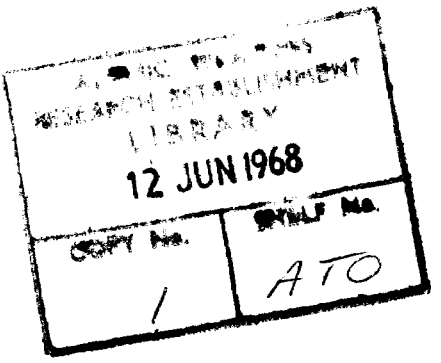
ATOM

Number 140 / **June 1968**



MONTHLY INFORMATION BULLETIN OF

THE UNITED KINGDOM ATOMIC ENERGY AUTHORITY

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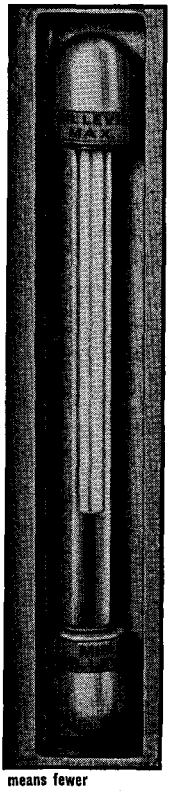

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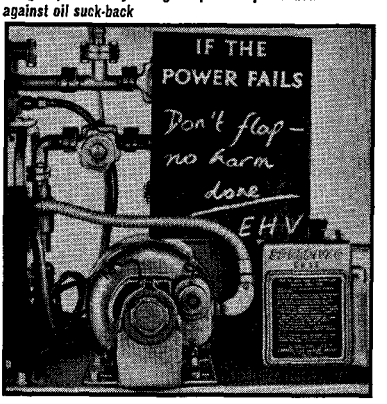

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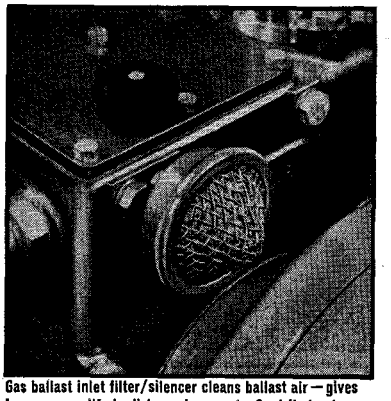

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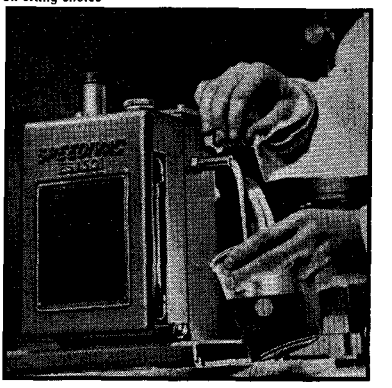

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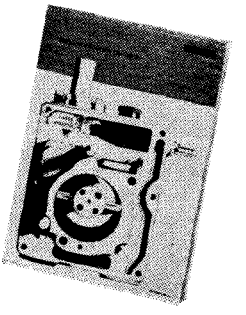

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ATOM

MONTHLY INFORMATION BULLETIN
OF THE UNITED KINGDOM
ATOMIC ENERGY AUTHORITY

NUMBER 140

June 1968

Contents

ATOM
monthly bulletin of the U.K.A.E.A. is distributed to the staff of the Authority, to similar organisations overseas, to industrial firms concerned with the exploitation of nuclear energy, to the Press and to others to whom a record of information of the work of the Authority may be useful.

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U.K.A.E.A. PRESS RELEASES

A.E.A. plutonium for Belgium

(A similar Press Release was issued in Brussels)

In Brussels today (May 3) the Euratom Supply Agency signed a contract with the U.K. Atomic Energy Authority for the supply of 180 kilogrammes of plutonium, delivery to start in 1972. Under the terms of the contract the plutonium will be purchased under international safeguards by the Belgian Government. The material will be used by BelgoNucléaire in the manufacture of fuel elements for the prototype fast reactor to be ordered by the Governments of Belgium, the Netherlands and Western Germany from the industrial consortium form by Siemens, Interatom, BelgoNucléaire and Neratoom.

Background Notes

BelgoNucléaire

BelgoNucléaire is a nuclear engineering firm founded at the initiative of Union Minière in 1956 by all the leading Belgian manufacturing companies. Fast breeder development and plutonium work have been among its main fields of interest since 1956: collaboration to the engineering and construction of the Enrico Fermi plant in Detroit, construction of a plutonium laboratory at Mol in 1958, concept, study and construction of the two fast neutron reactors Harmonie and Masurca operated in the European community, performance of the work required by the Euratom-Belgian Association on fast breeder development and, recently, participation in the Siemens-Interatom-BelgoNucléaire-Neratoom consortium for sodium-cooled fast breeder development, mainly in the field of core and blanket design, fabrication and safety.

BelgoNucléaire has been the partner of the U.K.A.E.A. for the development of the VULCAIN heavy-water reactor concept, operated successfully in the converted BR3 reactor at Mol, and will be the partner of T.N.P.G. and other European companies for the development of the high temperature gas-cooled reactor.

Production Group, U.K.A.E.A.

The Production Group of the United Kingdom Atomic Energy Authority pro-

vides a complete nuclear fuel service for the Authority's own reactors and for those of the public electricity generating Boards in the United Kingdom. In addition, the Production Group offers these services to operators of all types of reactors overseas. The plutonium will be supplied from material recovered from irradiated fuels reprocessed in the Group's reprocessing plants at Windscale.

3rd May, 1968.

A.E.A. to reprocess Swiss fuel

(A similar Release was made in Switzerland)

Nordostschweizerische Kraftwerke AG (NOK), Baden, Switzerland, have signed a contract with the United Kingdom Atomic Energy Authority for the reprocessing of irradiated fuel assemblies discharged from the two 350 MWe pressurized water reactors presently under construction at the Beznau site in the canton of Aargau. The fuel will be reprocessed at Windscale to extract uranium, which will still be slightly enriched, and plutonium. These materials will be re-used for peaceful purposes.

The contract involves the reprocessing of Beznau fuel for several years.

NOK is the largest electrical utility company in Switzerland and is responsible for generation and sale of electricity mainly in the north eastern part of Switzerland.

U.K.A.E.A.'s plant at Windscale in Cumberland has a reprocessing capacity of over 2,000 tonnes of spent nuclear fuel per annum and is capable of treating natural uranium metal fuels and also enriched uranium oxide fuels. It is currently processing the arisings from the reactors in Britain's nuclear power programme and also fuel from the Latina reactor in Italy and the Canadian N.P.D. reactor.

3rd May, 1968.

Film catalogue

A new edition of the United Kingdom Atomic Energy Authority's film catalogue has now been published.

It lists some 60 films, dealing with many aspects of nuclear energy, which are available on free loan from the Authority. Copies are available from Public Relations Branch, U.K.A.E.A., 11 Charles II St., S.W.1.

The Cockcroft Lecture

The Board of the British Nuclear Energy Society has proposed that the great contributions of the late Sir John Cockcroft, O.M., K.C.B., C.B.E., F.R.S., to the development of nuclear power should be commemorated by instituting a series of lectures in his memory. Lady Cockcroft has welcomed this proposal and has kindly agreed to these lectures being known as the Cockcroft Lectures.

Persons eminent in the fields of nuclear science, engineering or power, will be invited to give the Cockcroft Lecture which will replace the Invited Annual Lecture but will not necessarily be given each year.

The Board has announced that Lord Penney, K.B.E., M.A., D.Sc., Ph.D., F.R.S., until recently Chairman of the United Kingdom Atomic Energy Authority, now Rector of the Imperial College of Science and Technology, and an Honorary Member of the Society, has accepted an invitation to give the first Cockcroft Lecture.

Lord Penney will give his lecture at the Institution of Civil Engineers at 6 p.m. on Thursday, 13th June, 1968. The title Lord Penney has taken for his lecture is: "Cockcroft and Atomic Energy."

A.E.A. Reports available

THE titles below are a selection from the May, 1968, "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 report 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.

AERE-Bib 159
A Bibliography on Electrical Discharge Machining Covering the Period 1960-1967. Compiled by A. R. C. Whiteman and R. Leadbetter. February, 1968. 13 pp. H.M.S.O. 2s. 6d.

AERE-R 5474
The Determination of Radio-Nuclides in Materials of Biological Origin. Proceedings of a Symposium Held at A.E.R.E., Harwell, April 20-21, 1967. Edited by A. Holmes. October, 1967. 226 pp. H.M.S.O. 29s.

AERE-R 5725
A Computer Program for the Correction of Measured Integrated Bragg Intensities for First Order Thermal Diffuse Scattering. By K. D. Rouse and M. J. Cooper. April, 1968. 41 pp. H.M.S.O. 5s. 6d.

AERE-R 5757
Gallium Arsenide. A Review. By J. Frey. March, 1968. 18 pp. H.M.S.O. 3s.

CLM-R 78
A Method for the Microwave Heating of Plasma Electrons. By E. S. Hotston, J. M. Weaver and D. J. H. Wort. January, 1968. 24 pp. H.M.S.O. 3s.

CLM-R 79
The Calculation of the Distribution of Solar and Earth Heat Input to a Non-Spinning Satellite in a Circular Earth Orbit. By H. J. Crawley. January, 1968. 24 pp. H.M.S.O. 4s.

CLM-R 80
Plasma Production in a Gas Jet By Microwave Ionization. By J. Hugill. December, 1967. 7 pp. H.M.S.O. 2s. 6d.

CLM-R 81
The Calculation of Plasma Electron Temperature from Absorption Measurements of Continuum X-Radiation from a Plasma. By J. H. Adlam and I. C. Taylor. January, 1968. 17 pp. H.M.S.O. 3s.

PG Report 815(CA)
The Determination of Strontium in Bone, Milk and Vegetable Ashes Using Ion Exchange Separation and Flame Photometry. By G. Goodall. 1968. 12 pp. H.M.S.O. 3s.

TRG Report 1568(R)
The Accurate Solution of Transport Theory Problems by the Use of a New Version of Diffusion Theory. By R. T. Ackroyd. 1966. Reprinted 1968. 47 pp. H.M.S.O. 7s.

TRG Report 1635(C)
The Determination of Carbonate in Sodium. By J. A. J. Walker and E. D. France. January, 1968. 10 pp. H.M.S.O. 2s. 6d.

TRG Report 1636(R)
Economic Comparison of the Solar and Conventional Heated Sections of St. George's Secondary Modern School, Wallasey. By J. B. Love. 1968. 12 pp. H.M.S.O. 2s.

TRG Report 1640(R)
An Experimental Continuous-Indication Plugging Meter for Impurity Monitoring in Liquid Alkali Metals. By D. F. Davidson and P. F. Roach. 1968. 13 pp. H.M.S.O. 2s. 6d.

Medical research

A growing programme of research in the field of medical equipment is being undertaken by the Ministry of Health and the Atomic Energy Authority. Research by the two Departments has been developed over the past year and supported by laboratory work at the Atomic Weapons Research Establishment at Aldermaston. A considerable expansion of this collaboration is now planned.

Research and development of medical equipment is a long-term undertaking and preliminary laboratory projects are followed by work in clinics and hospitals before final production. Through co-operation between the Ministry of Health and the Atomic Energy Authority, the Atomic Weapons Research Establishment carry through an agreed programme of preliminary study and research and provide the necessary laboratory facilities. The general research and development programme is approved by an expert committee, within the Ministry of Health. The immediate link between Aldermaston and the Ministry is the Scientific and Technical Services Branch of the Ministry's Supply Division operating virtually as a joint unit with Atomic Weapons Research Establishment staff.

Investigations at Aldermaston may be exploratory or directed towards the improvement of present techniques and equipment. Progress is expected to be steady rather than dramatic, but the benefits could also accrue to industry.

Research is being carried out at Aldermaston on cardiac pacemaker devices, medical use of the laser beam, fibre optics, dental materials, metals and plastics for use as implants in the body, thermography (the application of infra red radiation to the production of pictures of the distribution of temperature over the body), ultrasonics, and patient monitoring devices. Help is also being given with the development of artificial kidney equipment and automated devices for use in biochemistry and pathology laboratories. Another part of the programme relates to the critical evaluation of available equipment and work of this nature has already been carried out on the myoelectric hand for the disabled.

Enlargement, now planned, of the area of collaboration will enable new projects to be brought into the programme.

Gas load factor

1st April, 1968

MR. SWAIN asked the Minister of Power what is the latest estimate of average load factor throughout their lifetime of the advanced gas-cooled reactor nuclear stations now being built.

Mr. Marsh: 75 per cent.

Power station building programme

2nd April, 1968

MR. SWAIN asked the Minister of Power whether he will now issue a revised fuel policy White Paper to take account of the recent slowing down of the nuclear power station building programme.

Mr. Marsh: There have been no changes in the nuclear power station building programme which would justify a revision of the Fuel Policy White Paper.

Delays

2nd April, 1968

MR. SWAIN asked the Minister of Power what proportion of the £60 million annual cost to the Central Electricity Generating Board caused by delays in commissioning new generating stations is attributable to nuclear stations.

Mr. Freeson: This figure was a broad estimate given to the National Board for Prices and Incomes by the C.E.G.B. of the order of magnitude of the cost of delays and the C.E.G.B. inform me that it cannot be readily broken down to individual stations or types of station.

Seaton Carew

2nd April, 1968

MR. LEADBITTER asked the Minister of Power what site preparation work at Seaton Carew is being carried out by the Central Electricity Generating Board with a view to constructing a nuclear power station, in view of his assurance that he has not yet completed his study of the relative merits of a coal-fired or a nuclear station.

Mr. Marsh: As I have already said in answer to my hon. Fried on 17th January, the degree of preparation of sites in advance of my decision is a matter for the C.E.G.B.'s commercial judgment. The preparatory work at Seaton Carew will make the site equally suitable for any sort of power station or industrial development and will in no way prejudice my decision whether to allow a nuclear power station to be built there. The Board have had this site for over 10 years.

3rd April, 1968

MR. LEADBITTER asked the Minister of Power when he now expects to complete his studies of the relative merits of a nuclear power station or coal-fired station for Seaton Carew.

Mr. Marsh: I do not intend to take a final decision until I have considered, in the light of the Electricity Council's new load forecast, the need for starting any new station at Hartlepool or anywhere else.

Pension schemes

8th April, 1968

MR. DALYELL asked the Minister of Technology what he is doing to synchronise the pension schemes of those in his establishments employed by the Atomic Energy Authority and the Science Research Council, respectively.

Dr. Bray: If my hon. Friend has in mind the terms of the proposed transfer of astrophysics staff at Culham from the Atomic Energy Authority to the Science Research Council in April, 1969, I can say that it is the intention that these staff should remain on A.E.A. conditions of service and be retained in the A.E.A. superannuation scheme. Legislation will be needed for this purpose, but I cannot say at this time what form it will take.

Mr. Dalyell: Does my hon. Friend agree that in view of the circumstances, there is a certain urgency about this matter?

Dr. Bray: The urgency is to ensure that proper pensions provisions are made. I assure my hon. Friend that there will be no lack of care taken to ensure that there is no injustice to individuals.

Seaton Carew studies

23rd April, 1968

MR. WILLEY asked the Minister of Power what are the series of studies being held regarding the proposed power station at Seaton Carew; and by whom the studies are being carried out.

Mr. Gunter: These studies cover the need for new power stations to meet the expected load; the relative costs to the economy of production from coal and

nuclear power; and the effect of power station orders on the economy and on the industries concerned. They are being carried out by my Department in consultation with the other Departments concerned.

Select committee report

29th April, 1968

SIR H. LEGGE-BOURKE asked the Minister of Technology when he expects to make his observations on the Report of the Select Committee on Science and Technology on the Nuclear Reactor Programme.

Mr. Benn: The Government have completed their study of the Report of the Select Committee, and the Chairman of the Industrial Reorganisation Corporation is beginning discussions with industry on this subject.

The Chairman will be keeping me informed of the progress of his negotiations and I will make a statement as soon as a practicable solution, to what is a very complex problem, becomes apparent.

Comparative costs

2nd May, 1968

MR. WYATT asked the Prime Minister whether he will co-ordinate the activities of the Minister of Technology and the Minister of Power, with a view to their producing a comparative study of the respective costs of providing power by means of coal, natural gas and nuclear energy.

The Prime Minister (Mr. Harold Wilson): My right hon. Friends already work closely together on all matters of common concern, but if my hon. Friend wants information about matters falling within their responsibilities, perhaps he would address Questions to them.

Mr. Wyatt: Is not my right hon. Friend aware that many hundreds of millions of pounds have already been wasted in building nuclear power stations which may not produce electricity as cheaply as the cheapest coal-fired station? Is he aware that the new coal-fired station at Drax will shortly be producing electricity at .54d. per unit as against the hoped for .56d. per unit at the new nuclear power station at Dungeness B, which may not be operating until 1971? What is the point of having a Select Committee recommending an independent full inquiry into costs and the Government doing nothing about it?

The Prime Minister: There are many views about the proper accountancy and the proper figures to be used for evaluating different methods of producing power. All these were gone into very fully before we produced our White Paper on fuel policy. My hon. Friend referred to the Report of the Select Committee, which went into these matters in very great detail and had available to it all the information the Departments could give it. He will be glad to know that it is hoped that in the very near future the House as a whole will be able to debate this very important Report.

Mr. Lubbock: Will the Prime Minister draw to his hon. Friend's attention the appendices in the Select Committee's Report containing a very full account of the Minister of Power's special committee set up to evaluate the costs of producing electricity from different sources? Does the Prime Minister agree that the Central Electricity Generating Board is most unlikely to choose as the source of fuel one which is more expensive than the minimum? That is why it is expanding the nuclear energy programme.

The Prime Minister: I agree with the hon. Gentleman's views, but no doubt my hon. Friend has already fully studied appendices 43 and 44 to the Select Committee's Report which contained all the technical information available, but I think that perhaps he had rather made up his mind on the subject before he read them.

Dr. Ernest A. Davies: Is my right hon. Friend aware that the real problem here is to have an agreed basis between the various conflicting parties on which to erect a calculation of these costs, and that until this is done there is no point in providing further figures for various lobbyists to quote back and forth to one another?

The Prime Minister: I was very much concerned with trying to evaluate the statistical quotations of lobbyists on similar matters even before nuclear power was used. At the end of the war the gas and electricity lobbyists could always produce figures to prove their own point. The most authoritative and independent work done in this field was that presented to the Select Committee.

Economics of plutonium utilisation in an integrated generating system of thermal and fast reactors

This paper, by C. E. Iliffe, UKAEA, Reactor Group, Risley, was presented at a symposium on The Economics of Nuclear Fuels, organised by the International Atomic Energy Agency from 27th to 31st May at Prague, Czechoslovakia.

Accounting for plutonium

A method of accounting for plutonium which has been widely used is to assign to the plutonium some fixed monetary value per unit amount. This procedure suggests the conclusion that the cost of nuclear power depends, amongst other things, on the value of plutonium. The true situation, however, is surely the reverse, and it is rather the value of plutonium that is determined by the economics of nuclear power. This conclusion seems certainly valid when applied to a closed system such as the world as a whole.

Albeit, within a closed system there may be limited scope for basing nuclear power costs on an assigned value of plutonium. Such estimates might be made by an individual community which is committed to dealing with some external market which buys and sells plutonium at the assigned value. The market itself might then be some much larger community or group of communities within the world system.

But a significant nuclear power programme would be dealing in several tonnes of plutonium a year and it would seem premature in this case to base a national power policy on the possible existence of an unspecified market for such quantities of plutonium at some future date. Even the appearance of such a market would have no effect unless a firm decision were taken to have significant and continuing dealings with it. For present purposes, therefore, it will be assumed that there is no market for plutonium outside the national generating system. The resulting economic assessment will then be conservative since the possible benefits of any external market that did emerge would have been ignored.

The economic assessment of such a closed system may be made in terms of the present worth of the total expenditure on it at some base date. This expenditure may be divided by the present worth of the electricity generated by the system to give an average, or " system ", generating cost. Provided that all plutonium generated within the system is also used within it, it is then found that any value assigned to plutonium cancels out in transactions between uranium- and plutonium-feed reactors within the system. The benefits of plutonium to the system appear through savings in expenditure on uranium.

It is now possible to avoid some of the less credible situations which result from the assignment of a fixed value to plutonium. The benefits from the plutonium discharged by thermal reactors are no longer independent of the reactors to which this plutonium is fed, particularly as regards capital costs and costs of fuel fabrication and processing. Again, in the case of a fast breeder reactor for which the doubling time is the reciprocal of the discount rate, assessments based on a fixed value of plutonium suggest that the economics of the reactor are independent of the initial plutonium inventory. This irrational conclusion is avoided by the closed system approach, in which higher plutonium inventories are reflected in a smaller installation of fast reactors and therewith reduced savings in expenditure on uranium.

Plutonium burning in thermal reactors

Perhaps the simplest example of the use of plutonium entirely within a closed system is provided by two installations of thermal reactors. The first of these operates on an all-uranium feed, and discharges all its plutonium to feed the second. The plutonium discharged from the second installation is recycled so that

the nett discharge of plutonium from it is zero.

As an attempt to quantify this system, it will be assumed that the nett supply of U-235 to the first installation is at the rate of 0.7 kgs U-235/MWe-yr., a figure which is typical for the low-enriched thermal reactor. If this U-235 costs $10/gm, say, then the cost of U-235 replacement will be

$$0.80 \text{ mils/kWh}$$

The nett supply of plutonium to the second installation could well be at the same rate as that of U-235 to the first, whilst the rate at which plutonium is produced by the first installation might typically be 0.2 kgs Pu/MWe-yr.

It follows that the plutonium-feed capacity will form a proportion of the whole equal to—

$$0.2/(0.7+0.2) = 0.22 = 0.22 \text{ say,}$$

after an allowance of 10% for the initial plutonium inventories of the plutonium-feed reactors. Finally, therefore, the generating cost saving to the system from plutonium burning works out at

$$0.20 \times 0.80 = 0.16 \text{ mils/kWh}$$

Although plutonium burning in thermal reactors is thus seen to make a useful contribution in costs of electricity generation, it is likely to be small.

Fast breeder reactor

The rather small benefits obtained from burning plutonium in thermal reactors are largely dictated by the underlying neutronics. One consequence of relacing U-235 by plutonium is that a greater number of neutrons is emitted for every fission. In the case of a thermal reactor, however, the proportion of these neutrons which are captured in plutonium without producing a further fission is greater than in the case of U-235. These two effects largely offset one another.

In the fast reactor, however, the average energy of the neutrons is relatively high so that the advantage of the greater number of neutrons released per fission in plutonium is no longer offset by a higher proportion of non-fission captures. Furthermore, high energy neutrons have a much reduced probability of parasitic capture, as in fuel element canning and materials of construction. As a result, a much higher proportion of neutrons is available for capture in U-238 and the consequent production of plutonium can comfortably outstrip the feed requirements of the reactor. In this event, the whole of the U-235 replacement cost of the uranium-feed reactor could be saved in the case of the two-installation system considered above.

Whether this full saving is realised depends, of course, on whether all other costs for fast and thermal reactors are the same. The fuel inventory of a fast reactor has a high concentration of fissile material so that a high fuel rating is required if investment in fissile material is not to be excessive. Although this high rating tends to reduce the capital cost of the reactor, there is no firm indication, as yet, that capital costs of fast reactor stations will necessarily be lower than those of contemporary stations energised by thermal reactors.

Furthermore, the high rating results in thin sections of fuel and therewith much high fabrication costs as compared with thermal reactors. Present indications are that this increase in cost will be offset by a corresponding increase in burn-up. At the present time, therefore, it seems likely that the fast reactor will be able to realise, at least, the full saving in U-235 costs.

An integrated system

An example of a closed system of coexisting thermal and fast reactors is illustrated by Figure 1 taken from an earlier paper([1]). The total installed capacity of all types of generating station is assumed to build up as shown by the upper full line. The full line below this gives the corresponding growth that has been assumed for the nuclear sector. Within this sector the installation of Magnox stations is fixed as shown. These stations are superseded by " advanced thermal reactors" (ATR) up to the end of the year 1977. At the beginning of 1978 1000 MW(e) of fast reactors are commissioned and a further 1000 MW(e) at the beginning of 1979. From the beginning of 1980 fast reactors are commissioned as rapidly as plutonium supplies will allow. Further data are given in Table 1. In

Fig. 1
Notional power programme

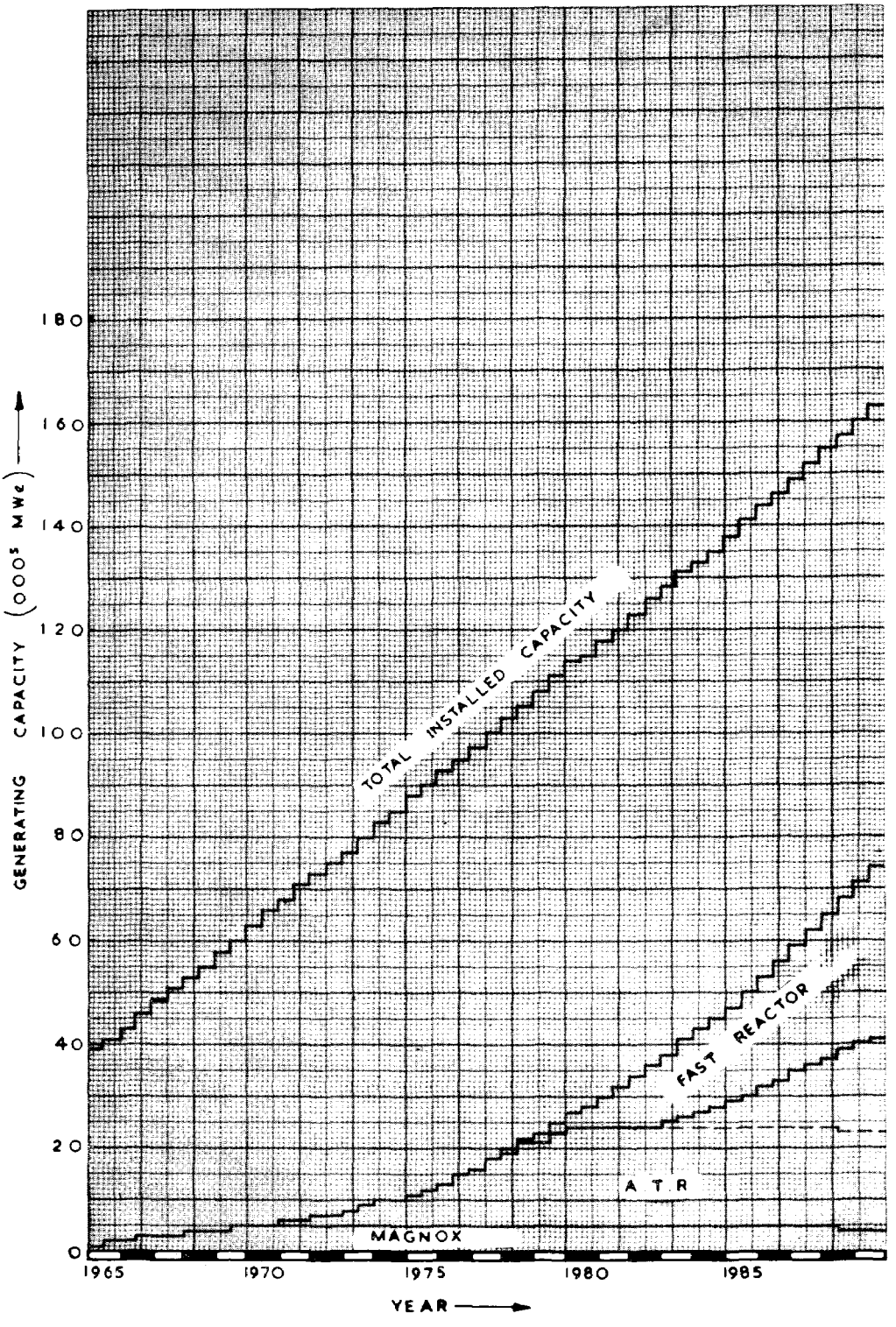

GENERATING CAPACITY (000's MWe)
180
160
140
120
100
80
60
40
20
0
1965
1970
1975
1980
1985
YEAR
TOTAL INSTALLED CAPACITY
FAST REACTOR
A T R
MAGNOX

TABLE I

Illustrative Data

Maximum load factor	80%
Proportion of total installed capacity @ max. L.F.:	1976 30% 1990 40%
Load factor of capacity exceeding this proportion:	falling uniformly to 10% @ 70.5% of total installed capacity.
Plutonium production from Magnox station	0.548 kg. ≡ 239/MW(e)-yr.
Plutonium production from ATR.	0.2 kg. ≡ 239/MW(e)-yr.
Proportion of fast reactor inventory outside core @ 80% L.F.	0.333
Nuclear station lifetime	25 years
Reactor type on highest load factor	Magnox
Base date	start 1976
Plutonium allocated to civil nuclear power from	mid-1970

order to allow for the differing isotopic composition of plutonium discharged by different reactors, all plutonium is expressed as its " equivalent Pu-239," having the same reactivity worth in fast reactors.

With this information the split between fast and advanced thermal reactors is uniquely determined as shown in Figure 1. Any change in the design of the fast reactor will, in general, alter the boundary between the fast and advanced thermal reactors. An upper limit to this boundary is the curve of total nuclear capacity. The lower limit is obtained when the installation of fast reactors is no longer limited by plutonium supply, as shown by the dotted line in Figure 1. If consideration is restricted to the design of the fast reactor, therefore, these two limits define an appropriate " system ". This definition has the convenience that the upper and lower limits of system generating cost are the generating costs for the ATR and fast reactor respectively, without including any contributions from a value for plutonium.

It follows from the earlier paper that the reduction in system generating cost due to the introduction of fast reactors is

$$\delta C = (c_a - c_f)\, L_f\, x$$

where

c_a = generating cost of advanced thermal reactor

c_f = generating cost of fast reactor (Both of these are quoted at the load factor denoted by a further suffix and include no credit for plutonium.)

L_f = discounted mean load factor for fast reactors

x = present worth of electricity generated by fast reactors as a fraction of that generated by the system.

The value of x might thus be expected to range between zero and unity. For cases in which the reactor generating costs vary with time, otherwise than due to changes in load factor, the system generating cost can not be expressed in this simple way but must be worked out on the computer in each case.

The reduction in system generating cost can be converted directly into a corresponding saving in present worth of expenditure. With the discounting period extending up to the year 2000 AD and a discount rate of 7½% per annum then, for the system selected, the present worth of electricity generation is 252,030 MW(e)-yrs. It follows, therefore, that a reduction in system generating cost of 1 mil/kWh is equivalent to a saving of $2,208M.

The saving δC presupposes that the alternative to the fast reactor is the ATR with plutonium thrown away. In practice, this plutonium would be burnt in ATRs so that the nett saving in system generating cost due to the introduction of fast reactors would be reduced somewhat. As can be seen above the extent of this reduction would appear to be about 0.16 mils/kWh.*

System results

In a given system the benefits of burning plutonium in fast reactors will depend not only on the parameters of the fast reactor itself, typically doubling time and fuel rating, but also on the rate of plutonium production from the advanced thermal reactor. For the system considered here, the variation in the fraction x with ATR and fast reactor parameters has already been published.[2] Over the range of fast reactor doubling time from 10-20 years and of fast reactor specific inventory from 2.5-3.5 kgs. ≡ 239/MWe,

* More probably nearer 0.30 mils/kWh after allowing for plutonium from the Magnox stations and the larger system affected by plutonium burning in ATRs.

TABLE 2—SYSTEM RESULTS

Reduction in F.R. reprocessing loss (%)	Reactor type on lowest load factor	New Year for introduction of F.Rs. (A.D.)	New Year for termination of discounting period (A.D.)	Discount rate (%/yr.)	Fraction of electricity generated by fast reactors (x)				Equivalent system expenditure ($M per mil/kwh)
					Specific inventory at 80% L.F. (kg ≡ 239/MWe)	2.5	3.5		
					Doubling time at 80% L.F. (yrs) 12.5	25	12.5	25	
0	A.T.R.	1978	2000	7½	0.743	0.665	0.568	0.508	2208
1	,,	,,	,,	,,	0.755	0.678	0.579	0.517	,,
0	F.R.	,,	,,	,,	0.723 (77.2)	0.648 (76.8)	0.549 (76.3)	0.489 (75.9)	,,
,,	A.T.R.	1976	,,	,,	0.793	0.702	0.607	0.535	,,
,,	,,	1980	,,	,,	0.670	0.610	0.521	0.472	,,
,,	,,	1976	2005	,,	0.771	0.668	0.598	0.516	2878
,,	,,	,,	2010	,,	0.796 (79.6)	0.678	0.632	0.531	3439
,,	,,	,,	2000	5	0.742	0.658	0.567	0.503	3249
,,	,,	,,	,,	10	0.746	0.673	0.570	0.515	1535

Figures in brackets are fast reactor discounted mean load factors (%) where these differ from 80%.

an increase in ATR plutonium production rate from 0.1 to 0.2 kgs.≡239/MWe-yr. raises the value of x by about 0.13. A further increase of 0.1 kgs.≡239/MWe-yr. raises the value of x by a further 0.10.

The system generating cost, however, may also be affected by other parameters of the system which are independent of the specification of the reactors themselves. The effect of varying several of these is shown in Table 2. Results are quoted for the fraction x and also for the change in system expenditure corresponding to a change of 1 mil/kWh in system generating cost. Strictly speaking the system, as defined above, should be extended to include an earlier part of the programme when considering an early date of introduction for fast reactors. Again, for the case in which the fast reactor takes the lowest load factor, the present worth of electricity generated by the system is slightly reduced. For the purposes of this investigation, however, the present worth of electricity generated by the system will be retained at its original level so that the resulting value of δC will still be directly proportional to the corresponding change in system expenditure. Assessment of the effect of changing system parameters is thus kept straightforward.

The same device is no longer helpful when changes in discount rate or discounting period are being examined. In these cases, the appropriate present worth of electricity generated by the system must be used. No inconvenience is thereby caused, however, since the only purpose of these cases is to demonstrate the effect of the system parameters on optimisation of the fast reactor.

Conclusions

The effect of a 1% reduction in fast reactor reprocessing loss is seen to be of the order of an increase in x of 0.01. The cost differential between the ATR and fast reactor is not likely to exceed 1 mil/kWh, so that the saving in system expenditure can hardly be greater than some \$20M. The effect of putting the fast reactor on the lowest load factor instead of the ATR is to reduce x by about 0.02. This reduction may be slightly offset by the accompanying reduction in fast reactor load factor if the capital charges of the fast reactor are less than those for the ATR. In fact, the increase in system generating cost due to the reduction in the faction x is offset by the amount

(ATR capital charges)

FR capital charges) L_f (δ L_f/L_f) x

where

δ L_f is the reduction in fast reactor load factor.

The amount of this offset, however, is very small and, in the present instance, would only be complete if the capital charge saving of the fast reactor over the ATR were some three times as great as the saving in running charges. For the variations in system parameters so far considered, the effect on fast reactor optimism is seen to be small.

Advancing the date of introduction of fast reactors by two years is seen to lead to an increase in the value of x varying from 0.025-0.050. The corresponding savings in system expenditure could thus vary from \$50-100M. Likewise, the penalty for delaying the introduction of fast reactors by two years is a reduction in the value of x varying from 0.035-0.070 which converts to a range of system expenditure from \$75-150M. The effect of the earlier introduction on fast reactor optimisation is seen to be slight by the effect of the delayed introduction is to give reduced prominence to the reduction in doubling time or specific inventory.

Changes in the length of the discounting period or the discount rate are only of interest from the point of view of fast reactor optimisation. As might be expected, the effect of a longer discounting period is to place increasing emphasis on reducing doubling time as opposed to reducing specific inventory. The effect on fast reactor optimisation of a change in discount rate is seen to be very small.

References

[1] ILIFFE, C. E. and SEARBY, P. J. "Problems asscíated with the integration of different types of reactor within a generating system". Paper 4 of I.A.E.A. Symposium on International Extrapolation and Comparison of Nuclear Power Costs. London. 9-13th October 1967.

[2] SEARBY, P. J. and ILIFFE, C. E. "The place of the fast reactor in the U.K. nuclear programme". Paper No. 1/1 of the British Nuclear Energy Society London Conference on Fast Breeder Reactors. 17-19th May 1966.

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

Particle size analyser

A particle size analyser which determines particle size from the intensity of the beta-radiation scattered by a layer of sediment has been developed at Harwell.

Summation Electronics Ltd., of 12, Jenner Road, Guildford, Surrey (Guildford 64676), have been licensed by the Authority to manufacture the equipment.

The advantages of using this equipment are the exceptionally wide range of particle sizes—0.1 to 80 microns—which can be analysed; its use of the sedimentation method, in which over 1,000,000 particles are measured, minimising statistical error; the fact that it measures sedimentation remotely and, therefore, avoids disturbing the sediment with sampling devices; and its provision of an instant response eliminating the need for subsequent analysis of samples. It can be used with toxic materials.

Background:

The milling or grading of mineral or synthetic chemical agglomerates is an essential part of many industrial processes. The resulting powder is a complex mixture of particles varying both in shape and size. It is necessary to separate from the bulk that fraction which is within the upper and lower limits of particle size for the specific application, often by passing each batch through a series of graded sieves if the material is fairly coarse, or by fluid separation in the case of fine powders.

For economic reasons, the limits of particle size are set as wide as possible but it is important to establish the particle size distribution of each batch so that comparisons can be made between one batch, or milling, and another. Only in this way is it possible to maintain uniformity in the finished product.

Analysis of particle size in the sub-sieve range is usually carried out by a sedimentation method where a respresentative sample from each batch is suspended in a suitable liquid medium and the rate of sedimentation measured over discrete intervals of time. From the rate of sedimentation it is possible to calculate particle size.

With this instrument the beta-radiation from a radioactive source is scattered from the bottom of a sedimentation chamber and detected. The intensity of the backscattered radiation is proportional to the thickness of the layer of sediment and the effective atomic number of the material.

In addition to the sedimentation chamber, the equipment consists of an electronic counting assembly—transistorised amplifiers, discriminator, range selector, rate meter, analogue computer, and recorder. The radiation source is 3 millicuries of strontium-90/yttrium-90.

Among the many industries in which particle size analysis is applicable are paint and enamel manufacture, phosphor production for fluorescent tubes, cathode ray tubes and electroluminescent devices, clay and china industries, cosmetics, sintered metals and ceramics, pharmaceuticals, chemical industries, nuclear products, etc.

The instrument will be shown on the U.K.A.E.A. stand at the International Chemical Exhibitoin, Paris, 24th May-1st June, 1968.

17th April, 1968.

Vulcain reaches initial target burn-up

The core in the joint U.K.-Belgian VULCAIN experiment in the BR3 reactor at Mol, Belgium, reached the peak burn-up of 40,000 MWd/TeU on 22nd April, 1968. This burn-up was the target set for the first phase of the planned core life and has been mainly achieved under steady state full power conditions with a load factor of 91%. The fuel is now to be subjected to experimental conditions including power cycling.

Background

As a result of a joint research and development agreement signed in May 1962, between SA BelgoNucléaire representing the Belgian Syndicate VULCAIN and the U.K.A.E.A., it was decided to undertake a small power reactor demonstration experiment in the Belgian BR3 reactor, primarily to develop an advanced core design particularly suitable for land based and marine applications over a range of powers from 20 to 60 MWe. An essential requirement was to achieve

long core life and simplicity of operation with the aim of improving the operational costs to the point at which commercial exploitation for small power reactors might become feasible.

The introduction and power testing of a VULCAIN-type core in BR3 involved:

Extensive studies in theoretical and experimental reactor physics and core performance.

Engineering design and component development.

Fuel design and development.

The modification of the existing reactor plant to operate with a mixed D_2O/H_2O primary fluid and to accommodate VULCAIN fuel assemblies.

This work was performed in close co-operation between the U.K.A.E.A., BelgoNucléaire SA, the Centre d'Etude de l'Energie Nucléaire and various manufacturing companies. Half of the fuel assemblies for the experiment were manufactured in the U.K. by the U.K.A.E.A. at their Springfields Works and half in Belgium by Metallurgie Hoboken SA at Olen and Metallurgi et Mecanique Nucléaires SA at Dessel.

The main objectives of the power experiment are:

To determine the fuel behaviour up to average burn-ups in the region of 25,000 MWd/TeU.

To verify the operating characteristics and thermal performance of a VULCAIN core throughout life.

To gain experience in the operation of D_2O systems at high pressure and high temperature.

To test components.

25th April, 1968.

Alumina die liner

An alumina die liner for use with graphite dies has been developed by the U.K.A.E.A. at A.W.R.E., Aldermaston.

Graphite dies are used in the compacting of powders by hot pressing at temperatures in the region of 1,000°C. Graphite is used as a die material at these temperatures because of its low cost and ease of machining, its low coefficient of expansion and its high creep resistance. It is also a good susceptor for induction heating.

However, hot graphite does not allow ready movement of powders under pressure over its surface and the resulting wall drag, besides causing graphite contamination and faulting in the sintered product, prevents the attainment of a dense compact.

With the alumina die liner, wall friction between the powder being compacted and the hot die surface is substantially reduced and the density of sintered compacts markedly improved.

The die is a sintered alumina liner which inserts into a preformed cavity in a graphite die block. It normally has sintered alumina end plates, one of which is a sliding fit within the die and in use is pressed down on the powder being compacted inside the die.

Powders compacted so far include ceramics and metals such as nickel, stainless steel and nickel-chromium alloys.

For further information apply to Patents Licensing Branch, U.K.A.E.A., 11, Charles II Street, London, S.W.1.

1st May, 1968.

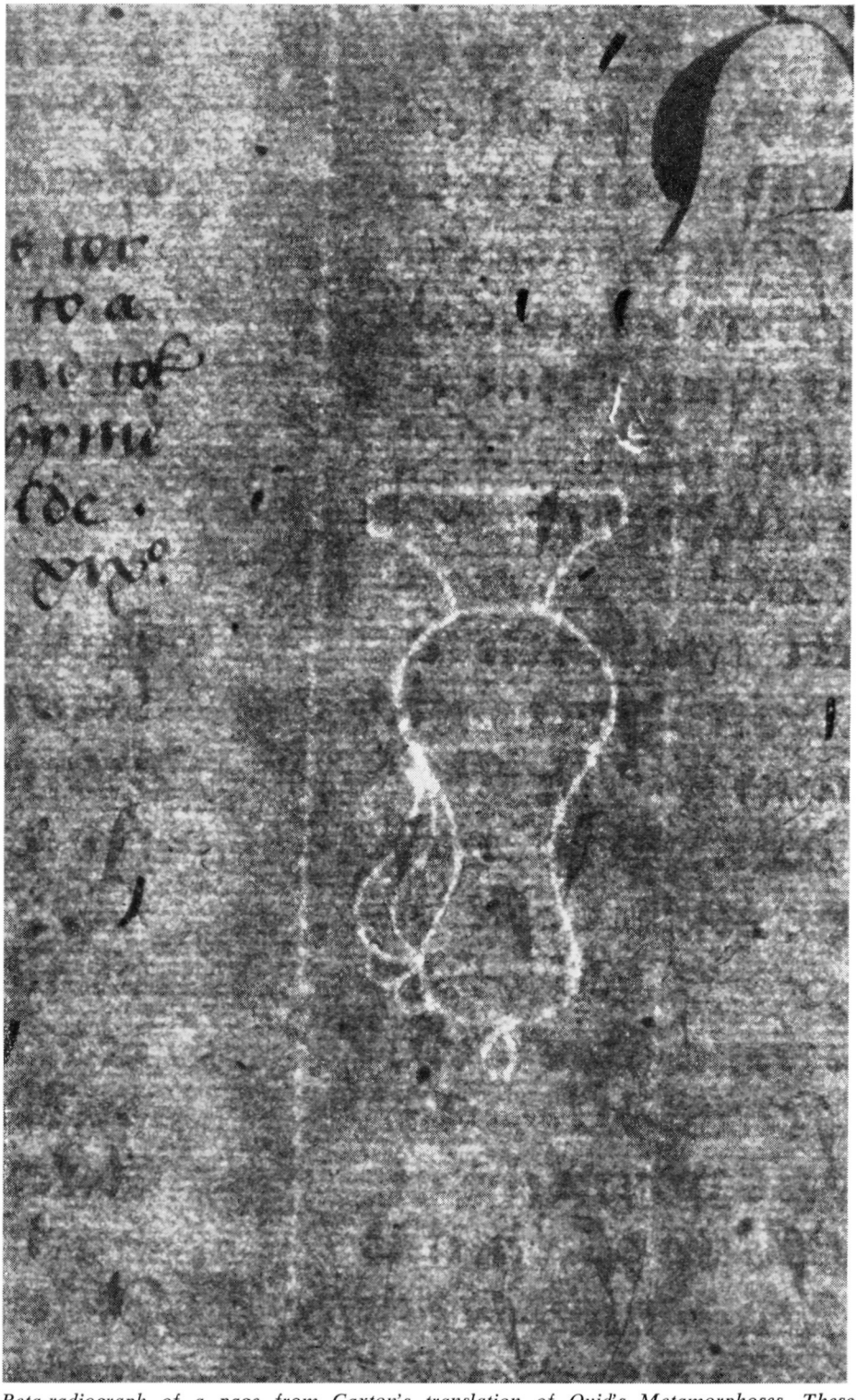
Dating by beta-radiography

Radioisotopes are being used to date historic documents in a process similar to X-radiography.

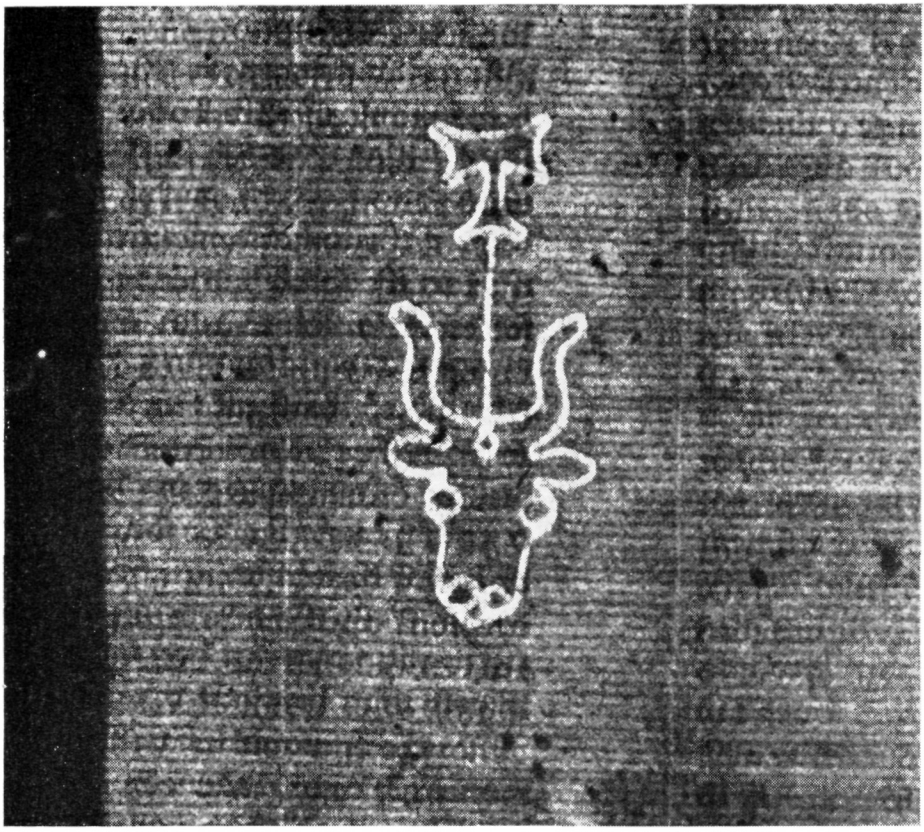
The method used is contact beta-radiography in which a distributed source of low energy beta-radiation in the form of a thin sheet of material is placed on one side of a sheet of paper and a photographic film on the other.

The exposure of the film depends on the local "basis weight" (mass/area) of the paper, since this determines the penetration of the beta particles and the film, when developed, shows not only the purposely low-mass areas of watermarks but also the texture of the paper. This includes, for example, the regular pattern of mass variations due to the supporting wires used in the manufacture of laid paper.

Dating is achieved by the character of the watermark, by examining features of the picture or pattern it represents. This, like a trade mark, is different for different paper manufacturers and is changed from time to time. The process, therefore, is one of historical identification (in particular, it should not be confused with carbon dating of very ancient documents, like the Dead Sea Scrolls).



Beta-radiograph of a page from Caxton's translation of Ovid's Metamorphoses. These beta-radiographs were made by Dr. Allan Stevenson, at the British Museum.



The photograph shows a beta-radiograph of a page from Caxton's "Golden Legend", c.1484.

The method is particularly good for examining paper in the pages of books, since the beta-emitting sheets and the films can conveniently be placed between the pages without damaging the binding. The resulting radiographs showing the watermarks and fine structure of the paper are generally uncomplicated by the printing on the pages, since the mass of this is very small and, therefore, the method is greatly superior to most optical methods of inspection.

The beta-source commonly used is carbon-14-labelled polymethyl methacrylate, which can be obtained from The Radiochemical Centre, Amersham, Bucks. Exposure time varies with paper thickness, being longer for thicker paper. A typical exposure is 15 hours for paper at 6 mg/cm^2 (the thickness of a sheet of newspaper), using a C^{14} sheet containing 80uc/gram. The necessary exposure will be doubled for each additional 2 mg/cm^2 of thickness, but will also be inversely proportional to the specific activity of the sheet and the Radiochemical Centre does supply more active sheets.

The method involves no radiation hazard.

6th May, 1968.

International Instruments Exhibition

The U.K.A.E.A. exhibited at the International Instruments, Electronics and Automation Exhibition, which was held at Olympia from May 13th-18th. The following items were shown on the Authority's stand:—

Automated metrology equipment

This exhibit consists of two instruments, the Min-max Gauge, which accepts analogue inputs from a range of measuring instruments and displays the highest and lowest tolerance errors on a digital read-out panel, and the In-tolerance Eliminator, which records intolerance measurements from an electrical pressure transducer on a chart as

a straight line, out-of-tolerance readings deviating from this to indicate the error measured.

Apex goniometer

This measures accurately and automatically X-ray diffraction angles; in terms of changes in crystal lattice parameter a precision of 1 part in 10,000,000 can be attained. The Authority has licensed McLean Research Engineering Co. Ltd., 59a High Street, Hungerford, Berks, to manufacture this instrument.

Quality control and automation in profilometry

A cathode ray tube curve follower and an on-line computer can be used for complete and rapid quality analysis of profile shapes, tabulating separately that proportion of measurements which are just outside tolerance and that proportion which have considerable errors.

Coal ash monitor

This uses X-rays produced by radioisotopes to monitor continuously and automatically the mineral content of coal. The coal ash can be from dried and pulverised coal ($\frac{1}{2}$ mm. top size) for one version of the instrument and crushed coal ($\frac{1}{2}$ in. top size) for another version. The measurements are insensitive to variations in the iron content of the ash.

A typical Harwell 2000 Series counting system

In this exhibit, units of the Harwell 2000 Series of modular nuclear instrumentation were arranged to provide a typical energy-selective counting system with print-out facilities. The Authority's licensees are Dynatron Electronics of St. Peter's Road, Furze Platt, Maidenhead, Berks., Fleming Instruments Ltd., Caxton Way, Stevenage, Herts., and Nuclear Enterprises (G.B.) Ltd., Beenham, Reading, Berks.

Thermoluminescence dosimeter

This uses the thermoluminiscent properties of lithium fluoride to measure radiation dose. Harwell 2000 Series units are employed. The Authority's licensees are Dynatron Electronics.

Paediatric audiometer

This is a small cheap audiometer suitable for carrying out screening tests of babies' hearing. It is designed to slip into the operator's pocket and a separate small loudspeaker is palmed by the operator in one hand so that the baby is not distracted by the sight of the instrument. The Authority's licensees for this instrument are Leyton Instruments Co. Ltd., 54 Albert Road, Caversham, Reading, Berks.

Digital converter and actuator

This is designed as a cheap fast interface between a time-shared computer and the controlled element for direct digital control.

Air bearing transfer table

This demonstrated the principle of supporting objects and moving them on a cushion of film of air. The air is supplied through holes coned at the top so that a steel ball, held up by air pressure, protrudes slightly above the surface; the air cushion is produced when the load depresses the steel ball.

Thermal flowmeter

This measures the temperature rise in the fluid when it passes through a heated zone. It measures flows of from 200 grammes per hour to 2000 grammes per hour.

Waveform ($\triangle T$) analyser

This compares an incoming signal against an internally generated reference level. The time Δt of each excursion of the incoming signal above the reference level can be measured and the individual values of Δt can be classified into pre-selected ranges and a histogram showing the distribution of Δt for a particular reference level can be made.

The U.K.A.E.A. stand was designed by Gunther Hoffstead, F.S.I.A.

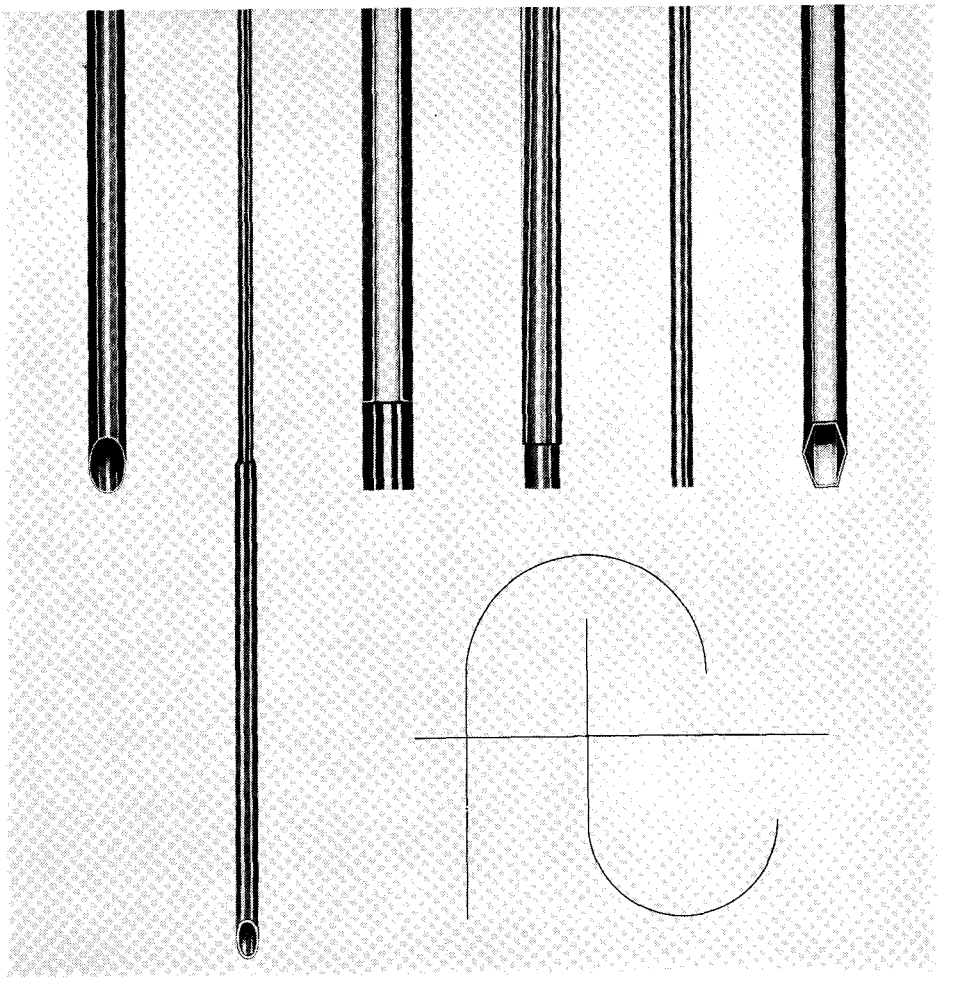
Radioisotope course

The University of Salford is holding a two-week full-time course entitled "The Use of Radioisotopes in the Chemical Laboratory" from 17th-28th June, 1968.

The course is primarily designed for graduates or others with equivalent qualifications working in research or development laboratories. The participants will follow an intensive programme of lectures and laboratory work to enable them to undertake radio-isotope work with confidence.

Lecturers on the course will include Dr. J. Ogle of the Radiochemical Centre, Amersham.

A booklet giving details of the course and an application form will be available on application to the Administrative Assistant, Short Courses, Room 322, University of Salford, Salford 5, Lancs.



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Fine Tubes supply the U.K.A.E.A. with fuel element can tubing used in their research reactors at Windscale, Dounreay and Winfrith. These are made to the Authority's rigid specifications in Vacuum Melted 20/25Nb steel, Modified AISI 316L, Double Vacuum melted AISI 304, Nimonic PE16 and many other analyses.
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