied to this are studies of the stable isotope ratio of sulphur-32/sulphur-34, from which the relative contribution of various sources of pollution can be investigated. A similar technique for identifying the source of carbon in river pollution involves the measurement of the mixture of recent and fossil carbon by carbon-14 measurements. Such measurements on atmospheric carbon dioxide, together with C^{12}/C^{13} studies have had limited application to localised pollution studies.

Examination and identification of sources of atmospheric pollution must be an expanding field in which many scientific disciplines will be involved but where radioactive and stable isotopes will play an extremely important part because of the unique facility of isotopic tracers to distinguish between added and environmental material of the same physical and chemical form and the ability, therefore, to study natural mechanisms without altering their normal behaviour.

Conclusions

It can be foreseen that advances in the major branches of environmental science during the next decade will rely heavily on the exploitation and development of isotope techniques in close association with more conventional methods. In particular, radioactive and stable isotopic tracers can contribute to the solution of otherwise intractable problems.

The following areas appear to merit special consideration:—

Hydrology

—Low-level tritium tracing of ground water

—Carbon-14 measurements (often in combination with natural tritium)

—Ground water stratification

Oceanography

—Coastal and off-shore sea-bed movement tracer studies

—Sea-bed *in situ* analytical techniques

—Coastal water pollution

Meteorology

—Tropospheric air movements on a large scale using added radioactive tracers

—Storm and anticyclonic isotope variations

—Atmospheric pollution, one of the most important.

Some of the large-scale investigations will be expensive. The rate of expansion in these and allied fields will be governed by financial considerations and these in their turn will be increasingly influenced by economic factors such as cost/benefit considerations.

The most rapid expansion will arise in those areas where direct economic gain is evident and where commercial rather than academic interests influence the programme.

In this enterprise, success will depend on close collaboration between environmental and nuclear scientists and neither should work in isolation from the other. The full benefit of isotope techniques can only be realized through a close interdisciplinary approach in full consulta-

tion with the commercial organizations which are likely to sponsor the necessary research.

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This bibliography is intended to provide general information on isotope environmental applications and to provide a lead to more detailed information where this is required.

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A.E.A. Reports available

THE titles below are a selection from the January, 1969, " U.K.A.E.A. list of publications available to the public ". This list is obtainable free from the Librarian, A.E.R.E., Harwell, Didcot, Berkshire. It includes titles, of all reports on sale, translations into English, books, periodical articles, patent specifications and reports which have appeared in the published literature. It also lists the Depository Libraries in the U.K. and the countries with official atomic energy projects which receive copies of U.K.A.E.A. unclassified reports.

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Analytical Aspects of Chemical Studies on Irradiated Oxide Nuclear Fuels. By V. M. Sinclair. August, 1968. 9 pp. H.M.S.O. 5s.

U.K.A.E.A. SCIENTIFIC AND TECHNICAL NEWS SERVICE

How dry is "dry"?

A conference on physical methods of measuring moisture in solids was held at Harwell on 22nd January, 1969, organized by the Institute of Physics and the Physical Society.

Quite small amounts of water can have very significant effects upon the properties and behaviours of materials—it is an everyday experience that a very little water will make a cotton garment feel damp or prevent a match from lighting.

In industry the importance of moisture is even greater, and quite small changes in the moisture contents of raw materials, intermediates or finished products can have profound effects on their behavour and on the economics of processing and marketing them.

For example, the final strength of poured concrete is linked closely to the amount of water in the mix and the calorific value of pulverized coal or coke is greatly reduced by excess moisture. Foundry sand that is too wet can cause dangerous sputtering of the molten metal. The moisture content of the sub-soil is as vitally important to the civil engineer as that of wood is to the carpenter. Every farmer knows of the dangers of stacking wet hay and of the loss in quality suffered by stored grain that is not properly dry. And when a product is sold on the basis of its dry weight—paper, for example, or cattle food—then the seller and the buyer must both agree on the percentage of water that it holds.

Moisture can not only have different practical effects in different materials and circumstances, but it can be present in states ranging from the fairly intimate chemical bonding that can be broken down progressively by raising the temperature (as in most biological products), to free water in the form of a film covering the surfaces or filling the pores of the material.

Because moisture in solid materials has so many different effects and can be held in so many different ways, and because the range of materials involved is almost infinitely large, there is no one ideal or even dominant way of measuring it. Many physical techniques have been developed, and in any specific field of use each of these techniques has its own advantages and drawbacks.

It is important, therefore, that the industrial users who need to measure moisture in the materials of their trade should be brought into discussion with the instrument manufacturers who supply the measuring devices, and with the physicists who develop new techniques of measurement. It was to encourage this contact and to review existing methods of moisture measurement that the Institute of Physics and the Physical Society arranged the Harwell conference.

The conference title was " Moisture Measurement in Solid Materials ", and it covered a wide range of physical techniques, including microwave absorption, dielectric constant, electrical resistance, nuclear magnetic resonance, neutron moderation, and all fields of application, including the special problems of the solid fuel and building industries.

IN PARLIAMENT

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was assumed to be higher than that of any coal-fired station yet built, and higher than the estimate for new coal-fired stations given by his predecessor in April, 1968.

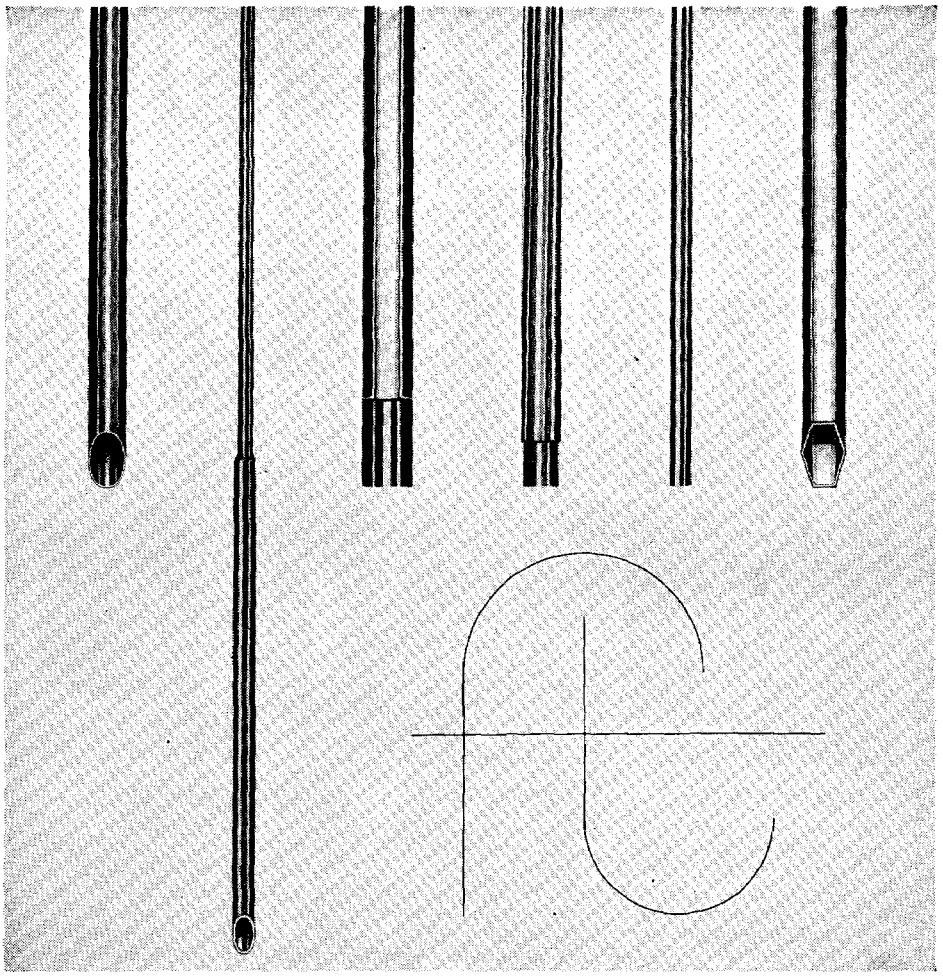
Mr. Freeson: The estimated capital cost of a coal-fired station was based on curent price levels and allowed for the difficult site conditions at Seaton Carew.

Cooperation on uranium enrichment

11th December, 1968

MR. DODDS-PARKER asked the Minister of Technology what progress has been made in the Dutch-German-United Kingdom project for the enrichment of uranium.

Mr. Benn: The House is aware that my right hon. Friend the Minister of State, Foreign and Commonwealth Office, and I met Dutch and German Ministers at The Hague on 25th November and discussed recent developments in gas-centrifuge technology and the possibilities of collaborative arrangements. We agreed, *ad referendum* to our Governments, certain basic principles on which we might co-operate. The Government are now studying these in preparation for a second Ministerial meeting, in London early in the New Year.



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