NOVEMBER 1978 NUMBER 265

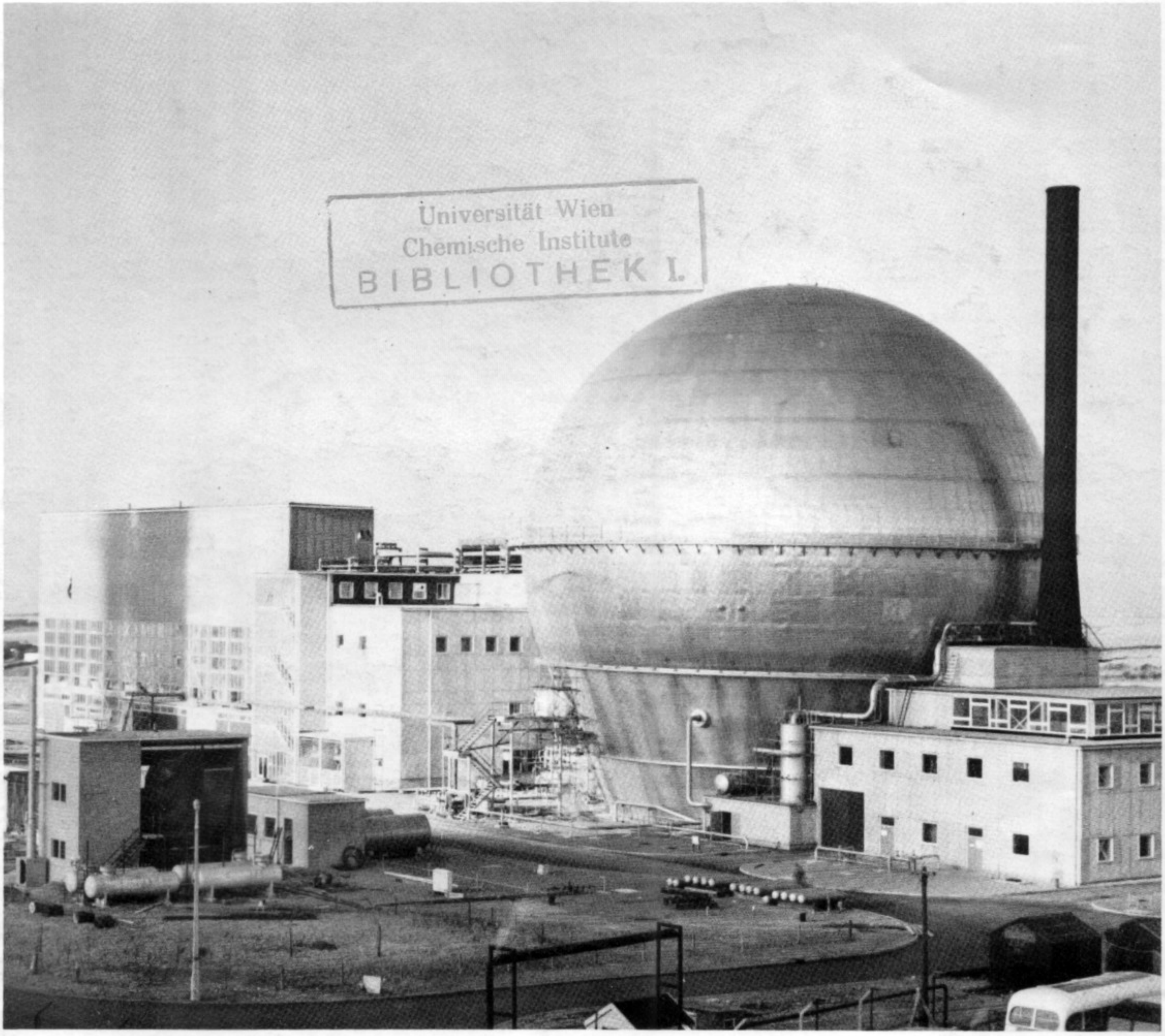
ATOM

THE URANIUM MARKET — ECONOMIC AND POLITICAL FACTORS

DECOMMISSIONING NUCLEAR REACTORS

THE DISCOVERY OF FISSION

TRCL ANNUAL REPORT



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THE UNITED KINGDOM ATOMIC ENERGY AUTHORITY

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Information on advertising in ATOM can be obtained from D.A. Goodall Ltd., Empire House
St. Martins-le-Grand London EC1A 4DR
Telephone 01-606 0577/8/9

Front cover: The Windscale Advanced Gas-cooled Reactor, the subject of decommissioning studies — see page 295.

THE URANIUM MARKET — ECONOMIC AND POLITICAL FACTORS

Terence Price*, Secretary General of The Uranium Institute, presents his personal view that rules governing world trade in uranium require codification "so that even if formal case-by-case decisions have to continue indefinitely, the outcome will be predictable except in the most unusual circumstances."

In recent months the future availability of uranium has become a central issue in the political debate on nuclear power policy and non-proliferation. The Ford-Mitre study, carried out by an influential US team, and published in April 1977 says, in effect: "there is no problem over uranium supply. Once the demand is there the supply will grow as needed — as has been the case for most commodities. Nor is there any immediate need for fuel reprocessing and recycling; no need for breeding technology; and no need to separate plutonium in a pure form — at any rate, not for a long time". This argument received strong support from the Carter administration; and soon afterwards, on a US initiative, INFCE — the International Nuclear Fuel Cycle Evaluation — was set up at governmental level, in effect to demonstrate to the world that previous notions of the likely development of nuclear power could be substantially modified. INFCE does not, however, now seem likely to succeed in achieving that purpose; nor is the world nuclear industry yet convinced that uranium supplies will be forthcoming on the scale assumed in the Ford-Mitre study, merely by the automatic operation of normal economic laws.

This paper is a personal attempt to set out the position as seen from an industrial, rather than a political, standpoint. The views expressed are personal, and commit no-one but the author.

Uranium demand

Any estimate of the likely future level of nuclear fuel demand involves predicting electrical power growth, which is closely correlated with general economic growth. As countries become wealthier, the convenience of electricity attracts more uses. The result has been, in the UK, that an average 2.5 per cent per annum growth in the economy (in real terms) in the decade to 1974 was accompanied by a 5 per cent per annum growth in electrical production. For the world as a whole the figures were 5 per cent and 7 per cent respectively.

The 1973-74 energy crisis has, however, interrupted and perhaps permanently slowed down economic growth, and has also conduced towards some conservation of energy. Just what the combined effects of these two factors will be on long-term electrical power trends is still uncertain. The uncertainty is particularly important for nuclear power. Being a new economic energy source, nuclear power is still largely concerned with *increments* of installed capacity. A one per cent uncertainty in economic growth — say 3 per cent instead of 4 per cent per annum — then translates into about a 25 per cent uncertainty in the cumulative requirement for uranium until 1990. This is the main reason for the sizeable reduction made to the forecasts published by OECD in 1973 and 1975. In fairness to the OECD officials, they were at that time largely working on data supplied to them by member governments, who may not have been ready to admit (even to themselves) that economic growth was likely to be permanently slowed down. The most recent official estimates are, however, more in line with what the industry now regards as its probable future. Some estimates are given in Table 1, together with the theoretical demand for uranium based on the data in column 2 of the table.

In practice, in the past few years the actual commercial demand for uranium has been higher, owing to the existence of a substantial number of rather rigid enrichment contracts which were entered into some years back, at a time when the general assumption was that nuclear power would grow rather more quickly. In the recent past, some US contracts — the major part of the enrichment market at the present time —

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Year	Nuclear [a] capacity (GW)	Quantity uranium needed[b] (10^3 tonnes of uranium element)	
		Annual	Cumulative from 1.1.77
1978	105	26	47
1985	255-280	50-60	300-340
1990	410-530	74-96	620-750

Notes:

(a) Figures are estimates for WOCA (World Outside Communist Area)

(b) Uranium requirements assume enrichment plant tails assay of 0.20 per cent.

Table 1: Natural uranium requirements

have been made less rigid. By about 1990 the available enrichment capacity will probably be better matched to reactor needs, and there will then be little difference between the two requirement estimates.

Sensitivities and uncertainties A number of factors could considerably widen the limits of uncertainty given in Table 1. One is the possible variation in the 'tails assay' — the uranium concentration in the reject stream of an enrichment plant. An enrichment plant can be operated within fairly wide limits of tails assay, and the actual choice will depend on the relative cost of uranium (high uranium cost — low tails assay) and energy (high energy cost — high tails assay). With present technology, the range of practical possibilities runs from around 0.16 per cent to about 0.3 per cent. If these limits are used instead of the figure of 0.20 per cent used for Table 1, the figure for the lower power-level for 1990, instead of 74,000 tonnes U, would become 70,000 tonnes at the low tails assay end, and as much as 87,000 tonnes at the high tails assay end.

The demand for natural uranium is also sensitive to whether or not uranium — and eventually plutonium — are recycled in fuel reprocessing plants. Recycling of uranium alone will allow uranium requirements to be reduced by 10 per cent. It will be some time before enough reprocessing plant capacity will be available to permit this; but by 1990 the quantity of uranium recovered could amount in total to perhaps 40 thousand tonnes. Once fuel recycling really gets into its stride — around the end of the century — the combined effect of recycling both uranium plant and plutonium would be to reduce annual uranium requirements by perhaps 25 per cent, provided of course that the economics of doing this are favourable in comparison with the price of newly-mined uranium.

At the present time nuclear power planners and uranium producers also have to contend with unquantifiable delays, stemming from:

- Delays in obtaining planning permission for nuclear power stations (Japan, Sweden)
- Success of nuclear objectors in invoking legal obstacles to start-up (especially in Germany)
- Delays in obtaining operating approvals owing to a mandatory need to define (e.g.) the exact way in which nuclear fuel is to be stored (Sweden)
- Possible delays in authorisation of programmes, owing to political uncertainties created by case-by-case approval system. (See the final section of this paper.)

In spite of these uncertainties the prospects of the nuclear power industry are, by the standards of most commercial operations, still extremely encouraging. Even though they fall short of the expectations of only three years ago, a threefold increase in installed nuclear power generating power by 1990 still appears probable.

Supply Capabilities

Uranium production — medium term. Uranium is a fairly abundant element, which occurs in the earth's crust in an average concentration of 2 parts per million — a figure which implies a world-wide total of nearly 10^{12} tonnes. This figure is, however, of only academic interest, because what matters for practical economic purposes is the amount which can be discovered and mined within the limits of cost that the market can bear. This focuses attention on the higher grade ores — with concentrations typically running at around 0.1 per cent by weight (The big Jabiluka deposit in Australia is 0.3 per cent; the ore extracted in the Denison mine in Canada currently has an average grade of 0.087 per cent.) Lower concentrations not only add to the problems of mining, but also create environmental problems, because of the volume of rock which has to be mined and crushed in order to extract the product. Nevertheless, projects have been considered for the exploitation of ores with concentrations as low as 300 ppm (e.g. Ranstad, Sweden).

The present pattern of production (Table 2) is not primarily a matter of geology, but is more a reflection of the Western World's reaction to the military demand of the 1950s. It is only in the past few years, since 1973, that the incentive has existed to look intensively for uranium in the developing world. It is to be expected that by the end of the century uranium production will be much more widely based. But it does not follow that all the principal users will, in time, be able to rely on their own indigenous production. There will remain wide variations in the extent to which user countries can expect to be self-sufficient. The UK and Japan are both likely to remain dependent on imports.

To meet the current growth in demand a major expansion is now under way in the mining industry. A comparison of Tables 1 and 2 shows that production should be capable in principle of keeping pace with demand, at least until the late eighties — though there may be some market tightness in the immediate future. Some qualifications to this optimism are, however, necessary. First, uranium mining is nowadays as susceptible to planning delays as the electrical power industry, and it is difficult to anticipate the extent to which regulatory procedures will slow down expansion in future. But there will be strong economic incentives not to prolong enquiries unnecessarily. Secondly, production plans are

	1976 (actual)	1977 (actual)	1980	1985[c]
Australia [a]	360	360	500	11 500-14 000
Canada	4 850	5 794	7 600	10 500-12 500
France	2 063	2 236	2 600	3 000- 3 500
Gabon	965	906	1 000	1 000- 1 500
Niger	1 460	1 440	3 800	7 000- 8 500
S.Africa & Namibia	3 412	5 300	10 700	10 500-13 000
U.S.A. [b] [e]	9 800	11 460	18 100	21 500-25 500
Other	350	640	2 300	4 000- 5 000
Total (rounded) [d]	23 300	28 100	47 000	70 000-84 000

Notes:

(a) Figures for Australia must be regarded as speculative, until all obstacles to production are cleared away. But the major expansion shown for 1985 is technically feasible.

(b) The US figures are the subject of some controversy. US official estimates are significantly higher (28 000—33 000 tonnes), with a forecast 1985 production *capability* of 36 000 tonnes.

(c) For 1985 the figures should be read as denoting potential capabilities rather than firm intentions.

(d) For 1990, production estimates range from 92 000 to nearly 120 000 tonnes uranium per year.

(e) By-product uranium, from phosphate and copper production in the US will contribute about 10 per cent to uranium production — about 110 000 tonnes U in all by the year 2000.

Table 2: Estimated Uranium Production 1976-85 (tonnes U/year)

largely in the hands of private industry, which will make its own judgement of down-side risks and uncertainties in demand. We can expect a climate of indecision on the nuclear power side to be reflected in reductions in plans for uranium production. Thirdly, uranium no longer follows the normal chemical rule of one atom being indistinguishable from another; safeguards of various kinds now attach to some uranium, though not to all, and this could influence the availability and distribution of the uranium which is actually produced.

Precise prediction of the world potential for uranium production after 1985 is impossible at this stage; but some impressions can be obtained by looking at the various contributory factors — resource availability, exploration, price, and government policies. These factors must be judged in the light of a demand pattern which, depending on the assumptions, implies that production needs to grow at something around 10-12 per cent per annum compound, for many years, until eventually breeding brings down the demand. Earlier expansions of the production of other mineral commodities were less rapid. Copper grew by a factor of 3.5 in 30 years (to 1916) or 4.2 per cent per year. Oil grew by 4.3 times between 1950 and 1970 (7½ per cent) — but oil exploration was able to use more powerful tools than are yet available for uranium.

It is impossible to say how far the better technology available today will make such a growth rate a practical possibility. Certainly with deposits which can be surface-mined very large scale operations are possible. But a great deal of uranium will continue to come from underground mining, where the physical limitations of ore-bodies — size, shape, and depth — will impose constraints on the mining rates.

There is also the effect of falling ore grade: work tends to start on the best ore-bodies, and then to progress into the more difficult areas, or areas of lower concentration. This means that progressively more rock has to be mined for a given level of production, so that output falls unless more milling equipment is installed. In the US uranium concentrate production remained almost constant at 12-13 000 short tons of oxide between 1968 and 1976, in spite of a 50 per cent increase in ore processing rates, almost entirely because the average ore grade had fallen in the meantime from 0.21 per cent to below 0.16 per cent.

Then the supply of underground mining labour cannot be taken for granted. Furthermore, as the labour force expands, its experience tends to be diluted; and a reduced level of skill can contribute to a poorer average return, equivalent in effect to working with a lower ore grade. While none of this is an absolute bar to attaining the required production rates, it does serve as a warning not to assume that satisfactory overall figures for resource availability will lead easily and automatically to the production of 'yellowcake' on the required scale.

Resource availability Apart from the rate of growth, the absolute size of reserves is a further major factor. World reserves are estimated periodically by the IAEA (International Atomic Energy Agency), working in conjunction with the Nuclear Energy Agency of the OECD, in terms of the likely cost of exploiting particular deposits. The cost enters into the assessment because minerals occur in nature in varying concentrations, the low concentration ores being more costly to mine. An increase in selling price in effect converts useless mineralisation into exploitable ore, and thus adds to the economically exploitable resources.

The process of discovery proceeds step by step, starting with rough general indications, and continuing until sufficient is known about a deposit for firm production decisions to be made. Methods of reporting the size of ore-bodies must allow for this spectrum of uncertainty. A variety of terms has

Category:	Reasonably Assured		Estimated Additional	
Cost Range: ($/lb U_3O_8)	Up to $30 RESERVES	$30-50	Up to $30	$30-50
Australia	289	7	44	5
Canada	167	15	392	264
S & SW Africa	306	42	34	38
USA	523	120	838	215
Western Europe	48	315	38	30
Other	317	41	164	38
Total (rounded)[(a)]	1 650	540	1 510	590

Source: Uranium Resources, Production and Demand (OECD/IAEA December 1977)

(a) A recently published report by the Committee on Nuclear and Alternative Energy Sources (CONAES) of the US National Academy of Sciences gives total US figures somewhat lower than those in the above Table (1.35m tonnes). Their figures for world reserves and other resources up to $30 per lb U_3O_8 are, however, somewhat larger: 1.8m tonnes of reserves, and 3.9m tonnes U of other resources.

Table 3: Uranium Resources, at 1.1.77 (thousand tonnes U)

been in current use; but to simplify reporting the International Atomic Energy Agency uses only two categories for each band of costs. The term *Reasonably Assured Resources* refers to uranium which occurs in known ore deposits, of such size, grade and configuration that it could be recovered within the given production cost range, with currently proven mining and processing technology. The Reasonably Assured Resources below $US 30 per pound tend to be regarded as "Reserves" in the traditional mining sense. *Estimated Additional Resources* refers to uranium surmised to occur in unexplored extensions of known deposits or in undiscovered deposits in known uranium districts, which is expected to be discoverable, and which could be produced in the given cost range. It does not include any uranium districts which have yet to be discovered.

Figures published in 1977 by IAEA show total world resources as just over 4 million tonnes U, at costs of up to $50 per pound U_3O_8 (Table 3). (A more recent estimate — see note to Table 3 — gives a slightly higher figure). Assuming the OECD's 'present trend' estimates for nuclear power growth — roughly the basis on which the demand figures given earlier are based — and without uranium and plutonium recycling, the total resources would cover the world requirements only up to about the year 2010. If we focus on the life-time requirements of reactors in place, then it is clear from a simple multiplication of the annual requirements figures in Table 1, by the design life-time of 30 years, that, very soon after 1990, fears could arise about the ability of the mining industry to satisfy demand later on, unless a substantial addition to the reserves has occurred by then. Reprocessing gives only a few years' grace, because of the exponential nature of the predicted growth.

Thus in order to make nuclear fuel policy hang together something else is needed: either a reduction in the nuclear requirement; or the introduction of breeding reactors, with their capacity for multiplying the energy production from a given quantity of uranium by a factor of up to 50; or an assurance that exploration will keep pace with the expanding requirement. Of these three possibilities the first seems unlikely. The second is relevant to the world-wide debate on the need for reprocessing — for without reprocessing the option is closed. The third, exploration, is a matter for the uranium industry, and is clearly crucial.

Exploration The OECD/IAEA conventions for reporting the probable size of world uranium resources could mislead a casual reader in one important respect. About half the total figure refers not to uranium which has been precisely located, but to inferences made about the probable occurrence of uranium, given what is already known about other deposits. This means that exploration discoveries may or may not represent additions to the world total: that depends on whether or not their existence has, or has not, already been "surmised".

From the moment that a deposit is located to the time when it can be commercially exploited takes in practice something like a decade. The time taken is spent in:

- drilling out the ore body to define its grade and size
- development to support the mining plan and engineering design
- environmental studies
- preparation of environmental impact statement
- design of mining and milling facilities
- governmental approvals unrelated to environmental considerations (e.g. export policy)
- production financing
- construction, including construction of infrastructure
- commissioning and startup

This process is closely parallel to what has to be undertaken for nuclear power stations, and for somewhat similar reasons. As with power stations, the time spent in obtaining government approval can introduce major and often unpredictable delays. The consequent slippage in uranium production schedules is currently a significant factor in world supply, and the industry is not necessarily in a position to use delays on the power station side to prepare itself for future production. This has already contributed to the tight market position for uranium deliveries in the next few years.

Ideally exploration should progress so that the world's known total resources do not diminish — which means that discoveries in a given year should match anticipated production several years later. The industry's target is for exploration to lead, if possible, by a decade. There are some difficulties in ascertaining whether this target is being achieved. Exploration results are not always announced. Drilling activity is more often publicised; but the wide differences in local geology greatly complicate attempts to infer the likely yield from the total drilling programme. Some rough guidance is, however, available, based on a rough average cost per pound of uranium oxide located (about 1 or 2 dollars). This leads to the conclusion that the recently greatly expanded levels of exploration[1] might be expected to identify, per annum, a quantity of mineable uranium roughly in line with the requirement ten years hence. There is, of course, great uncertainty in any such prediction; but such a level of return, if realised, would represent a useful prolongation of the life of the reserves. There is always the possibility of discovering further relatively large deposits, such as the Alligator Rivers ore-bodies in Australia. A few such discoveries could make a substantial improvement in the outlook. Nevertheless, when weighing future options it must not be forgotten that exploration is essentially a chancy business, and that there is still no firm evidence that it will be possible to keep pace with the progressively higher requirements of the 21st century. Moreover, a '10 year forward' criterion is not the most stringent that could be chosen. If we use an alternative test, of discovering in one year the amount of uranium needed for the *life-time* requirements of reactors commissioned in that year, then the task appears considerably more demanding.

Exploration prospects will, of course, alter as time passes. One obviously helpful factor is that more experience will be built up. Developments in theoretical geology, and experience in combining a variety of exploration techniques, should help to improve the return. In addition, only a relatively small proportion of the earth's land-mass has yet been thoroughly explored. Even if we discard the areas which are, at present, of minor interest (on geological, political, or logistic grounds) or which are already devoted to other non-compatible uses (such as urban or agricultural land) we are left with about one-quarter of the world's land surface. This is comparable with the area which has already been covered, which implies that a useful factor may still be in reserve — though not necessarily at the same cost, because of the poorer accessibility which would often apply.

There is, however, a major factor which acts in the other direction. The early discoveries of the fifties were made very largely with the aid of radiation detectors, which located surface outcrops of radioactive minerals. Low-flying aircraft provided what was in effect a "mass-production" approach to shortlisting sites suitable for follow-up ground survey. Unfortunately the range of nuclear radiations in earth and rock is limited to not much more than a few metres, which severely limits such methods.

In some cases, surface detectors relying on radon emissions can make use of seepage through fissures to extend the range of detection down to a few hundred feet below the surface. But lower depths must be attacked by an integrated approach based on all available methods — including, for instance, inferences from theoretical geology, or geochemical analysis of stream sediment or morainic boulders, supported by fence drilling in the final target area. While the variety of possible techniques makes an otherwise difficult task more tractable, the loss of the directness of the earlier phase of exploration can only be a hindrance. Nothing comparable with the "magic" potential of seismology for oil exploration seems to be in sight.

Conclusions regarding the ability of the uranium mining industry to meet the demand The above facts suggest the following conclusions. In the medium term, to the year 1990, there should be no worries about the ability to satisfy demand, even if very stringent tests are applied. Exploration will certainly add to the reserves, thus stretching out the safe period. In the longer term, however, we cannot yet be certain that there will be no problems. A scenario in which nuclear power generation grows at the rate implied in Table 1 is one which is likely to be followed by a continuing acceleration in demand, at least until base-load generation requirements are dealt with. Hopefully, living standards around the world will still be rising, which would mean continuing growth in electricity consumption. Population will also be going up, although admittedly this influence will be concentrated mainly in the less developed countries. The combination of these various factors takes us right outside the range where we can say with confidence whether there will be enough uranium in the early 21st century.

Even if we assume that the fast breeder will be introduced progressively after 1990, it is still not possible, at the present time, to give more than the roughest estimates of its effect on uranium demand. A great deal depends on the breeding doubling time. Present-day breeder reactors tend to have doubling times of over 20 years (i.e. an annual gain of around 3 per cent). Clearly, even if economic growth stays at quite a modest level, such breeders will take a very long time to catch up with demand. Even if breeders with considerably shorter doubling times become available, as seems not impossible, the annual requirement for fissile material will continue to grow for many years. The best that can be hoped for is for the annual demand to peak around the year 2025, and fall to a relatively low level after the middle of the next century. By then the cumulative requirement for natural uranium will have reached something of the order of 20 million tonnes, and possibly a good deal more. It is the impossibility of being certain, with our present knowledge, of being able to find and mine uranium on this scale, which drives the nuclear industry to insist on the need for breeding. Without breeding, at least to European eyes, nuclear power would be merely a transient phenomenon.

Thus in a very real sense the breeder is a potential benefit

[1] In Canada, for instance, the 1977 level of drilling was 293 000 metres, more than double the 1976 level of 137 000 metres.

to the uranium producers — even though it produces more fissile material than it consumes–because it enables the electricity industry to regard nuclear power as a permanent feature of the future, and therefore worth pushing hard. The FBR is likely to be more costly than thermal reactors, and there will almost certainly be a long period of economic competition between the two families of reactor — for how long will depend on our success in finding uranium. Nevertheless, the electrical utilities of the world believe the FBR to be essential as an insurance policy against possible future difficulties in finding and winning uranium.

Political aspects of uranium supply

Current difficulties Quite apart from these technical and economic considerations, another problem — the 'political availability' of uranium — has begun to exercise the industry in recent years. The 1973 oil crisis served notice on energy users that massive economic disruption could be caused to states which did not control their own sources of energy. This was certainly one of the factors which gave fresh support to nuclear energy programmes in 1974 and 1975 — it being assumed that because nuclear energy supplies were largely in the hands of friendly and stable states, security of supply could be guaranteed. Subsequent events have somewhat shaken this view, and the resulting anxieties are of particular significance for non-proliferation policy-making.

The anxieties stem from several sources. First, by no means all the developed countries have their own uranium supplies. The US, Canada, and France are well-provided; Japan, Germany and the UK are not. Countries in the latter group understand that they cannot count on uranium imports on a scale which would deprive exporting countries, like Canada, of the uranium needed to fuel their own nuclear power programmes. Canada has, in fact, made her position quite clear in this respect, which is helpful to other countries in making their plans.

In other respects the recipient nations have more cause to be worried. The past few years have witnessed delays in uranium production, and embargoes on uranium deliveries, arising from a variety of causes. One source of delay has been in obtaining planning permission to commence mining. Two well-known cases are the Fox enquiry into mining in the Australian Northern Territory, which led to almost a three year hold-up, and the Bayda enquiry in Saskatchewan. It is fortunate that these delays occurred before demand for uranium had started to grow rapidly.

The industry regards the export interruptions of the past two years as more serious in their long-term implications, even though the underlying reasons will have the sympathy and understanding of almost all countries. In the case of Canadian uranium the cause was a reaction to the disturbance to local public opinion caused by the Indian nuclear explosion of 1974. The Canadian Federal government, on 20 December 1974, announced a strengthened safeguards policy. Later on, this safeguards policy — for reasons connected with an unwillingness to open the way to discretionary exceptions — became entangled with the provision of the Euratom Treaty which (in theory at least) permits free movement of fissile material within the Euratom countries, two of which are nuclear weapons states. As a result, European states, which regarded themselves as politically stable and reliable — and which had every reason to believe that others so regarded them — found themselves for a time embargoed from receiving deliveries of Canadian uranium. There have been somewhat parallel problems in connection with future Australian deliveries to Europe. There were also difficulties over US enriched uranium, in the early days of the Carter administration.

It would be an exaggeration to suggest that these incidents caused much more than administrative inconvenience, though at least one European utility was forced to look for alternative sources of uranium to meet the feed requirement for a very stringently worded enrichment contract. Their real significance is that they served notice on all the countries affected that, in the absence of binding international agreements, no-one could count on the supply of nuclear fuel remaining uninterrupted, whatever the source. As a result, many voices can be heard, particularly in Europe, canvassing the need to complete the downstream nuclear fuel cycle capability, with full uranium and plutonium reprocessing; to maintain the priority of breeder development; and to encourage the diversification of supplies of enriched uranium.[2]

This, however, will take many years; and meanwhile countries which have embarked on major nuclear power programmes must continue to live with the requirements of the supplier states — unless, like France, they have their own indigenous uranium supplies. The consumer countries clearly have some unresolved anxieties. In particular, they are wary of case-by-case rules whereby the US, for instance, can exercise control over the future disposal of used nuclear fuel, in such a way as to constrain the freedom of European operators of nuclear fuel reprocessing plants — like those at Windscale and Cap La Hague — from handling foreign fuel. This seems to Europeans to be not only difficult to accept in political terms, but also technically unjustified, given the facts which have been set out above. Additionally, the unpredictability of case-by-case controls, as at present operated, is generally regarded as a substantial constraint on an industry which — more than almost any other — is one where long lead times are unavoidable when preparing forward plans. (The full benefits of the fast reactor, on which work started in earnest in 1950, will not be realised until about the year 2040.)

Fortunately, both the electricity industry and the uranium mining industries are fairly sophisticated. Both live close to government, for several obvious reasons; and they understand the reasoning behind current non-proliferation policies. Both sides of the industry are now actively engaged in assisting governments to find some *modus vivendi,* which will combine good non-proliferation controls with a regime in which trade in nuclear raw materials can be carried on with fewer uncertainties. The main need is for the rules governing controls on uranium trade to be codified, so that even if formal case-by-case decisions have to continue indefinitely, for political reasons, the outcome will be predictable except in the most unusual circumstances.

It would be neatest to have a single internationally acceptable set of norms, setting out the rules under which governments are prepared to allow the uranium market to operate. A single set of rules may not be negotiable, however; nor is one absolutely necessary, provided a broad consensus can be drawn out of the current INFCE deliberations. That would be in everyone's long-term interests. At the very least, it would damp down the present tendency for each major country to go it alone, which can hardly assist international plans to deal with non-proliferation. It should also help to create a healthy nuclear industry, operating without anxieties about the long-term adequacy of natural uranium fuel supplies — over which there can be no final certainty for many years to come. The industry believes that, in arriving at an international consensus, the FBR and recycling must be realistically dealt with as essential components of the fuel cycle. It sees no future in policies which attempt to hold back technologies for which there are clear long-term requirements. Clarification of these issues would have the positive and immediate effect of helping nuclear power to take its natural place in the spectrum of energy production.

[2] The Federal German Republic currently relies on Russia for one-third of its total enrichment needs, the remainder being from the US. By 1986 Urenco will have begun to build up its production, and will then be covering 32 per cent of German demand.

DECOMMISSIONING NUCLEAR REACTORS

Increasing attention is being focused on the decommissioning of nuclear installations when they are permanently withdrawn from operational service. In the following article W.H. Lunning* outlines work which has been done by the UKAEA in preparation for the decommissioning of the Windscale Advanced Gas-cooled Reactor.

Decommissioning requires that nuclear facilities permanently withdrawn from operational service be put into a safe condition to protect man and the environment, the ideal ultimate objective being complete removal and disposal. The UKAEA in conjunction with other organisations has for the past five years been examining the development issues and practical aspects of dealing with nuclear facilities no longer required in the UK. The objective is to include all types of nuclear installations but attention has been directed initially to nuclear power stations. Close liaison has been maintained with the Generating Boards.

At the present time world experience of decommissioning nuclear reactors is comparatively limited. A number of early, low power, units have been closed down and taken to various stages of decommissioning. The largest reactor to be completely dismantled to date was the Elk River Boiling Water Reactor (22.5 MWe) in the USA. There is, however, a wealth of practical experience of working under active conditions during plant maintenance, modification and adaptation which is directly relevant to the type of work involved in decommissioning.

International liaison is maintained through a technical committee of the International Atomic Energy Agency, which has concluded that there are no unsurmountable technical problems to decommissioning. Within the European Community a Commission proposal for a collaborative R & D programme on topics specific to decommissioning is currently under consideration.

Within the UK the UKAEA reactors in support of the power development programme together with the currently operating 26 Magnox reactors in 11 stations totalling some 5 GW will probably be retired by the end of the century. The timing of withdrawal from service will be dictated by development programme requirements in the case of UKAEA reactors and by economic and technical considerations in the case of commercial reactors. Decommissioning aspects were not a primary concern in the design of these facilities, but future designs will take this factor into account to reduce, where practical, the complexity of decommissioning problems.

The UKAEA selected the Windscale Advanced Gas Cooled Reactor (WAGR) as the initial reactor for decommissioning studies and a similar study is being undertaken by CEGB of a typical steel pressure vessel Magnox station.

*Central Technical Services, Risley Nuclear Power Development Establishment.

Decommissioning options

Three generally accepted stages of decommissioning have been identified from national and international studies. For the current classes of UK reactors these have been interpreted as:

Stage 1 Shut down, remove fuel, remove coolant and make safe. Maintain under surveillance.

Stage 2 Reduce installation to the minimum practical size without penetrating into those parts which have high levels of induced radioactivity. Ensure the integrity of the reactor primary containment and biological shield to prevent personnel and environmental hazard. Maintain under surveillance.

Stage 3 Complete removal of the reactor and all other plant and waste off-site followed by the return of the site for redevelopment or general use by the public. No further requirement for surveillance.

These stages, each of which establishes a safe condition, define the status of the reactor in terms of its physical state and required degree of surveillance. Accepting that complete removal of the facility is the ideal ultimate objective two main options are open: to proceed to stage 1 or 2 and to delay stage 3 operations to allow radioactive decay which will ease dismantling, or to proceed continuously from reactor closure to stage 3. The decision as to which option to adopt will be influenced *inter alia* by the dose commitment to persons during dismantling operations, the economic attraction of reusing all or part of an existing site, and environmental considerations.

Radioactive inventory

Decommissioning of a nuclear power station compared with conventional types of industrial installations is unique, due to problems associated with radioactivity. It should, however, be recognised that radioactivity is limited to specific areas and that a large proportion of a nuclear power station has no associated activity and can be decommissioned and disposed of using conventional methods.

To identify the development issues and practical aspects of decommissioning requires among other data, a knowledge of the total radioactive inventory and its decay together with its distribution within the system. The radioactive inventory includes:

(i) neutron-induced activity in the fixed structure of the plant.

(ii) neutron-induced activity of removable components remaining in the reactor after defuelling, eg control rods.

(iii) contamination around the primary cooling circuit arising from activated corrosion products or burst fuel.

(iv) contaminated/activated operational waste arising during the life of the reactor and stored in designated facilities.

Estimates for (i) and (ii) can be made by calculation but the accuracy which can be achieved is dependent upon the assumed chemical composition, in particular the abundance of trace elements which become radioactive, of the construction materials. For UK reactors currently being studied these are essentially mild steel, stainless steel, concrete and graphite. The composition of the last is well defined due to the 'nuclear' specification required for its use and analytical control. The specifications for WAGR steels were nominal and the decision was taken to extend them, after consultation with UKAEA metallurgists, to include reasonable quantities of inevitable trace elements. The abundance of trace elements in concrete is controlled principally by the aggregate which in turn is dictated by the geographical source. The concrete composition adopted is based on a nominal specification modified by measurements carried out on samples from the WAGR biological shield.

The calculation of the inventory for WAGR was based on a mean flux in the moderator of 5.7×10^{13} n/cm^2/sec at a nuclear load factor of 0.7 for a period of 15 years. Although a calculated inventory is considered adequate as a basis for technical judgements it should be validated and corrected if necessary by physical measurements of samples wherever possible from within the reactor. Item (iii) is dependent upon the operational history of the reactor and can only be estimated on the basis of sampling. Item (iv) should be identified from records. In the case of WAGR, operational waste is disposed of as it arises to general facilities on the Windscale site.

WAGR activation and contamination

Figure 1 is a diagram of WAGR indicating the main features of the reactor and its ancillary plant. The major neutron-induced activity occurs in the steel pressure vessel and the steel structure within it, which have collectively a mass of approximately 600 tonnes of mild steel and 40 tonnes of stainless steel. Also within the pressure vessel is some 300 tonnes of graphite forming the core moderator and reflectors, together with the neutron shield situated above the latter. The degree of activation varies within the pressure vessel due to neutron attenuation by internal components. The induced activity is concentrated in the steelwork, which incorporates the bulk of the stainless steel, in the immediate proximity of the core. The significance of the stainless steel is that it has a higher proportion of cobalt and nickel than mild steel and the overall inventory is influenced by the radioactive isotopes of these two elements. The neutron-induced activity and its decay with time, of the pressure vessel and its internal structure, is shown in Figure 2. The initial decay over the first 40-50 years is dominated by Fe-55 (half life 2.6 years) and Co-60 (half life 5.27 years) which are then superceded by Ni-63 (half life 92 years) as the principal isotope. The exponential decay of the system over this second phase therefore is much reduced. The radio nuclides resulting from neutron irradiation are exclusively $\beta\gamma$ and no α active nuclides are produced. From Figure 2 it can be seen that the β decay follows the total curie decay but the γ activity stabilises at a virtually constant value after about 100 years.

The degree of activation of the main concrete biological shield and its mild steel reinforcement which surrounds and supports the pressure vessel on internal corbels will vary with location. The maximum depth of activation of the concrete measured from the internal face is approximately one metre. The mass of the biological shield is approximately 4000 tonnes of concrete containing some 200 tonnes of mild steel reinforcement. It is calculated that after seven years' decay following shutdown the active portion will consist of around 750 tonnes of concrete and 90 tonnes of the inner reinforcing steel.

The four heat exchangers, each 20 metres high by 7.3 metres diameter and weighing 150 tonnes, are external to the main reactor biological shield. They are not exposed to direct neutron irradiation but are, however, contaminated internally with Co-60, Cs-137 and Cs-134. The degree and distribution of this contamination is monitored on a routine basis.

Decommissioning practice

The prelude to any decommissioning of nuclear reactors is the removal of the fuel and its contained fission products. This significantly reduces the radioactive content of the system leaving the bulk of the residual activity as neutron-induced and therefore in a safer form within the central region of the reactor protected by the massive concrete biological shield structure.

Stage 1 Decommissioning to this stage consists essentially in sealing the pressure vessel with plugs in the fuel element channels after fuel removal, and securing the integrity of ancillary circuits. This in effect renders the reactor safe and substantially intact on a 'care and maintenance' basis, backed by the appropriate degree of monitoring. This stage is the most economic to achieve but will attract high maintenance costs particularly if this stage is of long duration.

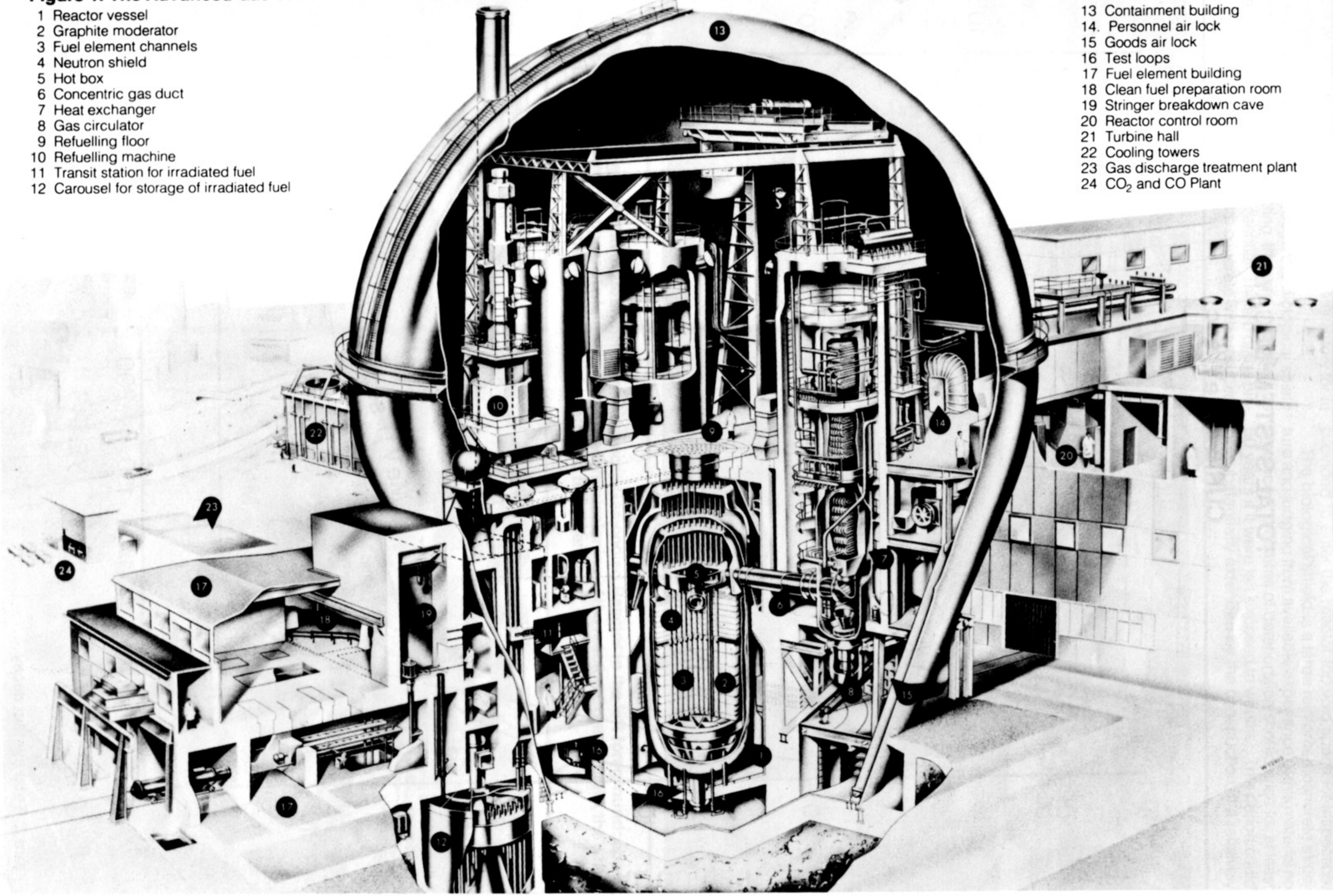
Stage 2 The decommissioning of WAGR to this stage would include the removal of all plant external to the reactor proper, together with the reactor containment building and all plant and equipment within it, outside the reactor biological shield but including the heat exchangers. The residual structure, which is the reactor biological shield containing active components of the reactor within the sealed pressure vessel, would be a 15 metre diameter by 15 meter high right cylinder. This would occupy about one fiftieth of the present WAGR site area and would also reduce the visual impact by a factor of six based upon the presented vertical area compared with the 41 metre diameter containment building which currently dominates the WAGR complex.

The most economic Stage 2 situation would be to leave the plant with both the pressure vessel and the interspace between the latter and the biological shield filled with air. No external ancillary operating plant would be required except for monitoring purposes. The following aspects relating to a long-term Stage 2 condition have been considered:

(i) *Temperature* The residual heating in the system associated with activity after two years' shutdown is less than 1 KW. Assuming no forced cooling of the graphite and applying a simplified model based on pessimistic assumptions it was calculated that the graphite temperature would not exceed 40°C. This temperature is well below the minimum graphite operating temperature (230°C) and hence there is no possibility of spontaneous energy release from the graphite, or of its combustion. Graphite temperature monitoring would be maintained as a safety measure.

(ii) *Structural integrity* This is basically dependent upon the corrosion of steel. Since the site is coastal a pessimistic corrosion rate of 0.075 mm per year on each exposed surface (ie 0.15 mm total thickness) was assumed. Ignoring corrosion retardant factors such as temperature due to residual activity, major component failure periods have been estimated. It is concluded that the integrity of the reactor

Figure 1. The Advanced Gas-cooled Reactor at Windscale



1 Reactor vessel
2 Graphite moderator
3 Fuel element channels
4 Neutron shield
5 Hot box
6 Concentric gas duct
7 Heat exchanger
8 Gas circulator
9 Refuelling floor
10 Refuelling machine
11 Transit station for irradiated fuel
12 Carousel for storage of irradiated fuel
13 Containment building
14. Personnel air lock
15 Goods air lock
16 Test loops
17 Fuel element building
18 Clean fuel preparation room
19 Stringer breakdown cave
20 Reactor control room
21 Turbine hall
22 Cooling towers
23 Gas discharge treatment plant
24 CO_2 and CO Plant

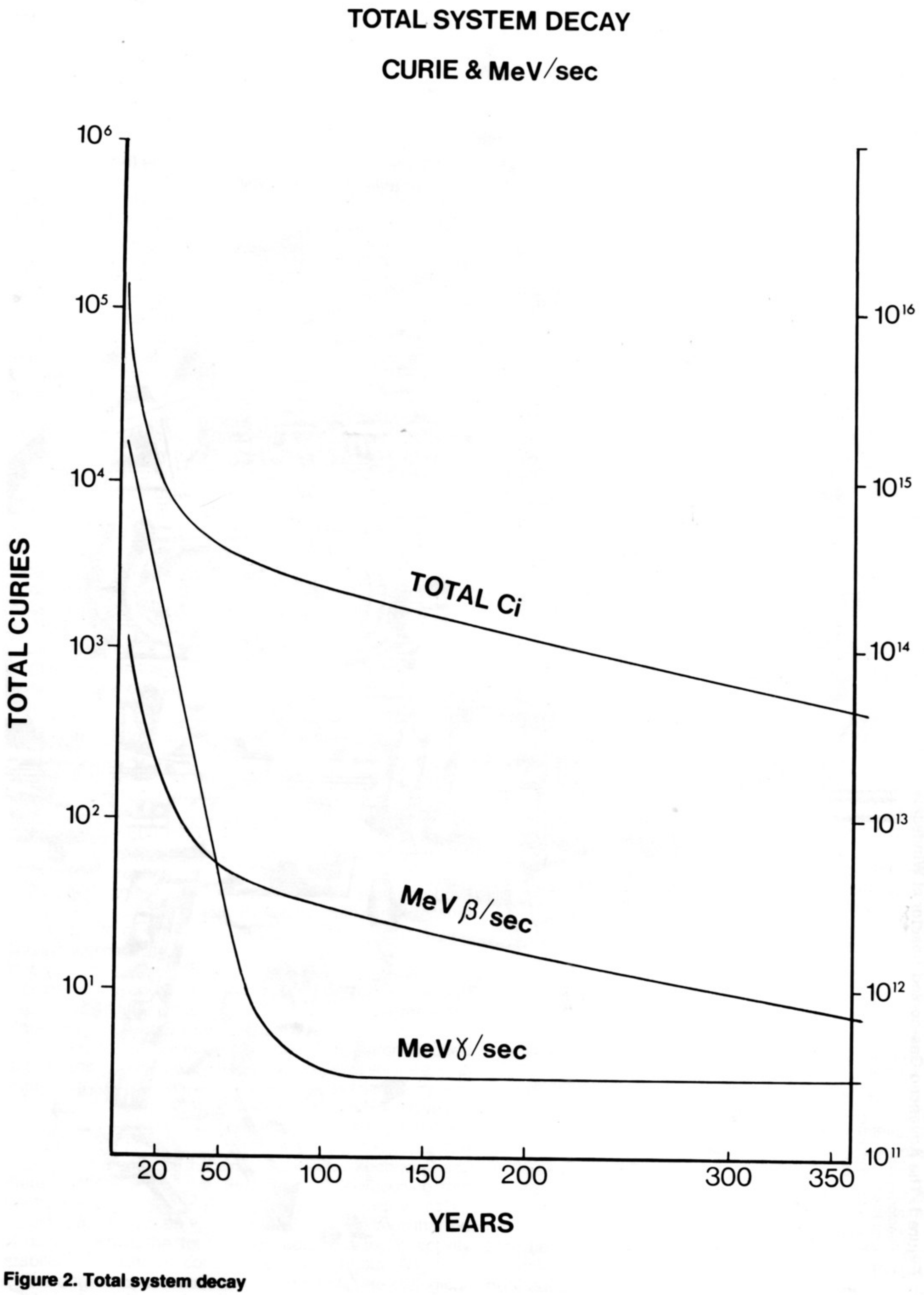
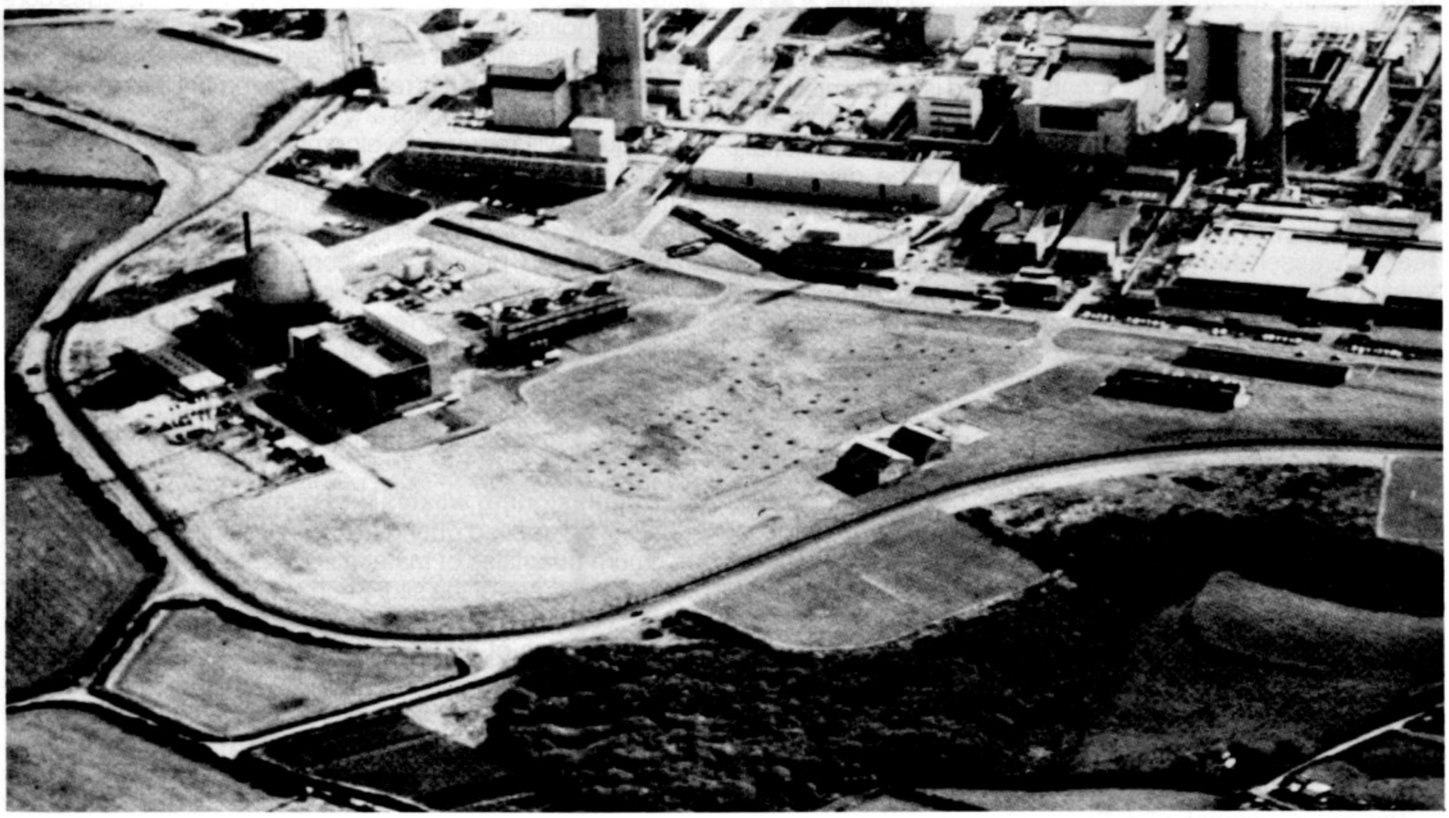


Figure 2. Total system decay

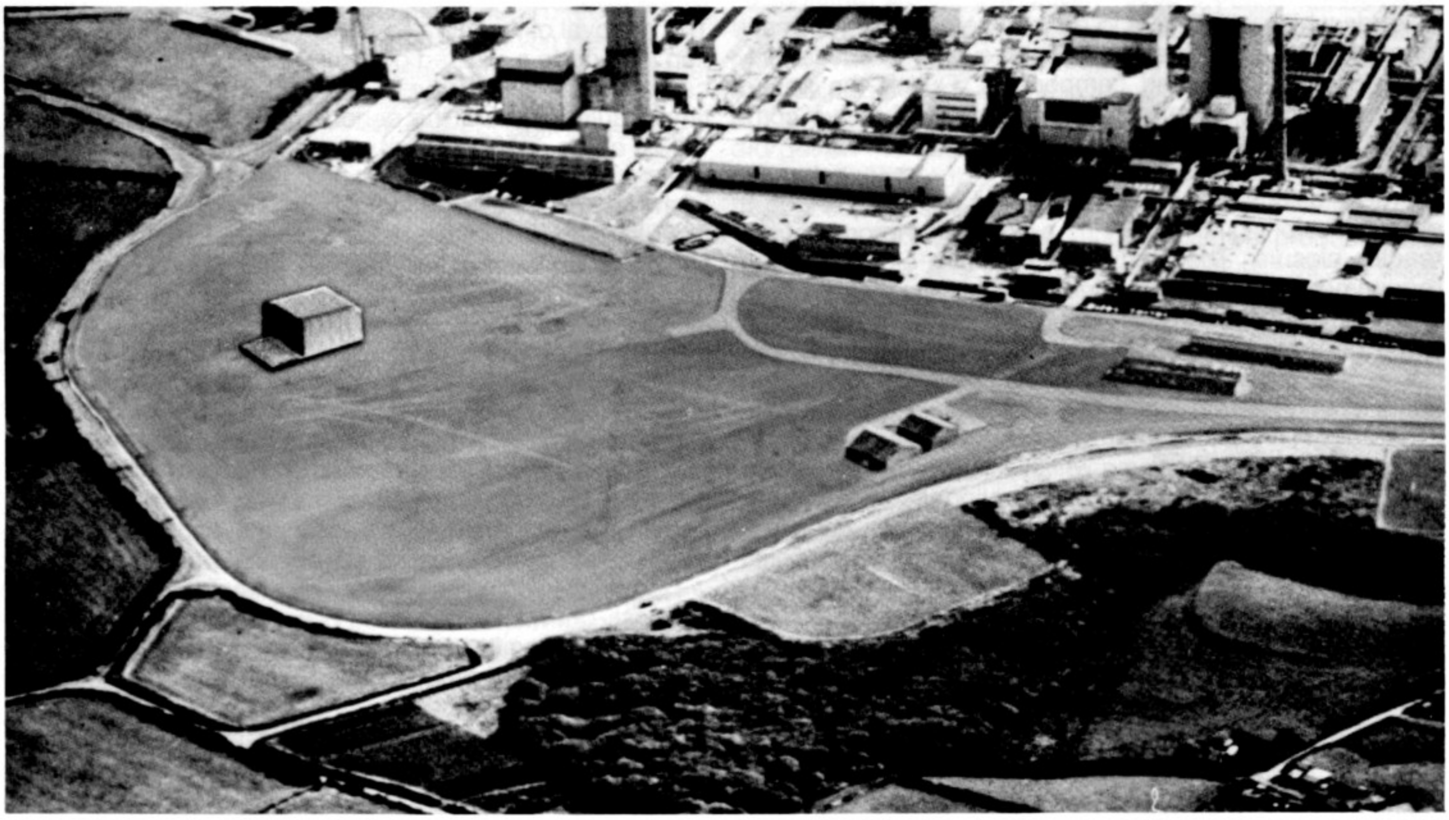
pressure vessel and its supports would be satisfactory for at least 100 years.

The sealing of penetrations through the biological shield resulting, for example, from cutting through gas ducts to release the heat exchangers, is essential. The top of the biological shield would be capped with concrete with an access provided to enter the reactor top void space for inspection.

The biological shield is a large reinforced concrete structure and judging from available experience of this material no significant problems of deterioration should arise for at least 50 years if it were left exposed to weather. This period could be substantially extended by the construction of a relatively



Aerial views of a part of the Windscale site showing the Advanced Gas-cooled Reactor in the left foreground: above, as it is today; below, as it might appear at a late stage in the decommissioning of the reactor. Conceptually, the whole area now occupied by the reactor might eventually be returned to "green field" condition.



light weight structure around and braced to the biological shield to afford protection.

(iii) *Radiological Aspects* No radiation hazard should exist at the external face of the biological shield after fuel removal and all penetrations have been sealed and checked.

Throughout the Stage 2 condition, corrosion, both within the pressure vessel and external to it, could produce loose particulate activity. This would be entirely contained within the sealed biological shield the penetration of which by particulates to create an environmental hazard is discounted. The possibility of radiolytic chemical reactions within the pressure vessel between the air constituents and materials of construction, such as graphite, cannot be discounted absolutely. They are unlikely to occur to any significant degree since the radiation fields are relatively low; the reactor vessel and the interspace between the pressure vessel and its biological shield would, however, be equipped with sampling points for routine atmosphere monitoring.

The barrier to any contamination reaching the surrounding ground water is the steel diaphragm floor beneath the reactor, which would require to be made weather-tight at ground level with provision made for access, maintenance, and monitoring.

Access to within the biological shield of the reactor under Stage 2 conditions would only be available through facilities engineered to permit monitoring or inspection. These entrances would be secured and only used by authorised persons. A boundary fence would be erected around the structure.

The engineering requirements to establish Stage 2 have been examined and no major problems have been identified except for the dismantling of the contaminated heat exchangers. These will require to be handled under special shielding and contamination control conditions.

The establishment of a Stage 2 situation will attract a higher initial cost than for Stage 1 but to offset this the long-term cost of maintenance and surveillance will be considerably reduced.

Stage 3 The two factors which dominate the technical approach to Stage 3 decommissioning are the radiological hazards which will require to be countered during dismantling operations, and the availability of suitable disposal facilities for the dismantled components. During the period between reactor closure and dismantling of active components radioactive decay will occur and so reduce the radiological problems.

A feasibility study has been carried out of the Stage 3 decommissioning of WAGR as a continuing process from reactor closure. The study took account of engineering requirements, radiological aspects and waste management and concluded that on technical grounds such an operation could be undertaken safely and efficiently. The study proposed that a demolition plan should be prepared on the basis of engineering logic. The plan should then be examined against the known or assessed magnitude of radiation/contamination problems which will arise at the various demolition stages; and that consideration then be given to their solution by methods — such as remote handling, shielded working or controlled access — which do not entail modification to the engineering logic. Only if at particular stages such methods prove impracticable will there be a departure from the strict engineering logic and the overall plan amended accordingly.

In broad outline the plan proposes the initial removal of inactive components, other than those associated with services which must be retained to a later date. With the same qualification, the active components external to the pressure circuit would then be removed, followed by removal of the internal structure within the pressure vessel, and of the pressure vessel. The concrete biological shield would be demolished in a manner which would segregate the active and inactive sections. The final operations would be to dismantle the steel reactor containment building, clear the site and back fill the reactor foundations.

A team is now developing a detailed decommissioning plan on the basis of the feasibility study, which includes conceptual engineering studies for remote handling equipment and the modification of existing facilities for dismantling and waste management. It is relevant to comment that demolition will not need research into any new technology; but existing techniques will require development to adapt them to meet special dismantling problems.

It is important to appreciate that the engineering logic differs between leaving decommissioning at Stage 1 or 2 for an unspecified period, and continuing to Stage 3, particularly in the retention and adaptation of existing plant facilities. Hence if the policy relating to the fate of the reactor can be declared well in advance of retirement it should be possible to select the optimum plan for decommissioning. The cost of direct Stage 3 decommissioning must exceed those of Stages 1 and 2 but no continuing costs are involved.

Decommissioning wastes and disposal

Effort will be applied during decommissioning to salvage the maximum quantities of materials suitable for recycling or re-use from all areas of the site. Such materials will be subject to rigorous monitoring before release. There will however be large quantities of materials which due to their radioactive content cannot be released and will require controlled disposal. The routes currently available are disposal to land and to sea, but at this juncture no firm statement can be made of overall UK policy. This topic is under consideration in the current review of the Government White Paper *Control of Radioactive Wastes* (Cmnd 884), — which is an advisory document and forms the basis of UK practices. The recommendations of the review cannot be anticipated but work has been carried out to assess the practical application of the options.

Costs and timescales

The removal of fuel from a reactor, which is the initial operation leading to a defined decommissioning stage, will in the case of WAGR extend over a period of about three years. The time required beyond this period to complete Stages 1 and 2 will be of the order of a further one and three years respectively, and in the case of continuing progression to Stage 3 from reactor closure the corresponding extension is about five years. Indicative costs, excluding the cost of defuelling (which is an operational charge) and with no allowance made for the value of recovered plant and scrap, have been assessed. For Stages 2 and 3 these costs represent less than 10 per cent and 15 per cent respectively of the current replacement cost for WAGR at around £70m.

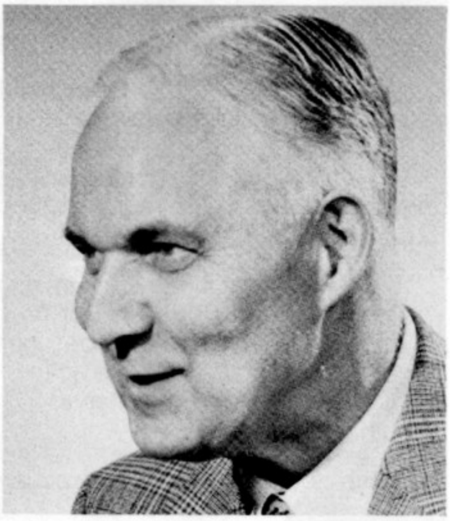
Conclusion

This article has concentrated on WAGR, which differs in design and size to commercial stations. Although the detail and scale of operations will differ, the general principles which have been discussed are applicable.

Decommissioning has not been a primary consideration in the past, but more attention is now being given to both the design and specification of materials of reactors to ease the problems of dismantling, and also to power station layouts to optimise land re-utilisation.

From the studies summarised in this article and those carried out in other nations there are no technical reasons to suggest that nuclear power stations withdrawn from service cannot be rendered safe and ultimately removed.

THE DISCOVERY OF FISSION



Dr. Lewis Roberts, Director of AERE Harwell, described Dr. H.A.C. McKay* at his retirement from service with the UKAEA in June this year as "doyen of separation process chemistry, not only in Britain but all over the world." In the article which follows Dr. McKay recalls what he terms "an exciting drama, the unravelling of the nature of the atomic nucleus" in the years before the Second World War.

To work in nuclear science before the War was very different from what it is today. There were no large establishments like Harwell, Oak Ridge, Fontenay and Karlsruhe. Professor Niels Bohr's Institute for Theoretical Physics in Copenhagen, one of the world's foremost nuclear centres, had only about thirty research workers when I went there in 1935, and some of those had teaching responsibilities. Similar groups functioned in a limited number of universities in other countries. It was a relatively small and intimate world.

It was also very much the world of the individual research worker. In Copenhagen most people worked on their own at their own problem, building their own apparatus. We even had to make our own Geiger counters. Young people like myself had a pretty free hand, getting general direction from above — in my case from Professor Georg von Hevesy, the great radiochemist — but not detailed instructions. There were no big machines or complicated projects, demanding large teams, though the Copenhagen cyclotron was built soon after I left in 1937.

Every summer, towards the end of August, about a hundred nuclear physicists — and that was a high proportion of the world's total — converged on the Institute for an informal, unadvertised conference. Among them was Werner Heisenberg, who was later to be a leader of the German wartime atomic project. He and Bohr spent long hours discussing the quantum theory, and then he would return home to work out the detailed mathematics.

Hitler and the Nazis cast their shadows over Copenhagen during those years. At the time I was there, it was still possible to hope that war would never come, but Germany had already reoccupied the Rhineland, Hitler's political opponents had been suppressed, and the Jews were being persecuted. Several of those working at the Institute, such as Otto Frisch, were Jews exiled from Germany. The Bohr family were partly Jewish, but Bohr would have offered such people a refuge in any case. Not surprisingly, some of them were Communists or Communist sympathisers, partly because they were prepared to side with anyone against the Nazis.

Unravelling nature

Yet although the world background was grim, the front of the stage was very pleasant. Bohr could still meet regularly with Heisenberg as a friend and team-mate, without the least feeling of constraint. We were all part of an exciting drama, the unravelling of the nature of the atomic nucleus. Not until the discovery of fission, with its horrific implications, did our carefree camaraderie begin to break down.

The story of this discovery goes back to 1934, when Enrico Fermi and his associates in Italy bombarded with slow neutrons all the elements they could lay their hands on.[1] When they got to uranium, they obtained some rather odd results. The radioactivity produced was difficult to identify. Various people took a hand in trying to clear up the problem, but it only got more complicated. Ida Noddack, a chemist, did get on the track of the correct explanation immediately after the Italians published their results, but failed to follow up her speculations.

By May 1937, nine different radioactive products had been identified, and various genetic relationships had been established. Chemical studies showed that none of them had an atomic number between 80 and 92 inclusive, with the possible exception of number 85 — belonging to the then unknown astatine. So they were all regarded as transuranium elements, and placed in three isomeric series of beta-emitters of atomic numbers 93, 94 and 95. A remarkable hypothesis!

Then came Otto Hahn and Fritz Strassmann's discovery at the Kaiser-Wilhelm Institute in Berlin of three activities that appeared to be due to radium isotopes, decaying to three activities that appeared to be due to actinium isotopes.[2] They used barium as a carrier for their supposed radium, and as a final step they intended to make a barium/radium separation by established methods. But the new activities stayed with barium.

As a further check they added a known radium isotope, ^{228}Ra (mesothorium I, formerly used in luminous watches), and tried the separation again. The genuine radium isotope behaved normally, but the unidentified product obstinately

*Dr. McKay gained his BA (and, later, D.Sc.) at Oxford University and worked at the Institute for Theoretical Physics in Copenhagen, Imperial College London and Kings College, London. After wartime research with the Admiralty he joined Harwell in 1947, becoming leader of the Separation Processes Group of the Chemistry Division.

remained with the barium. That was on Saturday, 17th December 1938, and Hahn wrote in his notebook, "Exciting fractionation of radium/barium/mesothorium".

On Monday, 19th December, they started a confirmatory experiment. If the substance they were investigating really was barium and not radium, then its daughter should be lanthanum and not actinium, and this could be tested by a parallel separation to the one they had just carried out.

While this was in progress, Hahn wrote a long letter to Lise Meitner, who had been a close fellow-worker until compelled to leave Germany because she was Jewish. In it he said:

> "It is now just eleven o'clock at night. At a quarter to twelve Strassmann will be coming so that I can see about going home. The fact is, there is something so odd about the 'radium isotopes' that for the time being we are telling only you about it . . . Our 'radium' isotope is behaving just like barium . . .
>
> We all know that it [the uranium nucleus] can't *really* burst asunder to form barium. But now we are going to see whether the 'actinium' isotopes formed by our 'radium' are going in fact to behave like actinium — or like lanthanum. All highly tricky experiments! But we must get at the truth . . .
>
> I have got to get back to the counters now."

A horrifying conclusion

Tuesday was the Kaiser-Wilhelm Institute's Christmas party, but by the end of Wednesday the confirmatory experiment was finished. The 'actinium' was indeed lanthanum.

On Thursday, 22nd December, Hahn and Strassmann wrote a short paper for the scientific journal *Naturwissenschaften,* describing their "horrifying conclusion", as Hahn had called it in his letter to Meitner, a conclusion "contradicting all known tenets of nuclear physics". The editor, Paul Rosbaud, was so impressed that he made room for the paper in the next issue of the journal, even though other material was already set in type. The journal appeared on 16th January, 1939.

Meanwhile, Meitner had received Hahn's letter.[3] She was at Kungälv near Gothenburg, spending Christmas with Swedish friends. Her first reaction to Hahn's news was cautious, but she kept an open mind. "We have experienced so many surprises in nuclear physics that one cannot dismiss this by saying simply, 'It's not possible!'"

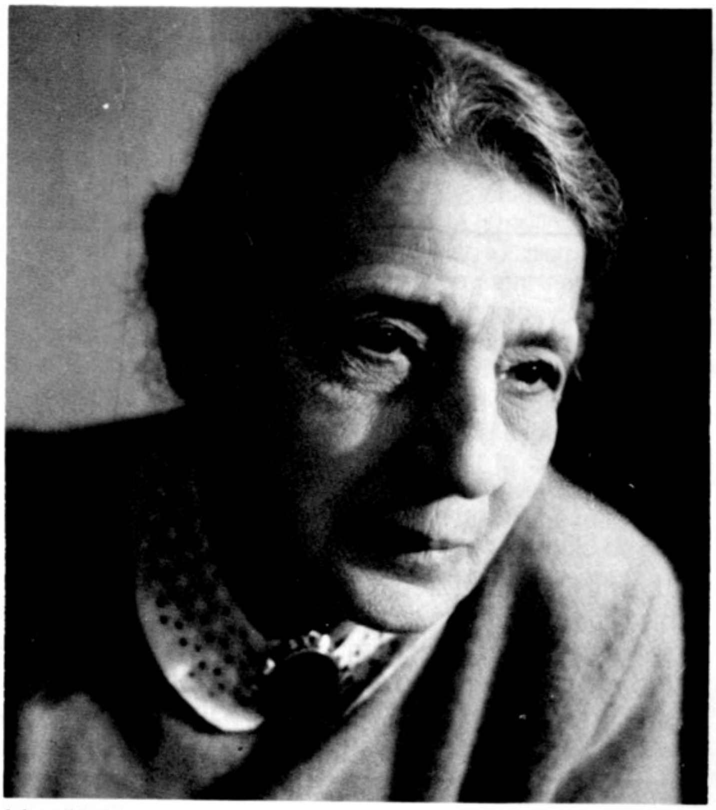
Her nephew, Frisch, came up from Copenhagen to join her for the holiday. He found her puzzling over the letter when he met her after his first night in Kungälv. He wanted to discuss a new experiment he was planning, involving a large magnet, but his aunt insisted on his reading the letter. He said later:

> "Its contents were so startling that I was at first inclined to be sceptical . . . The suggestion that they might after all have made a mistake was waved aside by Lise Meitner; Hahn was too good a chemist for that, she assured me."

Meitner and Frisch discussed the problem during a walk through the woods in the snow. The nucleus of the barium atom is not much more than half the size of the uranium nucleus; how on earth could the one be formed from the other? In all the nuclear processes known at the time, only small fragments were ever chipped off the nuclei. It would take a lot of small chippings to reduce uranium to barium, and there was not enough energy available for that. Nor could the uranium nucleus have been cracked in two; nuclei are not brittle like glass. Rather do they resemble drops of liquid, and it was this that gave the clue.

"Perhaps a drop could divide into two smaller drops in a more gradual manner, by first becoming elongated, then constricted, and finally being torn rather than broken in two? We knew that there were strong forces that would resist such a process, just as the surface tension of an ordinary liquid drop resists its division into two smaller ones. But nuclei differed from ordinary drops in one important way: they were electrically charged, and this was known to diminish the effect of the surface tension.

"At that point we both sat down on a tree trunk . . . and started to calculate on scraps of paper. The charge of uranium nucleus, we found, was indeed large enough to destroy the effect of surface tension almost completely; so the uranium nucleus might indeed be a very wobbly, unstable drop, ready to divide itself at the slightest provocation (such as the impact of a neutron)."



Lise Meitner © LOTTE MEITNER GRAF LONDON.

Mass = Energy

Pursuing this line of thought, they saw a possible snag. The two smaller drops into which the uranium nucleus divided would share the original charge on the nucleus, and — since like charges repel — the two parts would fly apart with great energy. The energy was easily calculated to be about 200 MeV, which was much larger than any encountered so far in nuclear laboratories. Where could it have come from? The answer was that mass had been converted into energy in accordance with Einstein's $E = mc^2$ relation. The two smaller nuclei together weigh slightly less than the uranium nucleus from which they are formed. Meitner calculated the difference to be about one-fifth of the mass of a proton; and when this was inserted into Einstein's relation, the corresponding energy came to 200 Mev. So everything fitted! The uranium nucleus *did* burst asunder.

After Christmas Meitner returned to Stockholm, while Frisch travelled back to Copenhagen "in considerable excitement" to report their speculations to Bohr. Bohr knew nothing so far, since *Naturwissenschaften* with Hahn and Strassman's paper had not yet appeared.

"When I reached Bohr, he had only a few minutes left [before sailing to the U.S.A.]; but I had hardly begun to tell him, when he struck his forehead with his hand and exclaimed: 'Oh, what idiots we all have been! Oh, but this is wonderful! This is just as it must be! Have you and Lise

Meitner written a paper about it?' I said we hadn't but would at once, and Bohr promised not to talk about it before the paper was out. Then he was off to catch his boat."

The paper was drafted over the long-distance telephone and despatched to *Nature* in London on 16th January with the title 'A New Type of Nuclear Reaction'.

From the analogy with cell division in biology, Meitner and Frisch named the new process nuclear 'fission'. Accompanying their paper was a second note containing the results of a confirmatory experiment, suggested by a Copenhagen colleague, George Plaçzek, in which Frisch demonstrated the very high energy of the two fragments produced by fission. Frisch called this a "very easy" experiment; it took him only two days to put together the apparatus for it.

The two papers appeared on 11th and 18th February respectively. It was as well for Meitner and Frisch that they had acted quickly because two Berlin physicists, Siegfried Flügge and Gottfried von Droste, had independently drawn the same conclusions after reading *Naturwissenschaften*, and were only a week behind in submitting them to a journal. Moreover, various American groups had performed experiments similar to Frisch's before January was out.

Discoveries

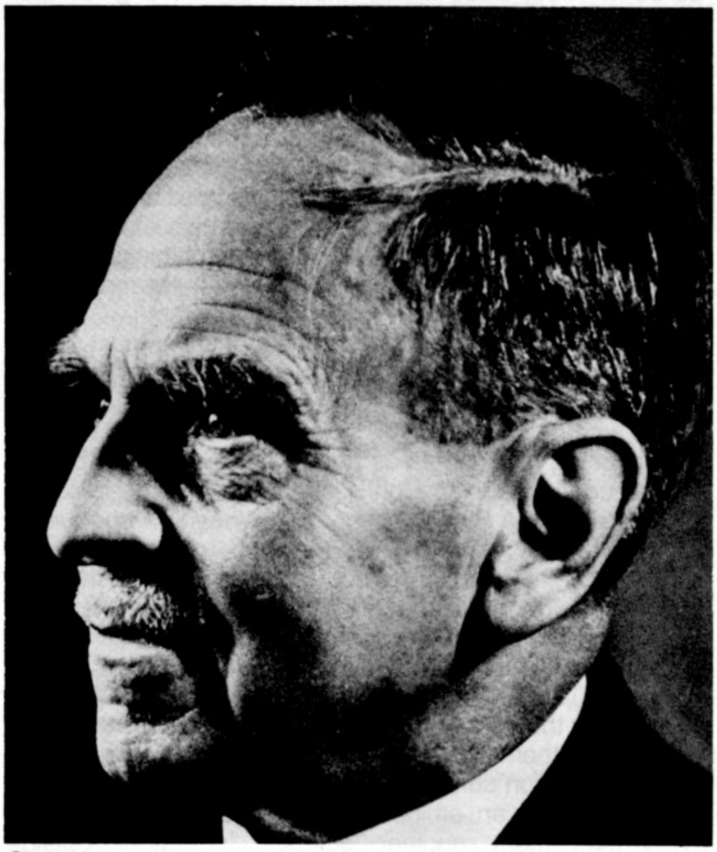
Bohr arrived in New York with his colleague Léon Rosenfeld on the very day that Meitner and Frisch posted their letters to *Nature*. On the boat they had discussed nuclear fission from every possible angle, but unfortunately Bohr had forgotten to warn Rosenfeld to keep the secret until the news was published. When they landed, Rosenfeld went to Princeton ahead of Bohr, who had business in New York, and there he let the cat out of the bag. *(Naturwissenschaften* was presumably still in the post to America). To Rosenfeld's dismay this unleashed a fantastic race in a number of American laboratories, most of them bent on proving the high energy of the fission fragments, not knowing that Frisch had already done just that.

Everything came to a head at a conference on theoretical physics in Washington in late January 1939. Bohr had perforce to tell the whole story, starting with Hahn and Strassmann's discoveries; this he did on 26th January. It is related that some of those present dashed to their laboratories in full evening dress even before Bohr had finished speaking, to get on the band wagon. Another tale is of a physicist watching his apparatus for evidence of the fission fragments and simultaneously reporting over the telephone to a newspaper man: "Now, there's another one." Seldom, if ever, has the scientific world seen such a scramble to be first with new discoveries. Bohr and Rosenfeld had some trouble in establishing the true priority in face of erroneous newspaper reports.

The effect of Hahn and Strassmann's, Meitner and Frisch's work was like switching on a light in a dark room. Those who had been groping could now see clearly, and others rushed in to join them. New results poured in from Copenhagen, Paris, Cambridge, Berlin, New York, Berkeley — virtually every nuclear physics centre in the world. Some looked back sadly at what they had missed for lack of illumination. In Cambridge the large electrical impulses caused by fission fragments had actually been seen, but dismissed as due to an electrical fault.

Within days of the discovery of fission, it occurred to a number of scientists that neutrons might be produced in the process. This idea led on to another, that here perhaps was the germ of a method for large-scale release of the vast energy of the atomic nucleus. There was talk of a 'superbomb'.

The point is that if neutrons both initiate fission and are produced by it, there can be a chain reaction. The secondary neutrons formed in fission go on to initiate more fissions; these liberate more neutrons; which cause yet further fissions; and so on and on without obvious limit. The idea of a chain reaction was already familiar as the explanation of chemical explosions. If an analogous nuclear explosion were possible, it might be a million or more time as powerful.



Otto Hahn © FRITZ ESCHEN — BAVARIA.

The changing climate

This was a terrifying prospect, especially in a world heading rapidly towards war. As the Frenchman Bertrand Goldschmidt has described,[(4)] the whole climate of nuclear research changed overnight:

> "From one day to the next, atomic physics ceased to be the domain solely of fundamental research, the preserve of the isolated research worker. A new elite, that of nuclear scientists aware of their moral and political responsibilities, was about to appear on the scene, and play a crucial part in the lives of great nations."

Fission had come like a bolt from the blue to the small, loosely-knit, international fraternity of nuclear scientists. Their working lives had been spent in the academic world in the quest for understanding of the fundamental nature of matter. Suddenly they found themselves the custodians of an alarming item of knowledge that might change the course of history. Up to 1938, physics had been fun. From 1939 onwards, nuclear scientists began to feel a heavy load of responsibility.

Some of them were for a time reassured by an argument due to Bohr, which runs as follows.[(3)] A slow neutron takes a fraction of a millisecond to travel from one uranium atom to the next, and a chain involving many such steps will take some milliseconds to build up. This is far too slow for an explosion. There will only be a 'fizzle', enough to disperse the uranium and so stop the reaction, but unable to liberate more than a minute fraction of the nuclear energy.

However, nobody could be sure of this argument, and it is obvious now that it must have gone astray. There is in fact no need to assume that the neutrons are slow. It was natural to do so in 1939, since it was known from the original 1935 paper by Fermi and his co-workers that there is much more reaction between uranium and slow neutrons than between uranium and fast neutrons. But fast neutron chain reactions do, of course, occur. They are propagated 100,000 times as rapidly as slow neutron chains; the parts of the bomb do not fly apart in time to stop the reaction, and there can be a major explosion. Bohr was not oblivious of this possibility, but dismissed it because he believed that it would require a separation of the uranium isotopes on an unthinkably large scale. He naturally did not foresee the vast American effort that six years later was to achieve a ^{235}U bomb.

The idea that it is the ^{235}U isotope that is the most readily fissionable occurred to Bohr during a discussion at Princeton as early as February 1939, and two of his colleagues had a bet on whether he was right.[5] The odds were 1846 to 1, the proton being 1846 times as heavy as the electron. Experimental confirmation of Bohr's speculation came in March 1940, so George Placzek sent John Wheeler a cheque for $0.01.

The thought of a super-bomb was deeply perturbing, especially to refugees from Nazism, and as early as February 1939 a Hungarian refugee living in New York, Leo Szilard, tried to get his colleagues to act.[6] He regarded war as inevitable, and wanted to deny the Nazis the fruits of research in the countries they threatened — fruits that were available to them so long as the usual scientific practice of open publication continued.

He gathered an eminent group together to circularise every significant nuclear science laboratory outside Germany, proposing a voluntary censorship of information on nuclear fission. Such an action would have been entirely contrary to the habits and passions of the pure scientist. Bohr was agreeable to the idea, but the French under Frédéric Joliot turned it down, describing it as unrealistic or even ridiculous. The absence of unanimity killed the plan, and over a hundred papers on fission appeared during 1939, to say nothing of sensational newspaper articles. Nevertheless, some aspects of the subject were kept secret.

A chain reaction?

Szilard had gone ahead while the neutron chain reaction was still an unproved though plausible theory. Evidence for it came first from Hans von Halban, Frédéric Joliot and Lew Kowarski in Paris. In a letter published on 16th March, 1939 in *Nature* they gave results showing that secondary neutrons are indeed emitted in fission, and on 22nd April they added the vital information that several such neutrons are emitted in each fission event. It is essential that there should, on an average, be at least one, to provide the next link in the chain. Indeed, two or three were actually required to keep the chains going, because some of the neutrons are used up by the processes other than fission.

On the other side of the Atlantic, the same information about neutrons in fission was obtained independently by two American groups, and published in the *Physical Review* on 15th April. In Russia, too, there was a similar publication about this time.

These discoveries were the signal for scientists in Europe and America to approach their governments to apprise them of the possibilities of nuclear power and nuclear explosives. The first to move were those in the United States. On 17th March, well before the *Physical Review* papers appeared, it was arranged for Enrico Fermi to meet a group of naval and military officers and scientists in Washington.[7] Their reaction was encouraging, but limited, partly it seems because Fermi was cautious, and did not want to go beyond the scanty scientific evidence.

A few months later, as nothing more had happened, Szilard became impatient. He and another Hungarian refugee, Eugene Wigner, went to see first Albert Einstein and then Alexander Sachs, an economist who had the ear of the White House. This led to the famous letter from Einstein to the President, warning of the potentialities and dangers of nuclear chain reactions, which Sachs took to Roosevelt on 11th October 1939, soon after the outbreak of war. Roosevelt said, "Alex, what you are after is to see that the Nazis don't blow us up," and then, "This requires action." He appointed an Advisory Committee on Uranium, under Lyman J. Briggs, Director of the National Bureau of Standards. The Committee reported promptly to the effect that nuclear power and nuclear explosives were possibilities, but still unproved. Thereafter, however, they came becalmed. Nearly two years were to elapse before the big American atomic bomb project got under way, although a great deal of research was carried out in American universities in the meantime.

In France, too, little happened at first on an official level. The group in Paris took out patents in May 1939 on the industrial and military applications of their discoveries, and Joliot had a discussion with the Belgians on the possibility of using their uranium stocks for a joint uranium bomb project in the Sahara.[8] Not until war was declared did they contact the French Government. Then they won the enthusiastic support of Raoul Dautry, the Armaments Minister, who granted Joliot "exceptional facilities: unlimited credit and the possibility of recalling from the army any co-worker he may require", and later was instrumental in acquiring the entire Norwegian stock of heavy water for their research. Eventually, however, the French group decided that nuclear weapons were too distant a prospect and, with half an eye on post-war exploitation, concentrated on pile-building and nuclear power.

In Russia, there was a small but vigorous research effort.[9] Papers were published on the theory of chain-reacting systems, and even on the possibility of their being explosive. Atomic energy featured in the newspapers. A committee was set up within the Academy of Sciences to study the 'uranium problem', but nothing seems to have been done to involve the Government, probably because military applications were not considered. For the same reason, there was no censorship. This state of affairs appears to have persisted until the Germans invaded Russia in 1941, when nuclear research in Russia came to an abrupt halt.

It was in Britain and Germany that action of an official kind was most immediate and decisive. In both countries the stimulus was von Halban, Joliot and Kowarski's 22nd April letter to *Nature*. In London, Professor (later Sir George) Thomson of Imperial College consulted his scientific colleagues and was in touch with the Government within four days of seeing the journal.[10] A co-ordinated research programme was set up in the Universities of London, Birmingham and Liverpool, and steps were taken to procure stocks of uranium.

However, there was at first widespread scepticism among leading British scientists. Sir Henry Tizard, advisor on Air Defence, spoke of odds of 100 000 to 1 against a successful military application, though he agreed that even an outside chance deserved investigation. Professor Lindemann (later Lord Cherwell) advised Churchill that exploitation would take some years, and that nuclear explosions might not prove exceptionally powerful. When war was declared, most of the limited nuclear effort was deflected in other directions, and not until the spring of 1940 was this trend dramatically reversed.

In Germany, it was two physical chemists, Paul Harteck and Wilhelm Groth, at Hamburg University, who sprang into action.[11] They were even quicker than Thomson. In a letter to the German War Office on 24th April they said:

"We take the liberty of calling to your attention the newest development in nuclear physics, which, in our opinion will probably make it possible to produce an explosion many orders of magnitude more powerful than the conventional ones."

This missive ultimately reached Kurt Diebner, the army's expert on nuclear physics, and led to the establishment of a nuclear research office under Diebner in the Army Ordnance Office, despite snide remarks about "atomic poppycock".

The road to the 'Atomic Age'

Most of Germany's foremost nuclear scientists were called to important secret conferences at the War Office in Berlin on 16th and 26th September, 1939, just after the war had started. Among them were Werner Heisenberg and Carl-Friedrich von Weizsäcker, who played leading parts over the next six years. A national plan was drawn up for the "exploitation of nuclear fission", and a centre was established in the Kaiser-Wilhelm Institute for a 'Nuclear Physics Working Group'. The official German project thus got off to a very good start, with a vigorous and well-organised effort. As early as 6th December 1939, Heisenberg was able to submit an optimistic report to the War Office, in which the routes to nuclear power and nuclear weapons were clearly outlined. At this stage there is little doubt that the Germans were ahead of the rest of the world.

Serious British interest in ^{235}U as an explosive can be dated from March 1940.[12] By that time the British project was at a low ebb. Nuclear power seemed unlikely to arrive in time to help the war effort, and ideas about a bomb tended to be vague. At this critical juncture Frisch and another refugee physicist at Birmingham University, Professor Rudolf Peierls, with whom Frisch was then living, produced a succinct and cogent memorandum, in which they argued the case for a bomb based on 'the use of nearly pure ^{235}U'. Among the salient points were:

- A 5 kg ^{235}U bomb might release as much energy as several thousand tons of dynamite.
- The uranium isotopes might be separated on a large scale by thermal diffusion, using uranium hexafluoride.
- The radioactivity produced in the explosion would constitute a further danger to life.

The memorandum proved a turning-point for the British project. It generated a powerful momentum that was later to be transmitted across the Atlantic. Without it, the American bombs might well not have been ready in time to deliver the coup de grace to Japan.

The road to the Atomic Age was open.

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(3) O.R. Frisch, in *Niels Bohr*, ed. S. Rozental (North-Holland, Amsterdam, 1968), pp. 144 ff.

(4) B. Goldschmidt, *L'Aventure Atomique* (Fayard, Paris, 1962), p. 24.

(5) R. Moore, *Niels Bohr, the Man and Scientist* (Hodder and Stoughton, London, 1967), p. 247.

(6) Ref. (4), p. 25.

(7) R.G. Hewlett, O.E. Anderson, Jr., *The New World 1939/46* (Pennsylvania State University Press, 1962), pp. 15 ff.

(8) Ref. (4), pp. 25 ff.

(9) A. Kramish, *Atomic Energy in the Soviet Union* (Stanford University Press (Stanford, 1960)), pp. 15 ff.

(10) Ref. (1), pp. 34 ff.

(11) D. Irving, *The Virus House* (Kimber, London, 1967), p. 34 ff.

(12) Ref. (1), pp. 41 ff.

TRC ANNUAL REPORT

The Seventh Annual Report and Accounts of The Radiochemical Centre Ltd. was published on 1st September, 1978. The Report included the following review of the year by the Company's Chairman, Sir John Hill.

The year covered by the seventh report has been one of further growth and general improvement throughout the group with The Radiochemical Centre in an even stronger position commercially and structurally at the heart of an expanding international business. The achievements of its increasingly effective subsidiaries, working in each case to the market requirements and business patterns of their home country, reinforce the group's strength and resilience.

Having established our position by developing, producing and marketing products that make a positive contribution to the whole community and having done so profitably for many years we see no reason to doubt the scope for the continued extension of these beneficial applications of radioactivity to medicine, industry and scientific research. We see it as our privilege to exploit the business opportunities available to us in this field and thereby to retain the very considerable advantages which accrue from being able to believe in what we are doing and therefore generally to do it well.

Accordingly I commend this report to our shareholders with confidence that they will share the pride of the whole company in its present progress.

Business performance

The financial results have been well up to expectations and the international development of the business has been most encouraging. Group sales increased from £21.5m to £32.7m, a rise of 52 per cent. These figures have been influenced by the change of Amersham Corporation from an associate to a subsidiary in the previous year. If the sales for 1976/77 were adjusted to the same basis as the current year they would have produced an increase of 29 per cent from £25.3m to £32.7m. These results represent a significant growth in volume. Profits for the year were little affected by movements in exchange rates and increases in unit costs were held down by improved efficiency in production and by spreading the higher overhead costs over increased volume. The group was thus able to maintain profitability on sales in achieving an increase in pre-tax profit from £4.9m to £6.7m.

In 1977/78, and on an historical cost basis, the group earned a return on capital of 33 per cent which, although at the upper end of the range of UK industrial company performance, is nevertheless essential if we are to maintain the investment in the group required to accommodate future growth. The cash flow generated by the level of profit has enabled us to expand and invest during the year without calling on our shareholders for further funds. Our commitments for 1978/79 however are such that the £3m uncalled balance of the additional share capital issued in 1976 will certainly be required during the year and assurances have been given that it will be available when the company needs it.

The directors' report shows that a substantial increase has been made in the proposed dividend. For various reasons the profit level has been particularly high in 1977/78 and a substantially greater dividend payment has therefore become possible.

Overseas operations

This year I should like to pay a special tribute to the contribution which our agents and distributors and our overseas subsidiaries, in particular, have made to these excellent results. The strength and commercial resilience of our overseas marketing operations is clear to see from the further growth in sales outside the UK to 83 per cent of the total and the increase in their value from £16.8m to £27.2m.

The group's subsidiary in Germany, Amersham Buchler, has had another year of encouraging progress with improved sales in each product sector and has sustained its steady profitability. Further hardening of the deutschmark has benefited results but the continued success of this operation is due mainly to the high standard of management and commercial expertise available in this well-established business. In the United States, Amersham Corporation has quickly established its new identity. Business activities increased substantially during the year and the corporation's commercial strength was considerably reinforced by internal reorganisation and closer liaison with the parent company at Amersham.

In late 1977 we were able to establish a wholly owned subsidiary in Australia. The new company, The Radiochemical Centre (Australia) Pty Ltd., took over from existing distributors and although at present quite small is already making very good progress.

UK operations

Substantially higher output has been obtained at home, notwithstanding the limited resources that are available until the new site at Cardiff is ready for use. The remarkable capacity of the staff to obtain a further increment in output, which this year was the equivalent of total sales five years ago, has required a major increase in the productivity of staff and the plant they operate. Contributory improvements in plant and equipment have of course taken place under the programme of planned capital investment at Amersham, which will continue during and after the construction of the new site at Cardiff, and worthwhile advances have been achieved in production technology in a number of departments, in some cases enabling output to be more than doubled.

Distribution of products originating in the United Kingdom which remains the source of about 95 per cent of group sales has become increasingly complex. Revised methods have been developed which have considerably strengthened the supply lines to overseas subsidiaries, agents and distributors.

Meanwhile progress with the development in Cardiff has been good. Construction of the main buildings is now well under way. Buildings put up during the first phase are already in use as a base for bringing the site into production late in 1979, and planning for the transfer of work from Amersham is well in hand. Encouraging progress has been made with preparations for the moves of staff with staff associations and unions closely involved throughout.

The product range

The flow of substantial new products has continued, with eight medical products added during the year. The most important and most demanding was the Mk.III technetium generator, a basic requirement for widely-used medical diagnostic methods. A new plant for its production was commissioned in April 1977 and the generator was introduced successfully in July. Two technetium scanning agents, an improved kit for liver imaging and a kit for lung imaging, were launched at the same time. These have combined to strengthen our range materially in this important product group. Other new medical products have been assay kits for unconjugated oestriol to supplement our successful total oestriol kit for monitoring foeto-placental function in pregnancy; for the anti-epileptic drug phenytoin to improve management of patients and for the blood factor β-thromboglobulin, which is released into the circulation when blood clotting is taking place, although its full diagnostic significance is still under study. In addition two improved kits for the large thyroid market have been launched. A novel selenium-75 labelled cholesterol derivative 'Scintadren'* has been developed to meet the need for an effective agent for adrenal scintigraphy.

In the medical area generally there has been a perceptible revival of world interest in radioactive imaging and functional agents, and a more rational approach to developing them. In chemicals there has been the usual infusion of new tracer compounds into the product list, the most interesting being perhaps the Bolton-Hunter reagent widely used for labelling proteins with iodine-125 and the extension to the range and availability of nucleotides labelled with phosphorus-32; sales of these products have been growing fast, in step with increasingly exacting specifications for experimental work in molecular biology and genetics.

The remarkable growth in demand for smoke detectors using tiny radiation sources, which I mentioned last year, continued. The company's superior technology in this field has been maintained and we have secured and retained the major part of the world market for alpha foil from which these sources are fabricated. In close collaboration with UKAEA staff at Harwell, TRC has developed a new design of ionisation chamber which offers improved and simplified features. As a result we can now supply an excellent product to those manufacturers who prefer to buy this component, complete and ready for use, direct from us.

Staff and organisation

We now have 1720 employees on the payroll of the parent company and the overseas subsidiaries, of whom 1308 are based in the United Kingdom. Virtually all the staff employed abroad are nationals of the countries concerned and the group operates its subsidiaries with a minimum of central control. The overseas companies are mainly engaged in marketing and selling activities but their closer involvement in product development decisions is being fostered to ensure that these are responsive to market requirements. The group has enjoyed another year of excellent co-operation, with staff at all levels contributing unstinted efforts towards the year's achievements. In the United Kingdom the staff grading structure has been further developed so that all employees now enjoy virtually identical conditions of service. This was achieved in close co-operation with employee representatives in the design of acceptable changes to the previous structure as part of the continuing development of a positive employee relations policy based on regular and constructive consultation.

The board wishes me to signal its appreciation of the firm working partnerships and responsive relationships which have encouraged and sustained so strong a team spirit throughout the year.

Board membership

Dr. D.H. Pringle has recently accepted an invitation to join the board as a non-executive director. The retirement from the board of Mr. T.E. Potts merits special mention in view of his distinctive contribution over ten years of service to The Radiochemical Centre and its associates.

* trademark

MAJOR PLANNING INQUIRIES

The Secretary of State for the Environment, Mr. Peter Shore, outlined his views on the role and significance of major planning inquiries — such as that proposed to be held into the Commercial Demonstration Fast Reactor — in a speech in Manchester on 13th September.

Mr. Shore said:

"I have during the past year given much thought to our system of planning inquiries — particularly as it operates on major and complex issues of which last year's Windscale Inquiry was an outstanding example. But in the period ahead there will be other major planning inquiries, and I want to indicate to you my present thinking about how they can be best handled.

"Perhaps it will help to clarify thinking if I remind you of how in the post-war years we have tended to approach the major important planning cases: those which are sufficiently controversial to come to Ministers for decision. Something like 5000 inquiries are held every year, and of these perhaps a few hundred are highly significant to the locality. But only, say, two or three a year interest, concern and affect the well-being of us all. It says much, I think, for our planning inquiry system and its procedures, that for the 30 years it has so far existed it has on the whole managed to deal with the whole range and variety of cases in an acceptable and satisfactory manner.

"Let me remind you of the three main principles on which our public inquiry system has rested. First, that it is for Government and Parliament to determine national policies against which particular proposals are considered at inquiry. These policies — except traditionally in minerals cases — have usually settled such questions as the basic need in national or regional terms for the type of development in question.

"Secondly, against the background of declared national policy there should be, when a planning application has been refused and an appeal has been made, or when a call-in has taken place, a full, scrupulous, impartial and structured inquiry conducted by an Inspector to consider whether there were sufficient reasons for a particular proposal on a particular site, in all the circumstances, to be allowed to proceed or to be turned down.

"Thirdly, in the light of the inquiry and the Inspector's report it is for the Secretary of State under powers specifically granted to him by Parliament in the Town and Country Planning Act to make a decision.

"As I say, in the great majority of important planning cases that come to Ministers, these principles have proved to result — and still do — in decisions that are effective, fair and accepted. Of course there have always been criticisms and this is inevitable because one party is bound to be disappointed and because the procedure, involving as it does a careful and impartial hearing of all the evidence, irritates those who want quick decisions and offends those who are on the losing side who believe that, only if more and more exhaustive studies could be made, their point of view might have prevailed. These criticisms are, I believe, unavoidable but they do not detract from the general utility and value of the system.

"So much for the established features of the system. But in recent times some critical questions have begun to be asked that previously were seldom, if ever, raised. I will instance three in particular. First, critics have sometimes questioned whether the need for a development has in fact been properly established. And they have claimed that Parliamentary discussion or Ministerial consideration of the first question of the need has often not been sufficiently searching and thorough.

"Secondly, the critics have claimed that certain major proposed developments have implications and repercussions going far beyond the direct impact of the project itself, that these wider effects are not sufficiently considered and that, if they were, the balance between, say national economic considerations and the effect upon the environment and quality of living, could turn out to be very different from that which the developers claim. Consequently, critics have argued for a more thorough and disciplined assessment of the total implications of large-scale developments.

"Thirdly, not only the critics but all those engaged in the matter of public scrutiny recognise that there are some development proposals — and I am referring here to major nuclear innovations — that are in a special category of importance and difficulty, not just because they involve technological judgement of great complexity but still more because they can affect our whole way of life and because they involve issues of utmost importance to the safety and health of future generations.

"These are serious concerns and all of them question the traditional approach to public inquiries that I outlined at the beginning of my speech. In short, we must ask the question, do we in fact sufficiently establish and define need in certain fields, particularly the energy field, when in the nature of things it is difficult to establish a settled and continuing national policy background before a particular proposal is examined at a public inquiry? Can we in fact take, at a given point in time, sufficient account of all the wide implications of major new ventures as they evolve; and are the techniques that we can employ sufficient to help us with them? Is it right to leave to the Secretary of State, in the vital field of major nuclear innovations which can affect all our future, the sole decision — or should Parliament be directly involved?

"Some of the considerations I have been outlining will arise on at least two major energy development proposals which will require Ministerial decisions — the National Coal Board's applications for planning permission for the development of a major new coalfield at Belvoir in North East Leicestershire which have recently been submitted: and the proposals — if and when it comes forward — for a fast breeder nuclear reactor, the CFR 1. May I give you my ideas about the examination of these two very different issues in turn?

"The NCB's applications raise issues of considerable national importance relating to the need for the development of this coalfield, and of course there is the impact such a development would have on an attractive agricultural area. While these issues are initially for consideration by the local planning authority, I intend in due course to call the applications in for public inquiry and my own decision.

"I have been giving serious thought to the most appropriate form of inquiry in this case. It is essential that all the implications of the proposal should be impartially and exhaustively examined. What is the best way of achieving this? One proposal is that we should set up a planning inquiry commission under Section 47 of the Town and Country Planning Act 1971. As you will recall, the planning inquiry commission system was introduced into the Planning Acts in the wake of the Roskill Commission on the Third London Airport, though it has never been brought into use. It was designed for important proposals which it was felt could not be properly evaluated unless there was a special inquiry, or which involved such unfamiliar technical and scientific aspects that a proper decision could not be arrived at without a special inquiry. However, ten years later we find ourselves in a different situation. At the Windscale Inquiry, important changes were made in the scope of the matters open for consideration. That Inquiry demonstrated how the scope of conventional inquiries could be made much broader. Of course I realise that the conclusions reached by the Inspector were not to everyone's satisfaction. But nobody, I believe, is in doubt that the range of the inquiry was exceptionally wide, with the question of need being exhaustively considered and with the Inspector being specifically asked to examine, for example, the national interest, as well as the rightness of the particular site. It is difficult to argue, therefore, that the planning inquiry commission system is uniquely appropriate now for major inquiries.

"There is, however, a further problem with planning inquiry commissions to which I personally do not see a solution. The system envisaged a two-stage procedure, the first being investigatory and the second consisting of one or more public local inquiries. In my view the investigative proceedings are bound to lead the planning inquiry commission to conclusions, by whatever means the proceedings may be conducted. Yet at the second stage, ie at the local inquiry, arguments of policy and principle on which they will already have formed a view are bound to be put to them as well as the more local issues, and I do not think that people will feel that they would get a fair hearing. There is no way round this problem. For all these reasons, I am not convinced that a planning inquiry commission is the right way to proceed.

The Belvoir Inquiry

"The planning inquiry I envisage on Belvoir would include questions relating to the need for the proposed development and possibilities for alternative locations, as well as important local economic and environmental implications which I understand have been the subject of a joint study by the County Council and the National Coal Board.

"On the organisation of the inquiry, it is already an increasingly common practice in major inquiries for a preliminary meeting to be held to seek agreement between all those concerned on basic facts and to establish areas of disagreement, as well as to draw up an order of business for the inquiry itself. In the present case I propose to ask the inspector to hold such a preliminary meeting, perhaps extended in scope, to identify the main issues on which he considers the inquiry should concentrate, and to indicate the documentation and further work on implications which he would expect to be presented at the inquiry. I hope that this procedure will enable the time at the inquiry to be used in the most profitable manner and will ensure a full and comprehensive examination of all the issues. I shall be making a further announcement in due course about the arrangements.

"But before I leave the NCB's proposal I would like to mention in connection with it another subject in which there has been general interest — the idea of assessing the environmental impact of significant major developments, as part of the planning process. My colleagues and I have considered how best to pursue this. We fully endorse the desirability, as set out in the Thirlwall/Catlow report, which my Department published in 1976, of ensuring careful evaluation of the possible effects of large developments on the environment. All could agree with that, though we must not forget the unacceptable delays and costs of some environmental assessment procedures used in other countries, nor the strong interest we have as a nation in the success of our industrial strategy.

"The Government has already accepted the recommendations of the Leitch Committee, on the assessment of trunk road schemes for future road inquiries. The approach suggested in Thirlwell/Catlow is already being adopted with many other public and private sector projects. We should therefore wish to encourage use of this approach in cases where its use is worthwhile in the circumstances; relevant to the decision; and necessary to the total evaluation of the project along with the industrial, the employment, the social, the health and safety, the land use and the other implications.

"Our feeling therefore is that in selected major cases, involving environmentally sensitive areas or circumstances, a more explicit approach should be pursued. In the selection of such cases, the initiative could come either from the developer or from the planning authority. We should expect that the planning authorities and the public or private developers would agree at as early a stage as possible whether environmental assessment was justified; and if so the form of, and methods of preparing an assessment, including the division of responsibility for carrying out the work. It would be helpful also if detailed consideration could be given to informing all interested parties including the general public of the scope and nature of the analysis to be undertaken. The sensible use of this approach, through the co-operation of all concerned, should I believe improve the practice in handling these relatively few large and significant development proposals.

"This will take time to bring into effect, but at North East Leicestershire I hope that, if necessary, the important environmental considerations that have already been the subject of a joint study by the County Council and the NCB will be further developed for presentation at the inquiry, perhaps under guidance from the pre-inquiry meeting.

Lessons from Windscale

"I now turn to the proposal, if and when it comes forward, for the first commercial fast breeder nuclear reactor, and here I think the lessons learned from Windscale have much to teach us.

"In handling Windscale, I had in mind two major objectives. The first was that I wanted to ensure as thorough an investigation as I could devise. I needed it for my own purposes as Secretary of State, in order to ensure a fully reasoned and informed decision — a decision that was, in all the circumstances and with due allowance for human fallibility, right! It was needed also for the reassurance of public opinion, and indeed world opinion, that a thorough investigation had been made. The second objective was to provide for the involvement of Parliament, for it seemed to me wrong to exclude from a decision of such high national importance — one in which the range and depth of the issues was unique and unparalleled, the elected representative of our people. This of course was achieved. There were in fact two debates in the Commons: a full day's general debate on the Inspector's report, and another on the Special Development Order conferring the permission. For the future, I am in no sense committed to a Windscale type procedure, but the same two objectives in my view apply to nuclear issues of the same complexity and importance.

"As I said, the Windscale Inquiry showed that a planning inquiry could range over a very wide field, so that it could take in major national and international issues, as well as questions of need and of environmental concern. And we were all helped by the Royal Commission's 6th Report on nuclear power which provided an informed and detailed background to nuclear development. But that inquiry did not settle whether the particular procedures there adopted were the best in all circumstances. I said at the time that this was new territory, that we were still working out our ideas, and that if we could devise a better procedure we should do so. So we have been asking ourselves whether, should we be faced with another major proposed development in the nuclear energy field, we need an arrangement which builds on some of the elements that went into Windscale, but includes also what I hope will be thought other valuable elements suited to the examination of the project concerned.

CDFR: A special procedure?

"My suggestion, which I hope you and others will turn over in your minds, is this. I have already, in the course of the Windscale inquiry (and in subsequent House of Commons debates), promised a special procedure for public consultation, a wide-ranging investigation going beyond local considerations and — as with Windscale — I am sure that we must involve Parliament in a decision which has the specially wide-ranging and uncertain repercussions attaching to nuclear projects. What I have in mind, is a first stage public examination, by a suitable body such as a Commission or a Committee, outside the inquiry system to assess the background and the need. The published report of such a body could form a major background document to a subsequent site-specific inquiry. The proposing authority could then be invited to ask the Secretary of State to publish a draft Special Development Order of the kind used for Windscale. This, together with any necessary additional material, would be the subject of a public inquiry with wide terms of reference, held by an inspector and assessors. The report of this inquiry would also be open to public discussion, and the Special Development Order in its final form would be laid before Parliament, becoming subject to debate on a motion to annul.

"To my mind such a procedure would give the most thorough-going investigation possible. In the sophisticated field of nuclear energy it is of the utmost importance to get the answer right. We are a democracy: and we govern by consent. It is our duty to ensure that that consent is justified and to make it possible for the public to feel and to know that the ultimate decisions reached are as wise, fair and acceptable as we are able to make them. This is what we owe to ourselves and that is the responsibility we bear to the future."

BOOK REVIEW

Ground for Concern —

Australia's Uranium and Human Survival

Edited by Mary Elliott, for Friends of the Earth, *228 pp.; Penguin Books, London, 1977, £2.00.*

In the words of the preface, this book sets out to provide "a reasoned statement of the concern that Australians and people throughout the world feel about the prospects of a nuclear future. The authors have tried to grapple honestly with the problems of the atomic age, which is our age."

The book is essentially a collection of essays covering different aspects of the theme — which is that it would be damaging to the Australian environment and morally wrong to export uranium for the world's nuclear power programmes. Nuclear power, it is argued, is unsafe and unnecessary.

Because of the different authorships, some overlap and contradiction is inevitable and the book, although well-structured, is not entirely coherent.

In terms of reporting facts, a fairly high degree of accuracy has been achieved, but a few glaring misconceptions cannot go unchallenged. For instance, in Chapter 1 we read that "thermal pollution from nuclear stations is a major environmental hazard." In fact, residual heat from the best nuclear stations is no greater than from the best fossil-fired stations, and even pressurised water reactors which have a lower thermal efficiency have only 25 per cent more residual heat — hardly a major increase on fossil stations. In any case, there are ways of dispersing heat from inland power stations (either nuclear or fossil) that are not detrimental to the environment; and the waste heat from coastal sites is generally beneficial to marine life.

Then, when dealing with fast reactors (p. 67), the book says, "it is happily not possible for a thermal reactor to become a nuclear bomb. Sadly the same cannot be said of a fast reactor." This is totally wrong. To produce a nuclear bomb the material has to be compressed while the chain reaction takes place. In a fast reactor, no such compression could possibly take place and therefore such a nuclear explosion could not occur. And it is certainly not true to say "they are potentially so dangerous that on detection of a fault the whole plant must be closed down". All power stations and many other engineering plants have automatic shut-down mechanisms which operate in the event of faults, primarily to protect the operators and the plant from damage and give an opportunity for investigation of the cause. Fast reactors have similar shut-down mechanisms for exactly the same reason, not because they are more dangerous. Finally (p. 214) there is the comment that "Not one commercial fast breeder reactor is working in the world at the moment, since they are beset by severe technical problems". The fact is that on the basis of their favourable experience in operating large prototype fast reactor power stations, several nations are now preparing to build their first commercial-scale station. The troubles experienced with the prototype stations have mostly been external to the reactors, and were no more than would be expected at the prototype stage. Indeed, it is the function of prototypes to reveal aspects of design which require improvement, before commitment to full-scale plant.

A more difficult aspect of the book to assess is its treatment of subjective issues such as environmental impact and the future supply and demand for various forms of energy. Here, even given agreement on the facts, there is room for honest, reasonable men to disagree. In this I must confess to being disappointed by this book. It is marred by several lapses from the good advice given by Paul Ehrlich in the foreword that the anti-nuclear movement should avoid impugning the motives and competence of the people who oppose them. Also, I would have liked to see the alternatives dealt with as critically as is nuclear power. Instead, we find immensely detailed criticism of nuclear power, despite its good record, and a naive and superficial acceptance of the claims of alternative energy sources and of conservation. For instance, despite a recognition in the book that Australia is the only developed country with a large area within 30° of the equator, where most solar energy is concentrated, we are told that solar power can provide the answer to the world's energy problems — although it may take 100 years. But, of course, we do not have 100 years to find a replacement for cheap fossil fuels — and will solar power ever be cheap enough to do so, no matter how much is spent on its development? The authors of Chapter 6 go so far as to say, "If nuclear energy is not going to fill the gap, what can? The immediate answer appears to be — nothing." They then suggest that we can do no more than conserve energy until alternative sources are developed. Increased economy and efficiency in the use of energy is taking place, but even in affluent societies this cannot be done suddenly without serious disruption of employment patterns. Certainly, research into alternative energy sources and conservation measures (so far as they are economic) should be encouraged, but this will not go far towards meeting the needs of the majority of the increasing world population who can afford to use only small amounts of high-cost energy. A minority of mankind has been rescued from a short and brutish life by an abundance of cheap energy. This has provided a substitute for other resources, particularly of labour and land, and it is difficult to see how maintenance and improvement of living standards world-wide can be achieved without greatly-increased supplies of cheap energy. Failing a large new source of cheap energy, large-scale unemployment, increased internal and international tensions and an increased probability of wars seem only too likely.

Finally, the nuclear energy issue is shown by this book as dividing left and right; as a choice between large concentrated technologies run by centralised bureaucracies and small dispersed, locally controlled, technologies; and as a confrontation between young idealists and a cynical money-making war-time generation of greybeards. Each new generation, seeking to make their mark is wont, like Don Quixote, to 'tilt at windmills' (or in this case the modern equivalent, nuclear power stations) while the real threat goes unchallenged. The judgement on the authors of this book must be that they have failed to look critically and honestly at the social, environmental, and economic costs of not having nuclear power. Having argued against its exploitation, they must bear some responsibility for showing (and not merely asserting) that there is a substitute — and the laws of physics and chemistry are against them.

H. Hunt

International Energy Agency Report

The International Energy Agency's (IEA) first annual report* on its energy research, development and demonstration activities, covering the period 1977/78, states that with the possible large increase in the number of nuclear plants and the development of new reactor technologies, safety standards must be kept high. It goes on to say that the costs of research to individual countries can be reduced by international co-operation.

The IEA has sponsored the Nuclear Safety Research Index in conjunction with the Nuclear Energy Agency of the OECD since 1975. The index, previously issued by the NEA since 1970, is a compilation of brief descriptions of nuclear reactor safety experiment projects conducted in OECD member countries and of computer codes developed relative to these safety areas.

Of the several multinational reactor safety experiments presently being conducted under the auspices of the IEA, two, core debris and reactor dryout tests, are being undertaken in the UK.

Hypothetical studies are being carried out on the behaviour of core meltdown in nuclear reactors and of the penetration of core debris into the bottom of reactor vessels. Studies of heat transfer in and around core catchers are to be undertaken with the aid of a specially-commissioned laser. All these studies are being undertaken in conjunction with the US.

More joint UK/US experiments are being carried out to study the onset of dryout and subsequent post-dryout behaviour of a dual zone enriched SGHWR fuel element under real operating conditions.

In the field of fusion research, the IEA has three projects in progress aimed at advancing solutions to some of the major problems in magnetic fusion. In the first, the Large Coil Project, super-conducting coils of a size much larger than used previously will be built and tested.

The second project, concerning plasma/wall interactions, will use TEXTOR, the first tokamak to be completely dedicated to the study of such interactions. This facility is currently under construction at Jülich.

The final project is a co-operative venture on the design of an intense neutron source facility at Los Alamos. Much of this work, however, was slowed down or phased out during 1977 because of the US Administration's greater emphasis on development of technologies with near-term impact.

* IEA Annual Report 1977-78; 67 pp. HMSO or OECD Publications Office, 2 rue André-Pascal, 75775 Paris Cedex 16.

Electricity Council appointment

Mr. Tony Benn, Secretary of State for Energy, has appointed Mr. Duncan Milton McGrouther, MA, LLB, NP to be a member of the Electricity Council for a period of five years from 4th September 1978. Mr. McGrouther is currently deputy chairman of the South Western Electricity Board.

Hazards responsibilities change

A new group has been set up within the Health and Safety Executive in an organisational change in the Executive's work on potentially major hazard plants, or notifiable installations as they are known under proposed regulations contained in a recent Health and Safety Commission Consultative Document.*

Under existing arrangements, responsibility for developing safety policy for these installations rests with the Major Hazards Branch. The re-organisation sets up two branches within a new 'Hazardous Installations Group', to be headed by Mr. Ronald Gausden, Chief Inspector of Nuclear Installations, who is also to be appointed director of the group.

The first of these branches is the Hazardous Installations Policy Branch, headed by Mr. Hugh Lewis who is currently head of the Major Hazards Branch. This new policy branch will have similar responsibilities to the existing branch, including servicing the Advisory Committee on Major Hazards, and devising regulations affecting notifiable installations.

The second is the Major Hazards Assessment Unit, lead by Mr. Tony Barrell, Deputy Chief Inspector of Factories. This unit will be responsible for developing a methodology for assessing risks and identifying areas where codes of practice would be helpful. It will also advise the Factory Inspectorate in dealing with difficult safety problems arising out of hazard surveys produced by the occupier for individual installations, which will go in the first instance to the Area Office of the Factory Inspectorate. Prime responsibility for dealing with individual installations will thus continue to lie with the Area Directors of the Inspectorate.

The decision to place both branches under the authority of the Chief Inspector of Nuclear Installations stems from the similarities between the techniques of assessment for the safety of nuclear and non-nuclear installations, and many of the engineering problems are also similar.

* Draft Hazardous Installations (Notification and Survey) Regulations, available from HMSO, price 50p.

Harwell completes GLC contract

Harwell scientists have successfully completed a major contract for the Greater London Council. The work, which was completed in just over five months, involved taking samples to check contamination levels on 14 derelict London sites. A total of 621 samples were taken from the sites, which total 70 acres and are all earmarked for housing redevelopment.

The object of the work was to help the GLC assess the safety of the sites, most of which were previously used by industry.

A total of 11,600 chemical determinations were made by a team of ten scientists, using a wide range of advanced analytical techniques which included many automated methods. The contract involved one of the largest programmes of analytical work undertaken by Harwell on a contract research basis for an outside customer.

The samples of soils, earth, waters and gases were taken by Harwell staff from holes three metres deep in selected parts of the sites, most of which are in East London.

The results have been sent to the GLC in the form of a report for each site. Each report contains recommendations for rendering the site safe for building purposes.

None of the sites was found to be completely clean from potentially dangerous pollutants, but some of them were found to need only a small amount of remedial work in order to render them safe.

Enquiries about the services Harwell is able to offer in environmental and analytical work, should be made to: Dr. C.J. Hearsey, Marketing and Sales Department, Building 329, Harwell, Oxfordshire OX11 0RA.

Nuclear safety booklet

The British Nuclear Forum has published a booklet on the theme "Nuclear Safety", explaining concisely how a nuclear power station works, radiation and its effects, and how the safety of a nuclear power station may be assured. The booklet poses and answers key questions often put to nuclear operators by members of the public, and notes that "the record of the industry extending over at least 20 years is impressive and, indeed, unique. No other industry has been so painstaking in the protection of its workers and in its avoidance of damage to the environment."

Copies of the booklet may be obtained, free of charge, from: British Nuclear Forum, 1 St. Alban's Street, London SW1Y 4SL.

New NDT technique for fatigue measurement

A promising new method of detecting fatigue in materials and components is beginning to emerge from a programme of research in Harwell's Nondestructive Testing Centre.

Recent results from work carried out by scientists in the Centre show that the technique of positron annihilation can detect mechanical damage in alloys, and indicate the presence of defects which could ultimately cause metal fatigue.

Present NDT methods, using eddy current or ultrasonic probes, are able to detect and monitor fatigue only when it has reached a fairly advanced stage. Positron annihilation, on the other hand, appears to be an NDT method capable of detecting fatigue damage much earlier in the life of the material. The work is still very much at the laboratory stage, but results are encouraging.

The small Harwell team of Dr. Cliff Coleman, Mr. Ted Smith and its leader Dr. Tony Hughes, is working in collaboration with Rolls-Royce Aero Division at Bristol. To date the fatigue work has concentrated on a titanium alloy which is used for turbine discs and other components in the aero engine industry.

Positron annihilation is a nuclear technique which several research groups are applying successfully to basic studies of defects in materials. The Harwell work, however, is the only project in the UK where the technique is being explored specifically with nondestructive testing applications in mind.

Positron annihilation works as follows:

- Positrons (which are essentially electrons with positive charges) are emitted from a weak radioactive source and directed into the specimen.
- They are quickly annihilated by the electrons present in the material. Characteristic low energy gamma rays are given off in this process.
- These gamma rays carry information about the local environment in the material where the annihilation event takes place.
- By means of a gamma ray detector the energy spectrum of the gamma rays is measured. The detailed shape of this energy spectrum indicates when the annihilations are taking place in a region of the material which is defective. In this way damaged regions of material can be detected.

The Harwell team is hoping to establish relationships between the results of positron annihilation experiments and the level of fatigue damage. If this is successful then it could lead to a useful nondestructive monitor for this important form of materials failure. Before that stage is reached more careful research is needed and it will also be necessary to design equipment suited to practical applications.

The positron annihilation work at Harwell is part of the research programme of the NDT Centre which is supported by the Mechanical Engineering and Machine Tools Requirements Board of the Department of Industry.

Quarterly statement on nuclear incidents

The second quarterly statement of incidents at nuclear installations in Britain in 1978 reported to the Secretaries of State for Energy and for Scotland was published on 30th August by the Health and Safety Executive.*

These are incidents reportable under the Nuclear Installations (Dangerous Occurrences) Regulations 1965, under conditions attached to nuclear site licences and also certain incidents of lesser significance. The statement includes similar incidents reported to the Secretary of State for Energy by the UKAEA. The report covers the period 1st April to 30th June, and contains summaries of investigations which have been completed during the quarter on some of the previously reported incidents.

The location of the installations mentioned in the statement are as follows:

Hinkley Point 'B' Nuclear Power Station, CEGB, Somerset.
Windscale Works, British Nuclear Fuels Ltd., Cumbria.
Winfrith, UKAEA, Dorset.
Hunterston Nuclear Power Station, SSEB, Ayrshire.
Wylfa Nuclear Power Station, CEGB, Gwynedd.
Berkeley Nuclear Power Station, CEGB, Gloucester.
Trawsfyndd Nuclear Power Station, CEGB, Gwynedd.
UKAEA, Dounreay, Caithness.
Atomic Energy Research Establishment, Harwell, Oxfordshire.
Drigg Active Waste Disposal Site, British Nuclear Fuels Ltd., Cumbria.

* Quarterly Statement on Incidents at Nuclear Installations: Second Quarter 1978: free from the Inquiry Point, Health and Safety Executive, Baynards House, 1 Chepstow Place, London W2 4TF. Tel: 01-229 3456. Ext. 732.

Microprocessors in NDT

A one-day briefing on 'The Future Role of Microprocessors in Nondestructive Testing' for managers concerned with the manufacture or application of NDT equipment will take place at Harwell on 23rd November 1978.

The briefing is being organised jointly by the NDT Centre, Harwell and Sira Institute Ltd.

The briefing will provide an introduction to microprocessors and their potential role in nondestructive testing, and will illustrate how they are already being applied in equipment used off-line and irron-line systems.

The far-reaching implications of the availability of microprocessors and their application to the production of new and improved consumer products and industrial equipment are exciting a great deal of attention in industrial and government circles. As a first step towards an assessment of their potential usefulness to manufacturers and users of NDT equipment, the NDT Centre at Harwell and Sira Institute have arranged this one-day introductory programme to stimulate discussion on the future role of microprocessors in nondestructive testing.

A group of speakers will set the scene in a number of formal presentations, which will aim both to inform and to generate constructive questions and discussion. They will explain how to improve existing products or design new ones by taking advantage of the microprocessor's capabilities. The team of speakers will include Harwell specialists in NDT instrumentation and Sira specialists in the application of microprocessors to measurement and inspection equipment. A speaker from industry will describe a current application and a speaker from the Department of Industry will explain government schemes for the financial support of microprocessor application projects. The topics will be treated in such a way as to be intelligible to those who may have read about microprocessors but who have no first hand knowledge of them.

The six topics to be presented for discussion will be:

(a) The relevance of microprocessors to nondestructive testing.

(b) An introduction to microprocessors: what they are and what they can do.

(c) What is involved in designing and developing a microprocessor-based instrument or system, and the investment required in staff and development facilities.

(d) Examples of NDT instruments incorporating microprocessors.

(e) An on-line system incorporating microprocessors.

(f) Government support for applications projects.

The total number of those attending will be limited to about 60 to ensure maximum audience participation.

Further information may be obtained from Mrs. R. Keiller, Sira Institute, South Hill, Chislehurst, Kent BR7 5EH.

Safety — chemicals seminar

"Safety of Chemicals in the Environment" is the title of a two-day seminar to be held at Harwell from 9th-10th May 1979.

The event is the second in Harwell's series of environmental seminars, the first of which was the highly successful "Major Chemical Hazards" seminar held at The Lorch Foundation, Lane End, Buckinghamshire in April this year. "Safety of Chemicals in the Environment" is to be held at the same venue.

The seminar is designed to appeal to all concerned with the safety of chemicals and those having a direct responsibility to protect the environment against both short and long-term toxic and polluting substances.

Its stated aim is: "To examine the effects of chemicals in the environment with particular emphasis on the issues of control, production, use and disposal."

The seminar, which is expected to have an international appeal, will cover the following topics: origins of chemicals in the environment; detection and toxicology; effects and epidemiology; regulatory implications in the United Kingdom, Europe and North America; industrial viewpoints; ecological aspects, and future developments.

Further information about the seminar can be obtained from Mr. C. J. A. Preuveneers, Education and Training Centre, Building 455, Harwell, Oxfordshire OX11 0QJ. Telephone Abingdon (0235) 24141, extension 3106.

UKAEA places computer order

The United Kingdom Atomic Energy Authority signed contracts on 6th September with International Computers Ltd., for 2900 computer systems worth in excess of £13 million.

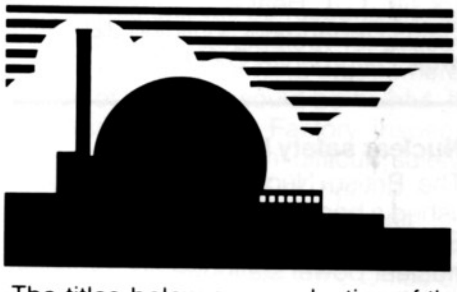
The order comprises two dual 2976 computer systems, enhancements to the 2980 computer inaugurated recently at UKAEA's Northern Diviion at Risley, Cheshire, and, for installation at a later date, a second order code processor for the Risley system. The order is the result of a growing demand for scientific computing facilities by the Authority's research establishments.

The dual 2976 computers will be installed at Winfrith in Dorset, where there is a System 4-70, and at the Culham Laboratory near Abingdon, Oxfordshire. At present there are two System 4-70 computers at Culham Laboratory, the UK centre for nuclear fusion research. The work at Culham forms part of a co-ordinated European programme to investigate the feasibility of achieving controlled nuclear fusion for electricity production. The largest project in this programme is JET (Joint European Torus) which is to be built on a site adjacent to the UKAEA laboratory at Culham. JET is a collaborative project involving all of the EEC countries and Sweden.

The Winfrith Atomic Energy Establishment is primarily concerned with the development of thermal and fast reactor systems including reactor physics, heat transfer and fluid dynamics, and control and instrumentation as well as studies in the chemical, metallurgical and engineering fields relating to post-irradiation examination of fuel, waste processing and disposal, and fuel transport flask technology.

The enhancements to the Risley 2980 include four megabytes of store and eight EDS 200s. Each of the 2976s and the second 2980 OCP have eight megabytes of mainstore.

AEA REPORTS



The titles below are a selection of the reports published recently and available through HMSO.

AERE-PR/EMS 5 *Environmental and Medical Sciences Division Progress Report for the Period January to December, 1977*. Compiled by W.M. Hainge. July, 1978. 138 pp. HMSO £3.00. ISBN 0 70 580449 6.

AERE-R 9056 *A General Purpose Program Interface to the EPSS Communications Network*. By B.D. Cooper and K.S. Heard. June, 1978. 69 pp. HMSO £2.00. ISBN 0 70 580329 5.