DECEMBER 1982 NUMBER 314

ATOM

ELECTRIFICATION AND URANIUM POWER

BUILDING ON SUCCESS

GAS-COOLED REACTORS TODAY

ANNUAL INDEX

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ATOM contents

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Enquiries concerning the content and circulation of the bulletin should be addressed to the Editor,
James Daglish
Information Services Branch UKAEA
11 Charles II Street
London SW1Y 4QP
Telephone 01-930 5454

Information on advertising in ATOM can be obtained from
D.A. Goodall Ltd., New Bridge Street House
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The vast four-reactor complex at Tricastin, on the Rhône in southern France. In this issue, Dr Chauncey Starr urges that the expanded use of "uranium power" is essential to provide a substantial portion of the electricity necessary to sustain world economic growth

ELECTRIFICATION, ECONOMIC GROWTH AND URANIUM POWER

The expanded use of "uranium power" is essential to provide a substantial portion of the electricity necessary to sustain world economic growth; obstacles to its expansion arise not from the technology, but rather from the inadequacies of national and international institutions needed to manage this new energy system.

Dr Chauncey Starr, vice-Chairman of the Electric Power Research Institute, presented the following paper at the seventh annual symposium of the Uranium Institute in London in September*.

The worldwide growth of uranium power plant capacity is obviously dependent on both the growth of electrification and the competitive status of uranium power. I am using the term "uranium power" in lieu of the usual "nuclear power", so as to avoid the common semantic confusion with nuclear weapons. In this paper I plan to develop the thesis that expanded use of uranium power is essential to provide a substantial portion of the electricity necessary for world economic growth. I further wish to make the case that the obstacles to this expansion arise not from the technology, but rather from the inadequacies of our industrial, political, and economic institutions to manage this new energy system effectively, nationally and internationally.

Let us recall the original premises thirty years ago for initiating a major worldwide development of uranium power. It was recognised then that the spectacular potential of uranium energy, particularly with breeder technology, could make a long-range contribution to the welfare and future of humanity by supplying an almost limitless source of energy heretofore untapped by man. The unique energy density of uranium fuel, and its foreseeable long-time availability when used with the breeder, imply low-cost worldwide transportability, minimal mining costs compared to coal, and a very low sensitivity of electricity costs to future uranium costs. Further, uranium power offers an environmentally benign source, because of the available technical means of containing radioactivity in a closed system. The facts as we know them today continue to support the importance of this objective. The world faces a cumulative energy consumption of the magnitude of 100 000 quads† during the next century, a growth rate of 2·3 per cent per year; and this is about equal to the estimated magnitude of the recoverable total fossil fuel resources of the world. While a century may appear to be a long time, in fact the history of industrial societies indicates that it takes about 100 years for a new energy source to become the supply for one-half of the total annual energy demand. It is thus not too soon to seek supplements to fossil fuels, as well as to be concerned with how to use present sources most efficiently. In large measure that is what we mean when we speak of the coming decades as a time of transition from one energy era to another.

While many things have occurred in the past thirty years to mire the sense of mission of the uranium community, the need and rationale for this new energy source has not disappeared. Instead, it has been made more urgent by the fact that what was essentially an academic exercise thirty years ago has now become a pressing contemporary economic problem. The rapidly growing reliance before 1974 on imported Middle Eastern oil by the industrialised world, in response to its overwhelming price advantage, has been coupled with the realisation of oil-exporting countries that their present price and production policies should be based upon the expectation of depletion of their oil resources, and the consequent increase in their value. World oil is now traded on the basis that it is

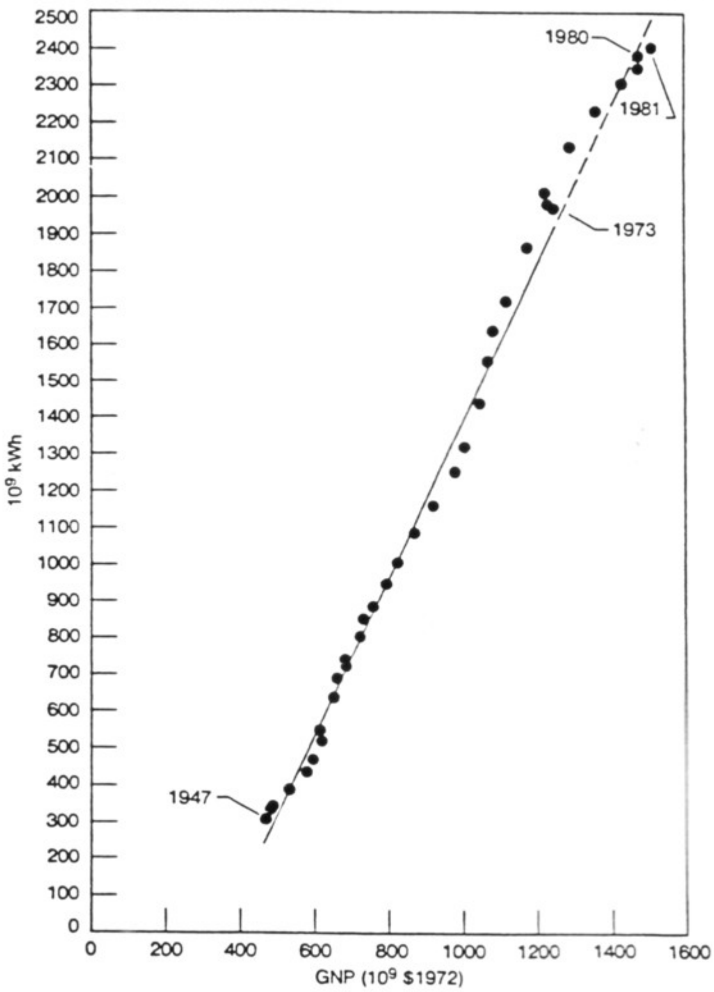

Fig. 1a Electricity versus GNP, United States, 1947-1980

*The proceedings of the symposium will be published by the Uranium Institute shortly, as *Uranium and Nuclear Energy 1982* (Butterworth Scientific Ltd, Sevenoaks, UK).

†1 quad = 293 TWh = 0·04 billion tons coal = 0·175 billion barrels oil = 1·05 Exajoules.

chiefly a near-term fuel and difficult to replace, and we must all plan on this basis.

Of the various supplements to fossil fuels, only two offer the technical possibility of a substantial contribution for the indefinite future. The first is the energy from atomic nuclei, using the fission breeder or fusion. We know how to produce energy from uranium via the fission process; we do not yet know how to use the fusion process. The second is solar. We know how to convert solar energy into the useful forms of heat and electricity. There is at present, however, a major difference between uranium fission and solar, namely the substantial difference in capital cost which is required to use these two energy supplies for electricity production. Unfortunately, of the world's resources, capital is one of those in short supply. At the present state of engineering knowledge, the use of solar energy for other than low-temperature heat involves capital investments in conversion equipment more than an order of magnitude greater than those required for the nuclear fission process. We anticipate that solar electricity as a fuel displacer in power systems during peak or intermediate load periods may eventually have a modest role; but the economic feasibility of independent solar electric generation, with energy storage appropriate for base load reliability, is at best a very distant prospect.

This reaffirmation of the correctness of the goal that was set decades ago for uranium power is hardly consistent with the atmosphere of public scepticism and criticism which today surrounds uranium programmes throughout the industrialised world. Certainly, if public doubts concerning uranium power are not diminished soon, they may seriously hinder the development of a much-needed long-term energy source. I will not here address the technical aspects of these doubts, because I believe that most of you share my confidence in our ability to handle the technical issues of public health and safety. And most of us recognise that the issue of nuclear weapons proliferation is a major international political problem, with only tenuous connections to civilian uranium power technology. I will therefore concentrate instead on the more tangible issues related to the role of uranium power on the world scene.

Almost everyone in the energy industries is aware of the lead times necessary to implement future energy availabilities on a significant scale—lead times usually measured in decades. For this reason, the decisions which face us today will determine the energy structure of the world for at least the next twenty years, as well as the direction of developments beyond then. Our present task, of course, is to initiate programmes timed to meet foreseeable needs. Unfortunately, perceptions of the future always cover a wide spectrum of opinion. But we need not blindly select among opinions. We can take as a planning base those few relationships which are most likely to be valid during the coming decades. The first of these is the demographic projection of the national populations which the world's economic systems must support by the year 2000. The second is the basic fact that electricity consumption has followed the economic output (GNP) of industrial nations with remarkable closeness through all types of changes in their social structure, through the two major oil price shocks, and through changes in their industrial mix. The historical relationship between electricity and economic output for some of the industrial nations is shown in Figures 1a and 1b. Although both kilowatt-hours and GNP are gross aggregates that include many complex relationships, consistency of the link between them, and some insight as to its cause, give us confidence in its use for long-range planning.

In Figure 2, I have illustrated my interpretation of some of the large-scale factors that influence the relationship, and that could change its future slope. We only partially understand the factors that have tied electricity and GNP together, even during the post-oil shock years, when total energy use—unlike electricity—experienced sharp drops. Our studies of the subject have indicated that there appears to be a continual shift into electricity as an energy form in commerce and industry. There also appear to be effects which compensate for the reduction in demand due to more efficient use, such as the continual trend towards increased electrification as a means of improving productive efficiency in the use of total

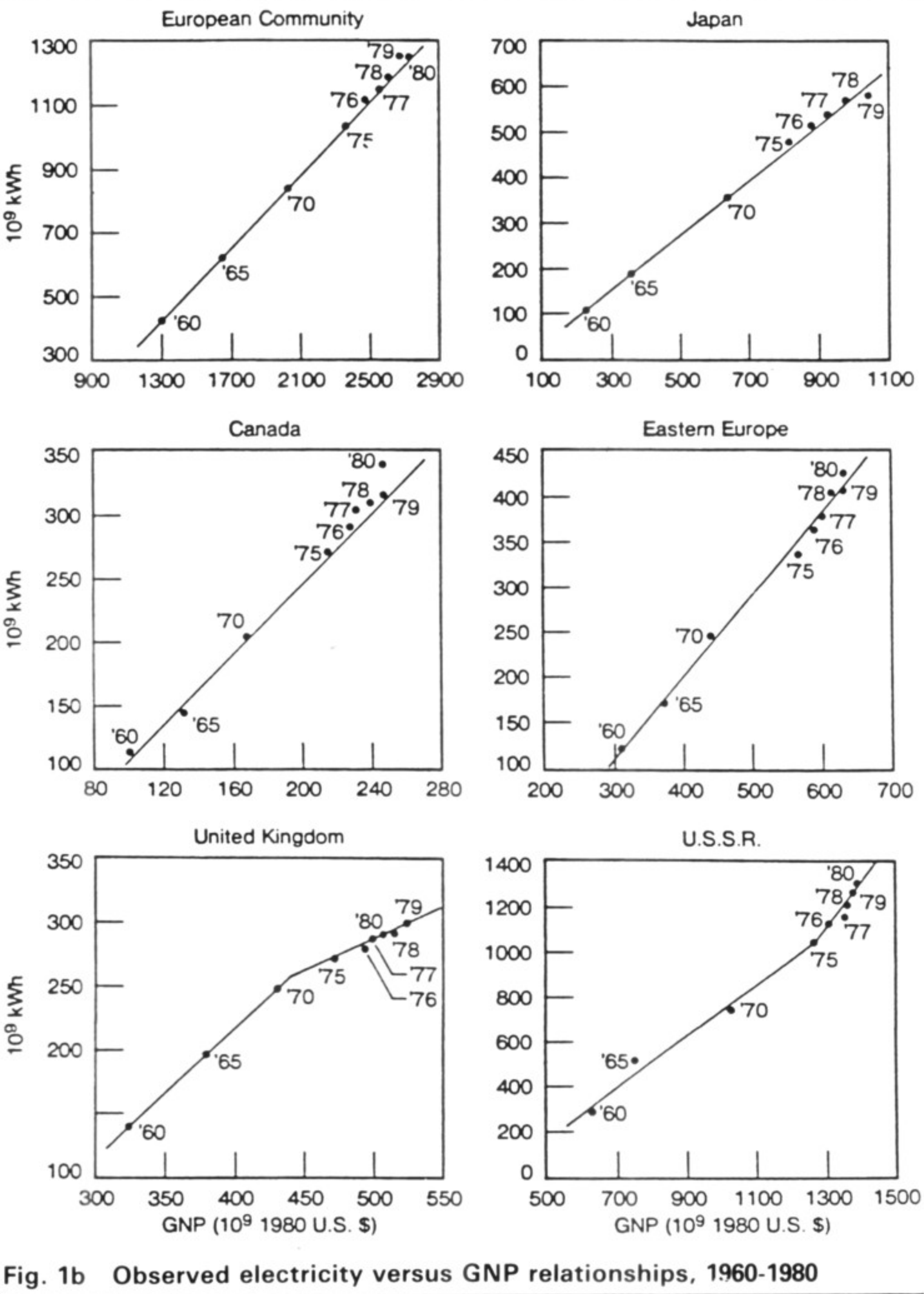

Fig. 1b Observed electricity versus GNP relationships, 1960-1980

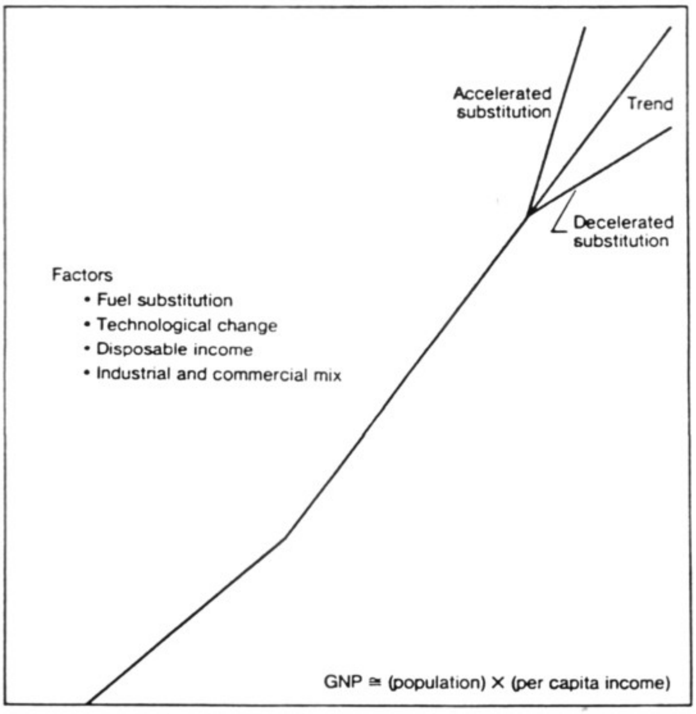

Fig. 2 Electricity versus GNP concept

remarkable achievement, and one that is almost never mentioned in current discussions. All the various factors that produced this outcome have not yet been conclusively unravelled, but the evidence supports the belief that electricity's role in supporting improvements in productive efficiency—and thereby expanding the nation's capacity to produce—was of major importance among the underlying causes. This was a period during which electricity use grew by a factor of more than ten, while all other energy consumption only doubled, and individual-drive motors, welding equipment, etc., permitted great flexibility in production systems and increases in their efficiency.

The US was not unique in its trend to electrification. Similar changes occurred in all industrial nations. In the past twenty years, world use of electricity has increased about four times; in the developed economies, about three times; in the developing economies, about seven times; and in the centrally planned economies, about five times. The low initial level of electricity use in the developing countries twenty years ago is, of course, the reason for the large increase in their ratio. As further background, worldwide electricity use grew 1·5 to 2 times as fast as total energy consumption.

For the next twenty years and beyond, the global increase in future electricity use is projected by the recent IIASA study* to range between 2·6 per cent and 3·4 per cent per year, based on electricity being limited to what is essential and to special resources. For such reasons, we believe that the close relationship between economic growth and electricity is likely to be maintained.

The submission of electricity for other energy forms is a key factor, of course, and this is shown for the US in Figure 3. Two principal factors have stimulated this progressive trend toward substitution. The first is the continual improvement in the relative economics of electricity and fossil fuels, even when both prices increase. This is shown in Figure 4 for the US. For the economists, this means that the own-price elasticity of electricity is balanced by the cross-price elasticity with oil and gas. In simpler terms, when prices go up, electricity remains a better buy than oil and gas, whose prices increase the most.

It should be remembered that the higher relative cost of electricity is usually more than compensated by the efficiency of its use, as compared with the normally low efficiency in the use of fossil fuels. Electricity is usually the ally of overall energy efficiency. Thus, the second factor leading to substitution is the unique effectiveness of electricity in improving the productive efficiency of the processes and systems for producing goods and services. The one long sustained period of declining energy inputs relative to overall national output in US experience ran from the end of World War I until about mid-century. From 1920 to 1945 raw energy consumed per unit of GNP (measured in constant dollars) declined by almost 40 per cent, a really

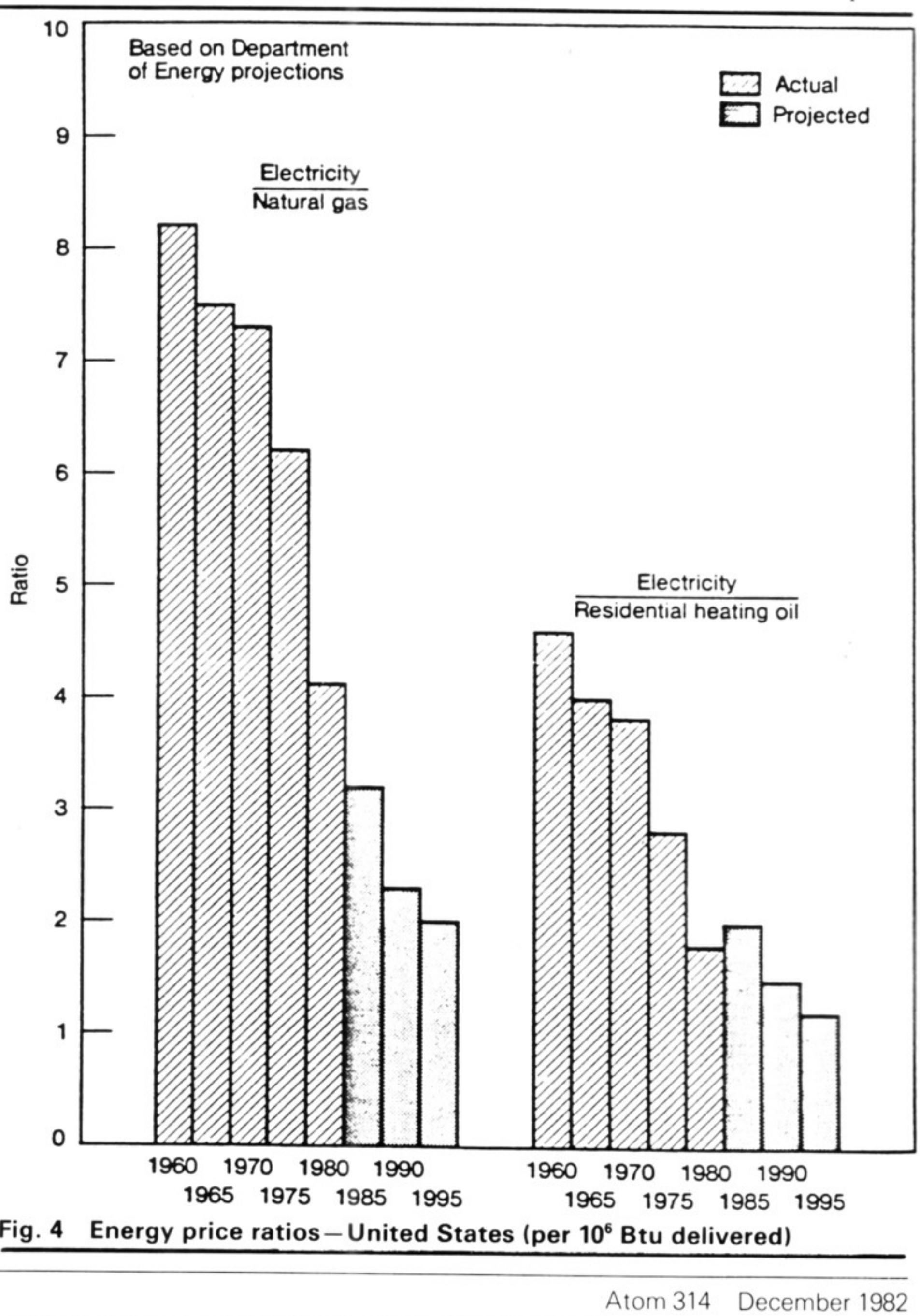

Fig. 4 Energy price ratios—United States (per 10^6 Btu delivered)

**Energy in a Finite World*, Wolf Haefele, Ballinger Publishing Company, Cambridge, Massachusetts, 1981.

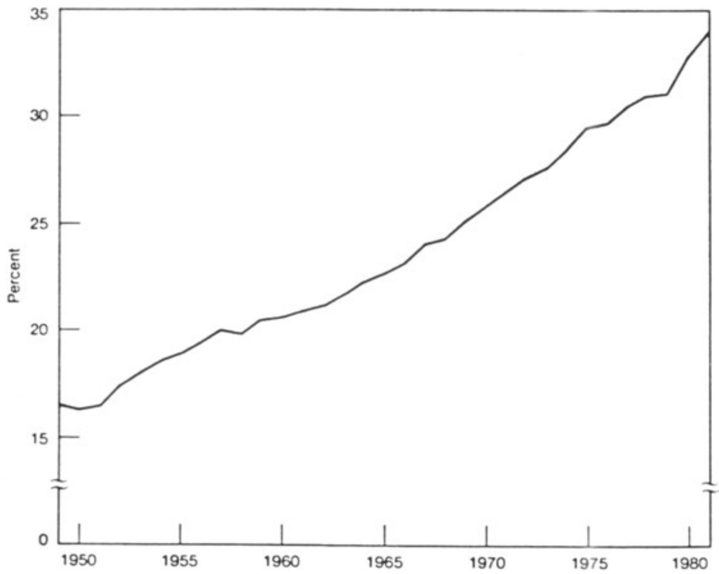

Fig. 3 Percentage of primary energy used for electricity, United States, 1947-1981

purposes. For reference, a 3·5 per cent per year increase is equivalent to a twenty-year doubling time. It is evident that, although this modest projection is about half the historical trend, it leads to almost doubling electricity use in the next twenty years. Is this adequate for the world's expectations of economic growth? Scarcely. In 1980 the per capita consumption among nations ranged from Norway at 20 327 kWhe per person, US at 10 469, UK at 5 102, USSR at 4 818 to India at 175 kWhe, a range of about 100 to 1. The average in developed countries is 6 724 kWh per person; in developing countries 381; and in the centrally planned economies 1 482 kWh.

Assuming that population growth can be constrained enough to permit economic growth, the developing economies, with half the world's population, would have to increase average electricity supply about eighteen times to match the present average status of the developed economies. Doubling electricity production worldwide is a formidable task, but still not enough to support the economic growth needed. Indeed, to match the present average status of the developed nations, a factor of about four times is needed, provided no population increases occur.

Where can this electricity come from? In the above study, it was projected that twenty years hence uranium power might supply about 30 per cent of the world's electricity, and coal about 40 per cent, with the remainder coming from hydro, oil and gas. The wide variations worldwide in the present fuel supply mix are indicative of the wide differences among nations. Recognising the realities of system size and electricity costs, the availability of the large blocks of capital needed for investment in large central stations may be the key factor in shaping national electricity systems. Uranium power plants are economical only in very large sizes, so their billion-dollar unit investment must be available, as must also be the market for such large blocks of electricity. Coal plants can be built in smaller sizes, and certainly will be. And, of course, oil and gas plants are the small users' choice. If the industrial nations wish to help the developing world, they should build uranium power plants, so as to make fossil fuels more available and less costly for the small users.

So the world will find itself divided into two groups: the industrial nations that can afford to use large central stations based on solid fuel—coal and uranium; and smaller developing nations using coal, oil, and gas in small units producing higher-cost electricity. Very roughly, two-thirds of the world's electricity is now used by the industrially developed nations, which also use about one-third of the total primary energy; and these industrial nations represent less than one-fifth of the world's population. So four-fifths of the world still faces the combined task of achieving economic growth and the electricity supply needed to support it. Some few developing nations that can promote the capital needed for investment may succeed; but most of the less developed nations face dismal growth prospects, especially in view of the inhibiting effect of the very high cost of imported fossil fuels today.

What about the prospects for the industrial nations? Let me use the United States as an example, as I know its situation best. If we take the projected US labour force for the year 2000—most of which is already born—and the economic output (GNP) needed to support it, then using the historical relationship we find that in the year 2000, to provide the goods and services needed to maintain today's scale of living, will

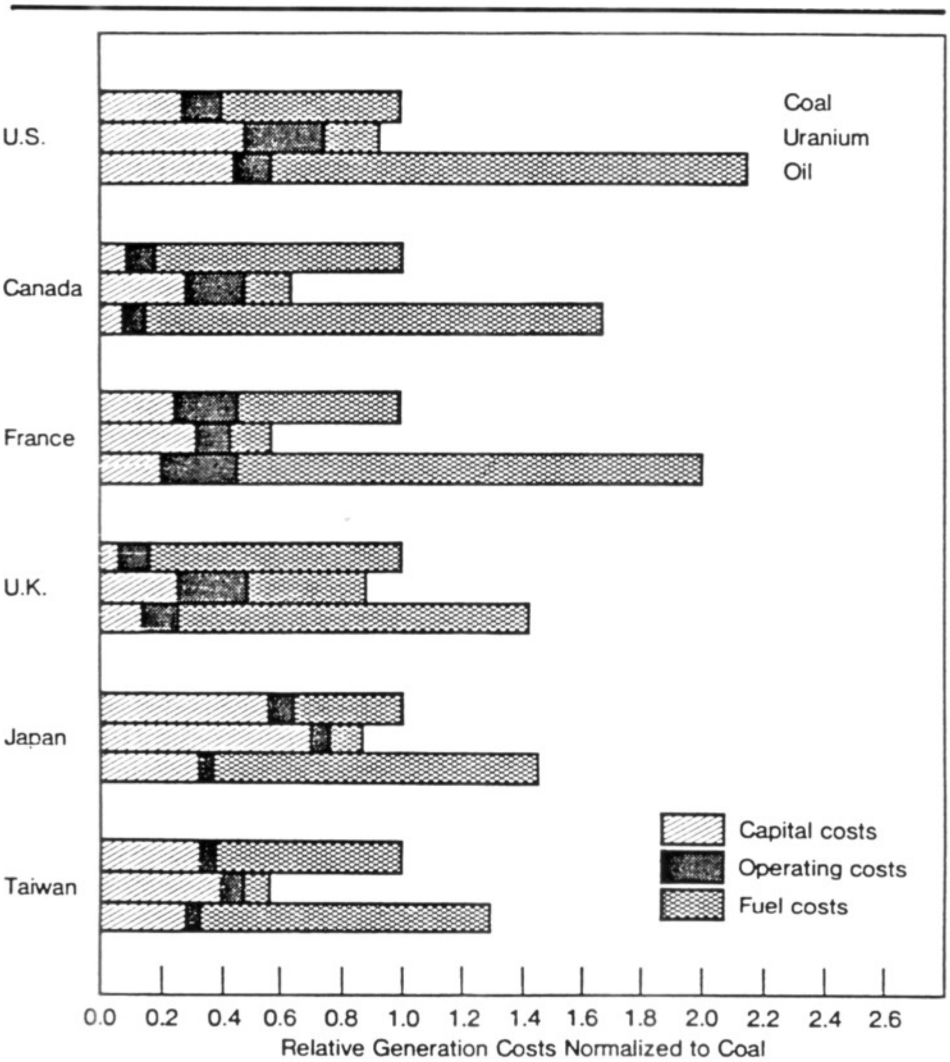

Fig. 5 Relative generation costs of uranium, coal and oil-fired power plants in 1980-1981, normalized to coal costs in each country, at national denominations

require an annual electricity production roughly twice today's figure.

This, then, leaves us with the question: How should the US plan to supply that electricity? At the present time, coal is almost half of our primary fuel for generating electricity. If we attempt to double electricity production by the year 2000, we should certainly plan to double the amount of coal made available for electricity generation. At EPRI we have examined the details of this process, and we believe that this goal is probably as much as is likely to be achieved for both coal production and coal utilisation by the electric utility industry. As many of you know, the lead times and constraints on the expansion of coal-based electrical production are almost as severe as those we face in the uranium electricity sector. This, then, leaves us with the problem of filling the gap of the other half of electricity demand. For many familiar reasons, we do not believe that the use of oil and gas for electricity production can be expected to increase in the next several decades. In fact there are many reasons why their contribution to our electricity supply may be reduced. We foresee only small increases in hydroelectric power, and only modest contributions from the renewable resources which are now being explored. Thus we are left with uranium power as the only major electricity source available to fill the needs that we foresee.

A recent paper, which I co-authored with Milton Searl, on the various rates at which power plants might be put on line in the next two decades*, leads to the conclusion that in view of today's modest planning of the utility industry for new plants, we are likely to be short by as much as one-fourth of the total capacity needed to meet the minimum social expectations of our populations by the year 2000.

Now of course these projections, which are undertaken for planning purposes, oversimplify the situation. In fact, electricity shortages of the type we describe do not become visible as clearly as they do in a numerical analysis. They will not even merit the usual news flash on TV, so the public will not notice, because the process is too subtle. The first effect of electricity shortage is to stimulate the rehabilitation of the older and inefficient power plants; the second is that generation equipment which is now used for intermediate and peak loading because of its higher costs gets used for more of the extended operation necessary for base loads; the third effect is the emergency purchasing of short lead time but expensive and inefficient sources, such as gas turbines for driving electric generators; and the fourth effect is the purchase of electricity from neighbouring networks at a high price, an option which eventually runs out. The net effect of these changes is to raise the cost of electricity to the consumer, and to drive electricity-dependent industry, which needs low-cost reliable supplies, into other regions and other countries of the world; and thus, to reduce the scale of living and economic growth of the nation. Thus supply and demand will always superficially appear in balance, but the effects of the shortage are nonetheless very real and far-reaching.

So, even though the US is a coal-rich nation, the projected need for uranium power plants is quite large. The situation must be even more evident to those nations without large fossil fuel resources. In the US we have several obstacles to an accelerated uranium power plant programme, which have resulted in an average construction time three years longer in the US than in most other countries. Some of this lengthened time arises from the administrative inefficiencies of the institutions involved in the process of licensing, constructing, and operating these plants. For example, many of the uranium plants being completed have experienced very large cost overruns due to retrofits, construction errors, regulatory changes, and other unanticipated causes. For these reasons, and because coal is a domestic fuel in the US, the generation cost advantages of uranium power over coal are less in the US than in other industrial countries. This is shown in Figure 5, which compares coal, uranium, and oil generation costs internationally.

The capability of uranium power technology is best illustrated by the French experience, where the continuity of learn-

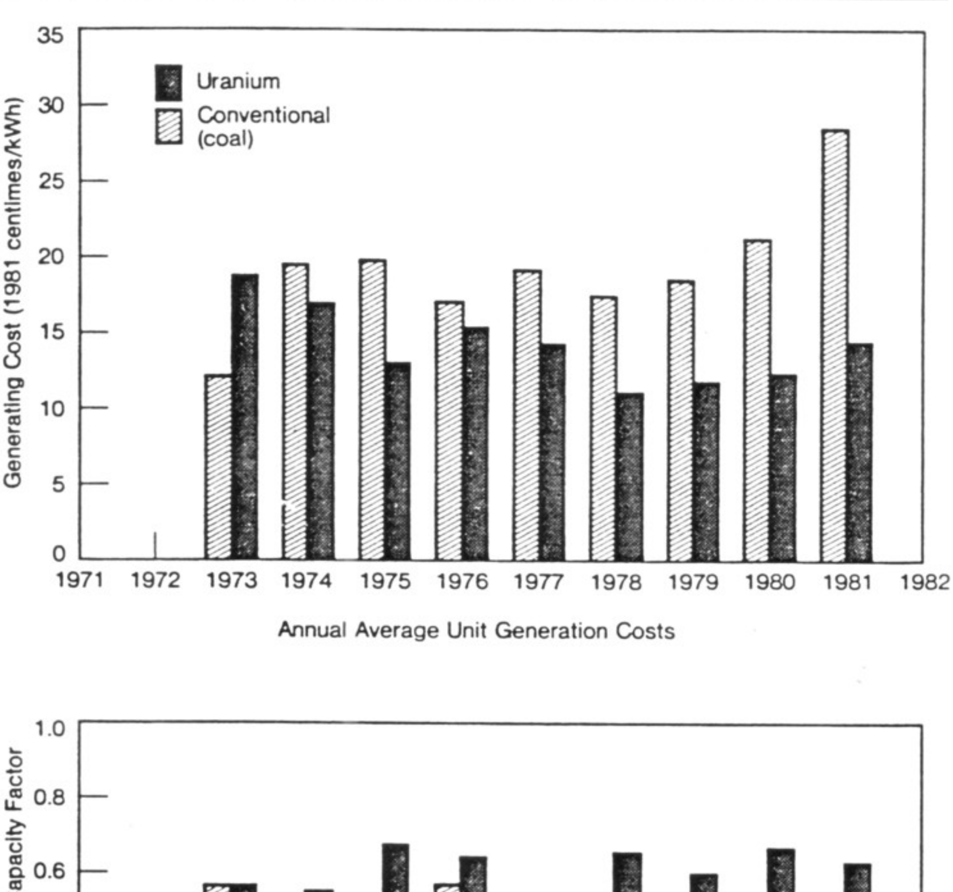

Fig. 6 Evolution of generating costs and capacity factors of conventional (thermal) and uranium power plants in EDF system. Constant 1981 francs

*Generating Capacity Requirements for Economic growth, 1990-2000, Chauncey Starr and Milton F. Searl, *Public Utilities Fortnightly*, April 29, 1982.

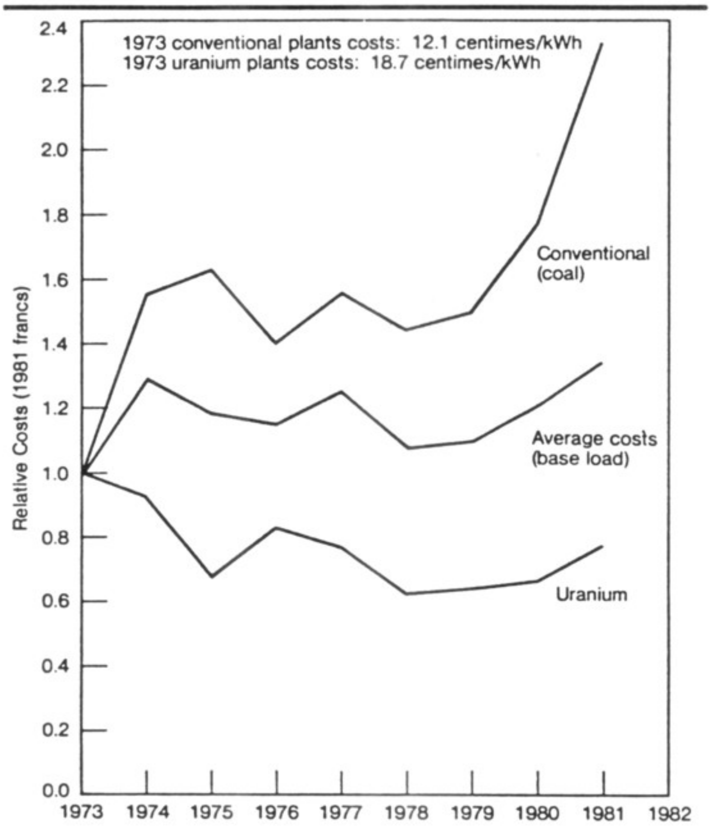

Fig. 7 Uranium and conventional (coal) fired plants generation costs in EDF system, normalised to 1973 costs

ing has been organisationally concentrated. Figures 6 and 7 show the trend during the past decade in the relative performance of coal and uranium plants. Most interesting is the projection of electricity costs for plants starting operation in the year 2001, as shown in Figure 8 (for Switzerland/Germany).

It is evident that in nations with effective institutional structures for its management, uranium power is clearly going to be the economic choice. The experience in various nations has also led many of us to believe that management of uranium power, from concept and construction to daily operation, requires organisations specifically tailored to this technology. Unfortunately, we continue to have some electric utility systems in the US that persist in trying to manage uranium power within their historical fossil fuel organisations, with the unpleasant economic and operational consequences reported in the news. If, then, the generation of uranium-based electricity is to play its most effective role, it must be perceived as a venture requiring its own management structure in every respect. Its comprehensive managerial needs are more like those of the large-scale programmes for space satellites, rather than the individual and independent programmes for building refineries to supply gasoline.

The unique management aspects of uranium power are most apparent when we consider its fuel cycle. First, the economics of enrichment and chemical reprocessing plants result in unit sizes which can support a large number of power plants. Second, international concern that enrichment or chemical processing technology might be used for military weapons manufacture has led to several technical and institutional proposals to inhibit such diversion of capability. Thus, it is apparent to many of us that only multi-national or international management of the fuel cycle plants could provide the security of supply and assurance of dedication to peaceful purposes that each uranium fuel user would seek as an alternative to his own national facilities. This issue will become more pressing as uranium power spreads to more developing countries. Unfortunately, the subject has only been casually considered by the industrial nations as yet. It should be addressed before the situation becomes inflexible.

In an unplanned manner, national uranium power programmes have already become dependent on each other. Public acceptance of national programmes is based on the people's perception of plant performance, both as to cost and safety. A serious accident or failure at any uranium power plant affects the future of all national programmes. The Three Mile Island accident was a damaging blow to all uranium power programmes everywhere. So all national programmes are now hostage to each other.

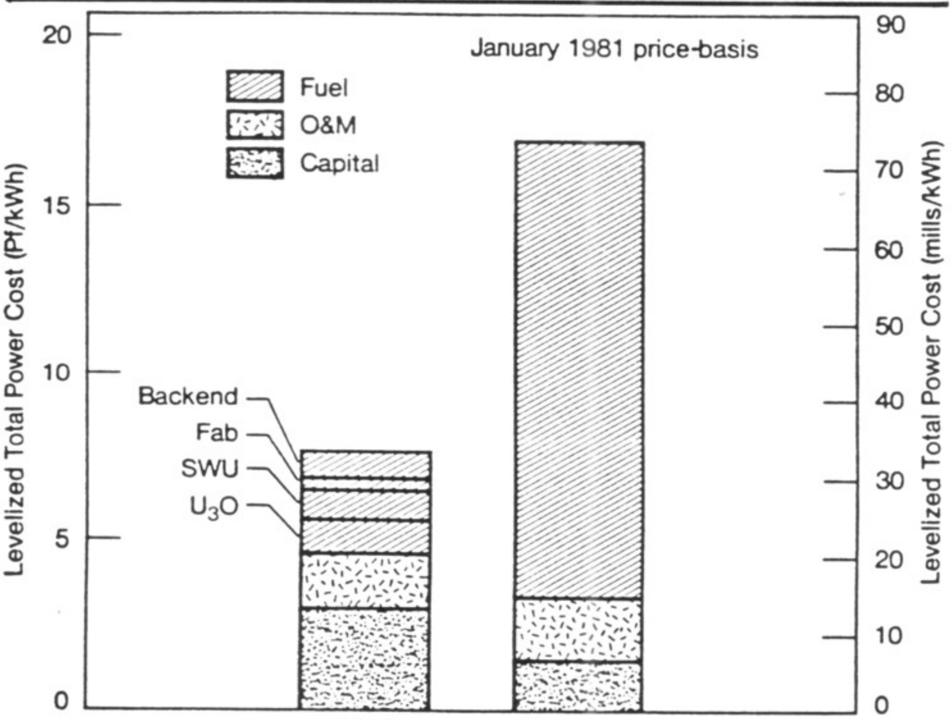

Fig. 8 Comparison of levelized total power costs for an LWR and a coal plant in Switzerland and the Federal Republic of Germany starting operation in 2001

In a similarly happenstance manner, the fuel cycle practicalities of both the front and back ends have resulted in an international interdependence on fuel supplies. We have a few nations exporting enriched fuel, undertaking reprocessing, and setting their rules for such commerce. At the highest levels, these nations do attempt to coordinate their views. However, the importance of a secure fuel supply, and the absence of an international arrangement to assure such a supply free of the potential for political intervention, are moving the fuel buying nations to initiate domestic facilities, even if these are uneconomic. If internationalising the fuel cycle is ultimately desirable—and I believe it is—the time window for doing so exists in this decade, but may start closing thereafter.

So I have come to a positive view of the potential for electricity in the world's future need for energy, and for a special role for uranium power. But making this happen will require that the industrial nations should thoughtfully plan and establish the unique institutions and management that this special technology demands. □

BUILDING ON SUCCESS

The initial confidence that the AGR fuel designs used in the British nuclear power stations would yield their output for their design life is being confirmed progressively. This confidence has led to consideration in recent years of how the development potential inherent in the design can be exploited with reduction in fuel cycle cost and consequently power cost. R.A. Shaw* here describes the fuel design, the basis for development, and the design and material changes that are being considered for introduction in the immediate future.

The fuel assembly for an Advanced Gas-cooled Reactor (AGR) is shown in Fig. 1. It consists essentially of two halves: the top half is called the plug unit and contains the gamma shield plug and the gag for controlling the gas flow up the channel containing the assembly; and the lower half is the fuel stringer. This consists essentially of seven or eight fuel elements, with neutron reflectors above and below, carried on a bottom support unit. Each element is approximately one metre long and has 36 fuel pins arranged in three rings and held by a grid and two braces which are located in a graphite sleeve assembly. The fuel stringer and its associated components are lifted in and out of the reactor on a tie bar of Nimonic PE16 which passes through a central guide tube fixed to the grids. An anti-gapping unit accommodates differential thermal expansion during fuel charging operations. The coolant flowing up the fuel elements is separated from the moderator by the two concentric graphite sleeves which have an insulating gap between them. Gas enters the channel both directly and from a re-entrant flow between the outer sleeve and the moderator; the bottom support promotes mixing of these flows.

The Advanced Gas-cooled Reactor (AGR) fuel design is derived from prototypes irradiated in the Windscale AGR and, although there are differences in flow, pressure and flux, experience with fuel in that reactor remains a major component of any assessment of future developments in fuel design. The use of a hollow fuel pellet to obviate problems that could arise from fission product gas release was a consequence of work in WAGR. Between three and four hundred fuel stringers containing fuel pellets of two different bore sizes (0·2 and 0·25 in.) in the same cans as are used in AGRs have been irradiated under a wide variety of conditions in WAGR. Fig. 2 shows the irradiation levels which had been achieved in these two fuel types when WAGR was shut down. Well over a hundred stringers had achieved mean burn-up levels greater than 18 GWd/te and the maximum level of stringer mean burn-up achieved was 25·3 GWd/te corresponding to a peak element burn-up of 33 GWd/te. It is worth noting that a WAGR stringer has a much higher ratio of peak burn-up to mean burn-up than one irradiated in one of the Generating Board's AGRs so that, at the same mean stringer burn-up, the peak WAGR element will have been more highly irradiated than its CEGB/SSEB counterpart by 15-20 per cent. The excellent condition of a cluster irradiated in WAGR to a peak element burn-up of 29·3 GWd/te and of the corresponding pin surface at the position of maximum temperature is shown in Fig. 3. This experience clearly supports the present confidence in the decision made years ago that the AGR fuel cycle should be based on an irradiation of 18 GWd/te. It also illustrates the potential now available for exploitation.

*Mr Shaw is Research Manager at the UKAEA Springfields Nuclear Power Development Laboratories.

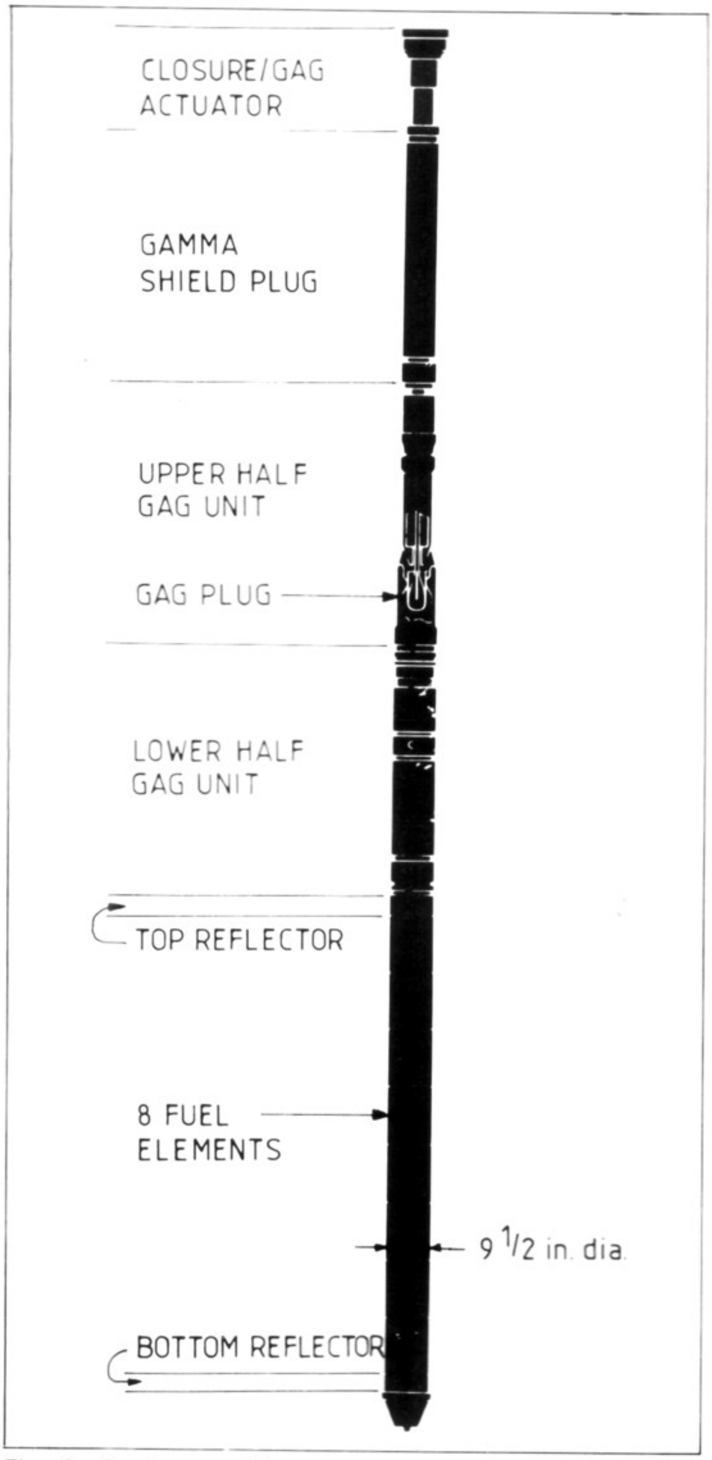

Fig. 1 Fuel assembly arrangement—Hinkley Point B/ Hunterston B

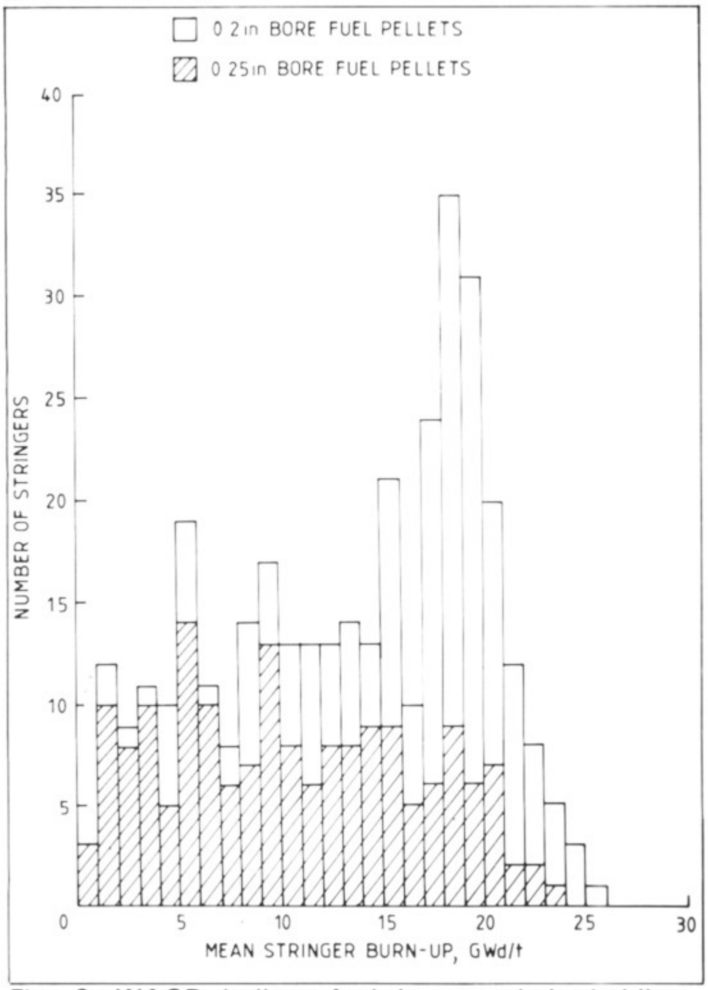

Fig. 2 WAGR hollow fuel in annealed cladding—Burn-up distribution (May 1981 end of reactor life)

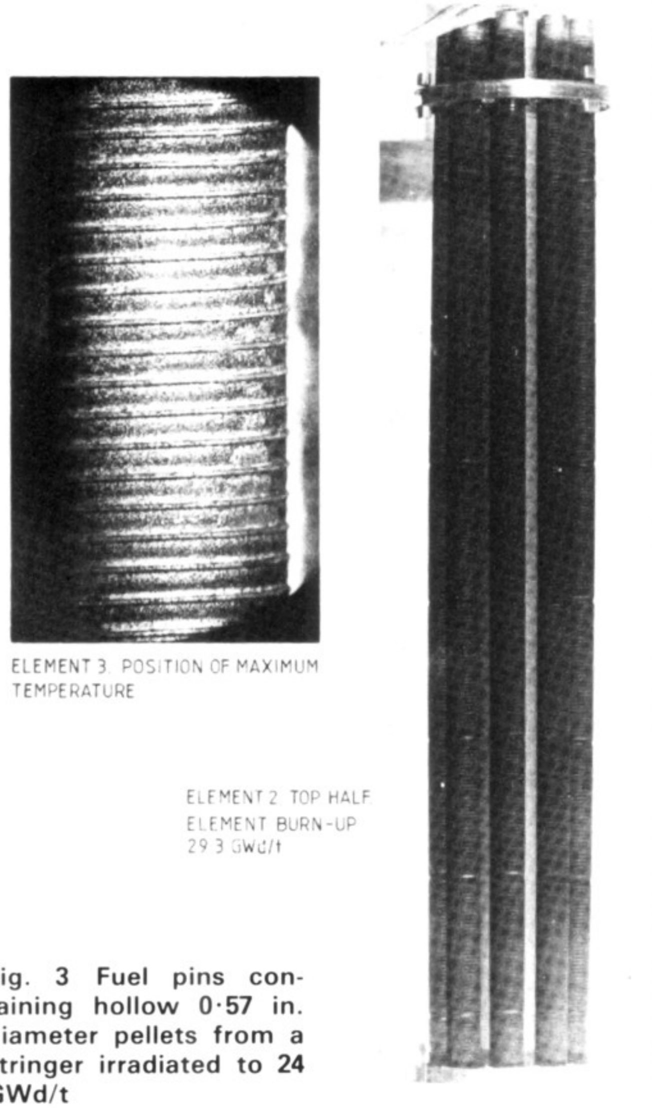

Fig. 3 Fuel pins containing hollow 0·57 in. diameter pellets from a stringer irradiated to 24 GWd/t

The current position in the operating stations sustains this view as the reactors continue to perform well, producing power steadily and reliably. The three lead reactors are approaching a cumulative gross generation of 14 000 GWh, with fuel burn-ups at over 70 per cent of the design target and the stations operating at thermal powers greater than 1 400 MW. Against this background, objectives for forward fuel development have emerged which have been adopted by the industry (CEGB, SSEB, NNC, BNFL and AEA) in a cooperative endeavour and upon whose various contributions this article is based. The available experience suggests fuel is capable of achieving a higher burn-up. Reappraisal of fuel cycle costs since the 18 GWd/te target discharge irradiation was fixed has shown the economic optimum discharge irradiation has risen to between 24 and 30 GWd/te; very considerable savings emerge when such irradiations are achieved. Refuelling has taken place off power whilst fuel sleeve inspection techniques have been developed to ensure the sleeves are capable of accommodating the differential pressures involved in on-power charge/discharge, and the impacts in the handling routes have been characterised. To provide replacement power when an AGR is shut off for refuelling is economically unattractive and the development of fuel that can be handled at as high a power as possible is a second objective of the forward programme.

The AGR fuel pins carry the same ribbed surface as was evolved for WAGR. Considerable experience is now available regarding its manufacture, performance and endurance. However it has been shown that the performance of the fuel element can be improved so that the same gas temperature can be obtained with lower fuel temperatures or to provide an increase in output of 5-10 per cent with the same maximum fuel temperature limitation. This is the third objective. Progress towards achieving the three objectives outlined must of course be made whilst ensuring that the original objective of achieving 18 GWd/te is met in generating board reactors and the demonstrable safety record of AGR fuel is maintained at this high level. Thus the five objectives can be summarised thus:

(i) Maintain safety.
(ii) Confirm 18 GWd/te under power reactor conditions.
(iii) Increased irradiation—target 24-30 GWd/te.
(iv) Handling on power—target 70 per cent or more.
(v) Increased output—target 5-10 per cent extra.

Increased irradiation

Operating limits for AGRs are set so that, in the highly unlikely event of a depressurisation fault, the cladding will be able to contain the fission gas pressure inside the pin. This pin pressure is predicted by a performance code called MINIPAT and in normal operation for the present discharge burn-up the calculated pressures are well below the coolant pressure and there is negligible risk of gas pressure failures, even during a depressurisation fault. However, even though the present margin is considerable, increases in burn-up will potentially reduce it, as will increases in rating, and such advances would clearly be aided if fuel could be developed to retain more fission gas.

The generation and release of fission gas is complex, involving initially diffusion of fission gas atoms within UO_2 leading to the formation and eventual linkage of gas bubbles on grain faces and tunnels on grain edges. This suggests a major rate controlling parameter will be the grain size, and if this could be consistently coarsened without any concomitant deleterious effect, significant reduction in gas release could be achieved.

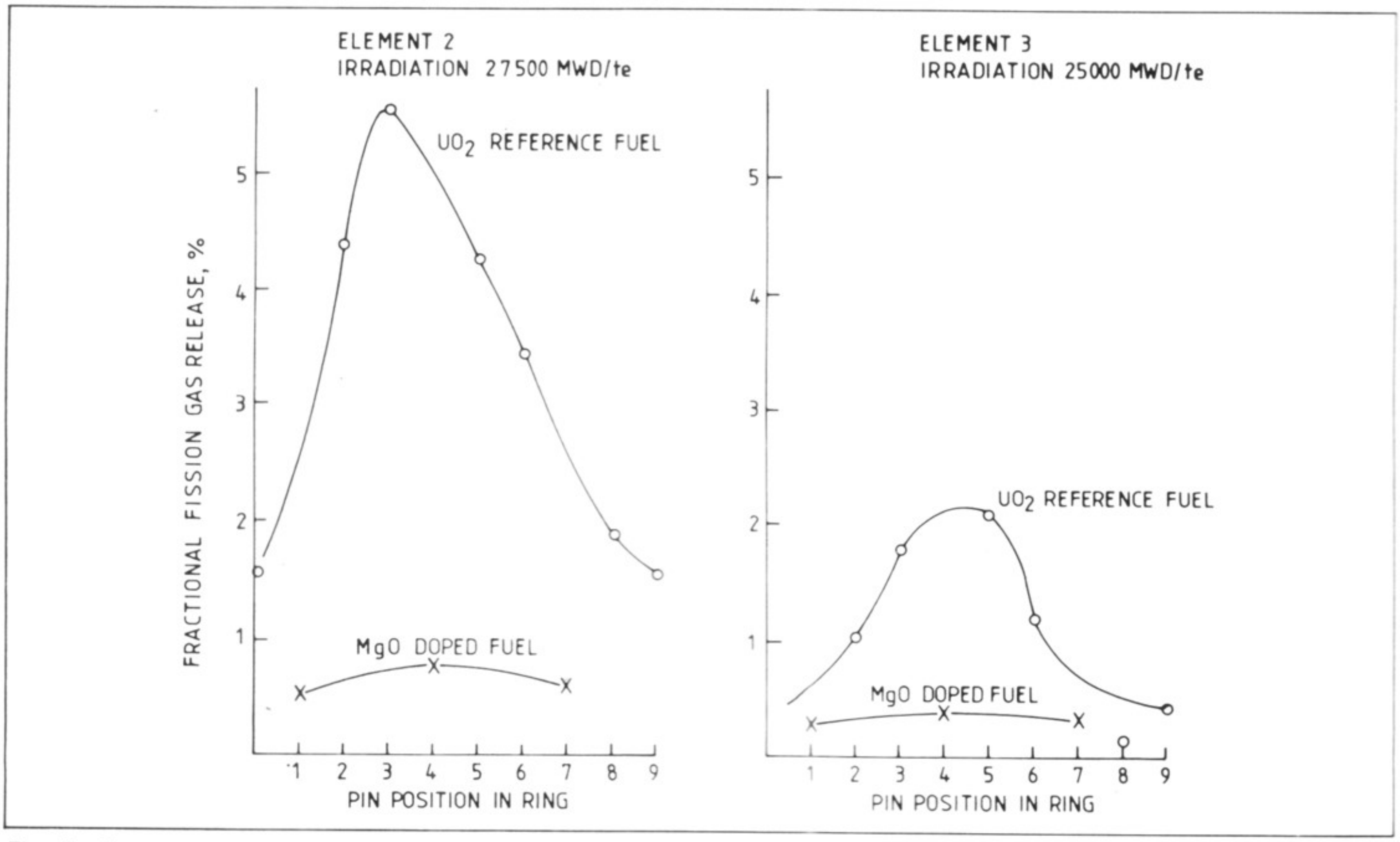

Fig. 4 Variation in fission gas release from pins containing reference and magnesia-doped fuel

A large grain structure can be produced by several techniques, two of which are: a purely thermal treatment in which the grain size is increased by holding sintered pellets at a high temperature; and a method in which grain growth is aided by the use of a dopant added to the UO_2 prior to fabrication which allows the coarsening to be achieved at a lower temperature. These techniques and others have been examined so that their advantages and disadvantages could be determined. The principal dopants which have been used are magnesium oxide, niobium pentoxide and titanium dioxide. Large grain fuels have been subject to laboratory evaluation and included in several series of irradiation experiments, mainly in WAGR but also in materials test reactors and in the SGHWR at Winfrith. In one of the most significant experiments in this series, magnesia-doped fuel with a mean linear intercept grain size of about 35 microns was compared with undoped UO_2 with an initial grain size of about 6 microns. The results at mean irradiations of 27 500 and 25 000 MWd/te(U) for elements 2 and 3 respectively are shown in Fig. 4. Analysis shows the reduction in gas release obtained in the coarser fuel was greater than 2·5 times and was at least the reduction which would be expected theoretically on the basis of grain sizes over the irradiation period. Of the doped fuels tested, the most promising is that incorporating magnesium oxide. The information available on large grain size undoped UO_2 is less extensive and does not extend to such high irradiations, but the results suggest that this fuel may also have the expected degree of improved gas retention. BNFL plan to purchase an intermediate scale production furnace and 50-pin quantities of both high temperature undoped fuel and magnesia-doped fuel have been manufactured for an irradiation experiment in Hinkley Point B which was to be loaded in the last half of 1982.

Cans have been examined after irradiation in WAGR and the operating AGRs, and the surface condition has, if anything, been better than anticipated from out-of-reactor work. However, fuel from the AGRs is obviously not yet available that has operated under design conditions for the current 18 GWd/te cycle life. It is essential that the behaviour evidenced to date is maintained to the current fuel cycle irradiation and the same margin is maintained at any higher burn-up adopted. Oxidation of the cladding results in a loss of section generally and locally, and clad corrosion can lead to spallation of the active oxide either in the primary circuits of the reactor or in the post-irradiation fuel handling route which could produce problems with plant maintenance. Although no such problem has been experienced in AGRs to date, it is prudent to ensure no such problems could arise as the potential of the system is exploited. It is also necessary to protect the moderator; for this purpose the CO_2 coolant contains secondary constituents such as methane, carbon monoxide and water vapour which, depending on their concentration, can lead to radiation-induced carbonaceous deposits forming on the fuel cladding and these can impair the heat transfer characteristics of the surface.

Accordingly, to increase the flexibility of fuel and coolant management schemes, and as a possible requirement for increased fuel life, protective coatings for the fuel cladding have been developed as an insurance measure. A number of coatings produced using sol-gel and vapour deposition processes have been evaluated. One of the better coatings for adoption as a production process is a vapour-deposited silica layer a few microns thick. The effectiveness of the coatings in improving the oxidation behaviour and reducing spallation has been established by an extensive laboratory programme which included assessment of the influence of thermal cycling and mechanical stress. The results of continuing tests at 825°C lasting 15 000 h to date, in which the oxidation of uncoated steel was compared with coated, with daily temperature cycles to 675°C or 275°C, are given in Fig. 5. Data on the influence of coatings on carbonaceous deposition afforded has been obtained using gas loop facilities in the AERE materials test reactors and on full length coated pins irradiated in WAGR and the results are being assessed.

The current fuel pin cladding is 20 wt per cent Cr-25 wt per cent Ni-Nb stabilised steel which has a moderate creep strength and creeps down under the action of the coolant pressure into close contact with the fuel. The cladding was developed for use in reactors operating on base load and under such conditions it is capable of accepting the limited stressing arising from interaction between fuel and clad. However a stronger alloy would allow more flexibility in reactor operation over a longer period and consequently the 'TiN' alloy (20 wt per cent Cr-25 wt per cent Ni-Ti steel nitrided to produce a dispersion of TiN particles) has been developed. Its greater strength will also allow increased irradiations to be considered whilst maintaining fission gas release safety margins. An increase in strength of several orders of magnitude in the steady creep rate is achieved depending on the amount of titanium included. This is achieved with an adequate ductility to failure of about 20 to 30 per cent in the unirradiated condition. A stringer containing fuel pins with TiN cladding has been irradiated to 16·8 GWd/te in WAGR, and other pins were included in loop experiments at AERE and Windscale with standard clad pins. The duration of this WAGR experiment was limited by reactor closure and thus, while not demonstrating fully the advantage of the 'TiN' alloy, it did show that it could accommodate an uprating from 11 to 19 GWd/te under the conditions of the experiment without failure. About 12 stringers, with pins clad in TiN alloy made in a prototype furnace, are currently being irradiated in Hinkley Point B. A full-scale nitriding furnace is currently being commissioned by BNFL.

The differential axial strain which is induced by temperature and power changes is distributed by pressurising the can into grooves—anti-stacking grooves—in the fuel pellets, but the cycling when the AGRs were first commissioned was more severe than originally anticipated and caused axial ratchetting particularly in the top element where cladding temperatures are high and fuel rating and temperature relatively low. This created axial gaps between fuel pellets and immediately below the top end caps into which the end cap bases deformed. Since some of the end caps in this early fuel had an unsatisfactory grain structure, minor cracks and leaks developed, although fission product gas release has been sufficiently small not to be operationally embarrassing. There is also a tendency for the can to be pressurised radially into the inter-pellet gaps, although no failures in power reactors have resulted from this cause. These problems have been reduced very significantly by doubling the end cap base thickness, changing the manufacturing process to avoid large regions of grain growth, including additional grooves in the pellets especially at the pin ends, and increasing as-manufactured fuel pellet density to reduce in-pile densification. These should allow significant increases in fuel irradiation without any ratchetting problems.

It has been emphasised that the conditions under which fuel can be used have to be restricted so that it can be demonstrated that very stringent safety criteria can be met. For instance, one reason for fixing maximum can temperatures and ratings is to ensure the maximum fuel pellet temperature at the bore is such that fission product gas release is limited. As this is very temperature sensitive, close attention has to be paid when introducing a new design for, say, higher burn-up, to ensure these safety criteria are in no way transgressed. The basis of the fuel cycle in AGRs is the decrease in reactivity and rating of the fuel as its irradiation progresses. Clearly, if a fuel pin is to be irradiated to a longer life, the uranium oxide fuel must be more enriched in the U-235 isotope. The rating of such an element initially would be higher than for elements designed for lower burn-ups and bore temperature limits would be exceeded. This can be compensated for by using burnable-poisons using coils of tubing filled with rare earth oxides which have a high thermal neutron absorption cross section initially. These "burnable" poisons disappear at approximately the same rate as the fuel is poisoned by fission products, and temperature limits are maintained. The burnable poison coils are carried in the grids and braces. Prototype designs of these have been endorsed in out-of-reactor tests and two channels of fuel carrying such poisons have been irradiated in Hinkley Point since 1980.

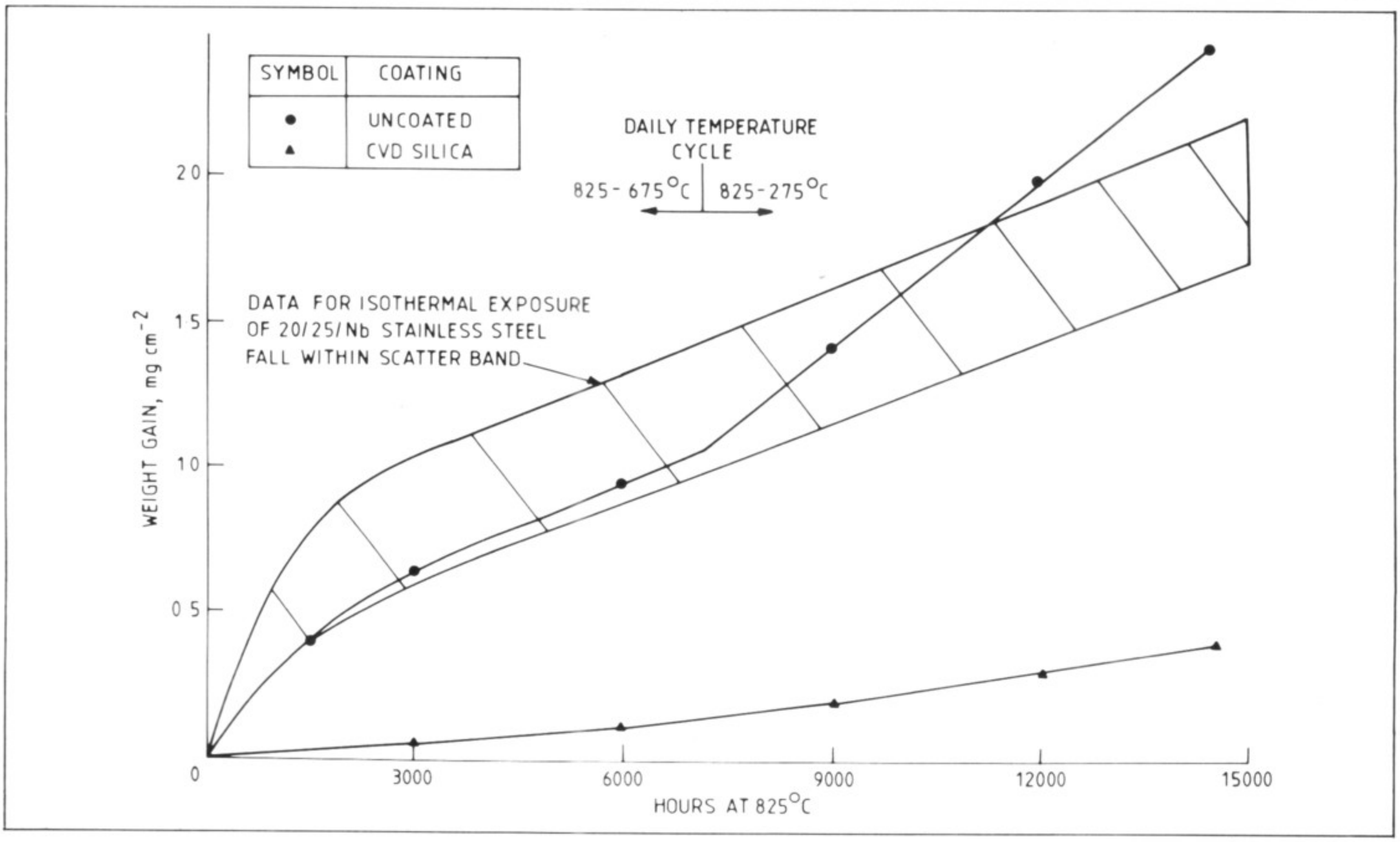

Fig. 5 Reduction by coatings of the extent of oxidation of the 20/25 Nb stainless steel in carbon dioxide at 825°C with daily thermal cycling

Handling on power

The AGR stations have been designed for on-load refuelling. During part of this procedure, the fuel element graphite sleeve is internally pressurised (the reverse of the normal in core conditions) so as to impose significant tensile stresses in the sleeve wall, and can be simultaneously impacted on the charge tube by the buffeting coolant gas. A sleeve failure has occurred at Hinkley Point, in a No. 4 element, which was due to the presence of an undetected axial crack. Inspection techniques, including eddy currents and proof pressure testing (to about three times the working level) have now been developed to eliminate cracks which cannot be detected visually. Taking account of both charging unirradiated and discharging irradiated-fuel, on-load refuelling can now be carried out confidently at low power, and reactor trials are in progress. New element designs and new graphites are being developed to allow refuelling at high power and burn-up.

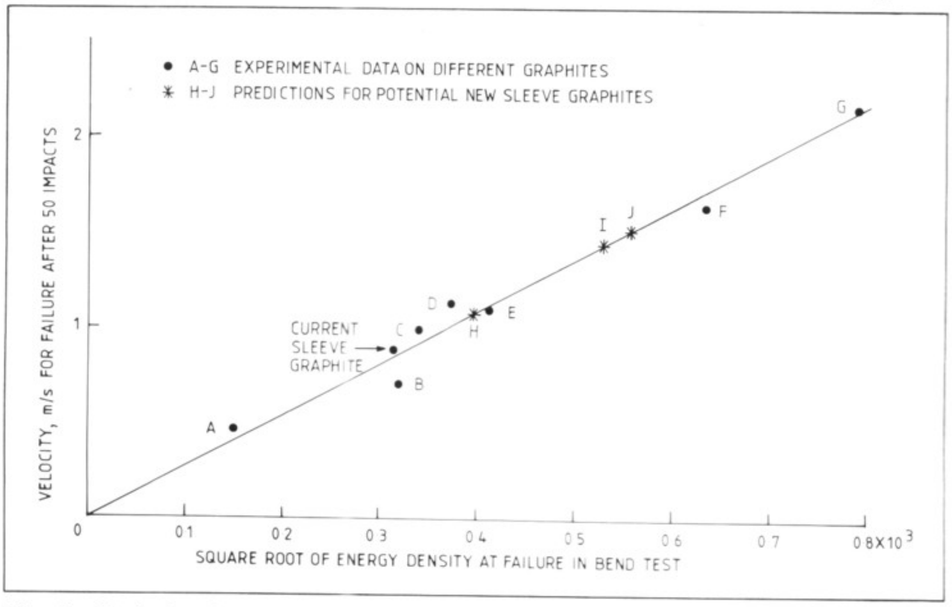

Fig. 6 Relative impact behaviour of different graphites

One of the new fuel designs is based on a single thick graphite sleeve. This will withstand more than twice the differential pressure sustainable by the current sleeve, higher radial impacts, and is more tolerant of any structural imperfections. The adoption of this design necessitates changes to the brace and grid rim structures to facilitate fuel element assembly. The actual refuelling power will be derived from current development work, but is expected to be in excess of 70 per cent depending to some extent on the specific reactor design. To achieve full power fuel handling at irradiations in excess of 24 GWd/te may require stronger graphite materials which have the further advantage of greater dimensional stability. A number of such graphites are compared in Fig. 6, which compares impact and static fracture behaviour and shows the possibility of almost doubling the impact resistance. The use of such graphites is being assessed currently to evaluate whether other properties such as oxidation resistance and permeability are acceptable, and a selection has been made of graphites from which sleeves will be fabricated. The initial results are promising.

Improved performance

It is expected that the developed designs of AGR fuel will employ braces, the edges of which are streamlined. These have been shown to reduce the core pressure drop by about 6 per cent, which can be used to reduce can temperatures by about 20°C or to increase output by about 4 per cent at the same can temperature. Prototype streamlined braces have been included on some elements in current AGRs.

The heat transfer from the current AGR can is enhanced by a single start helically ribbed surface and an option under development to improve the thermal performance has multi-start ribs. This reduces the gas temperature variation across the cluster by several tens of degrees and offers the possibility of further increasing output. The can temperature is also reduced significantly allowing more flexibility in operation. These effects have been demonstrated in rig experiments. The multi-start surface is also more tolerant of any deposition or oxidation on the can and additionally gives a reduced tie bar temperature during discharge on load. The adoption of this type of rib surface will depend in part on the assessment of the results of a 10-stringer irradiation trial which was loaded with the Hunterston B initial charge. So far three stringers have been discharged for examination which have indicated satisfactory behaviour to the irradiations achieved. Their adoption is also dependent on an assessment of factors such as fabrication costs and neutron absorption, which is in progress.

Conclusions

The generally excellent behaviour of fuel in Windscale AGR and the generating board's AGRs has been such that an immediate increase in irradiation can be sought by the use of an increased uranium oxide enrichment coupled with burnable poisons. The inclusion of improved designs in the existing reactors is of course gradual because the fuel is continuously charged and discharged and so the burn-up advantage will similarly be achieved progressively. This limitation does not apply in a new station and the fuel development programme for Heysham II/Torness is aimed at a fuel irradiation capability of between 24 and 30 GWd/te with an element that can be refuelled at high power. The achievement of these two aims of handling at high power and increased life will result in savings of several hundred million pounds over the station lives, and improve the flexibility available to the operators. The developments in the design can yield additional performance advantages. The use of streamlined braces will increase the output from the station as less power will be bypassed to operate the gas circulators. The use of a multi-start can surface would result in further similar gains, and additional margins in fuel operating conditions. Advantage could be taken of these in obtaining a further output increase by using up available margins in the alternators or by making modifications to increase their capacity. The decision whether to include multi-start fuel in the initial charges of Heysham II and Torness will be made at the end of 1982, but it could readily be introduced into the fuel cycle as soon as its potential is confirmed.

The achievement of these various targets as a result of the Heysham II/Torness development programme will allow similar progressive advantage to be taken in the existing AGRs but their full potential will not be realised for some years.

It is predicted that the fuel in the AGRs will certainly achieve its design conditions and will over the next several years yield substantial gains in endurance and performance leading to significant savings in the cost of power generation.

Acknowledgement

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GAS-COOLED REACTORS TODAY

A mass of detailed technical information which has come out of work in support of Britain's lone programme of commercial exploitation of gas-cooled reactors was reported at a major conference in Bristol in September. Simon Rippon, European editor of *Nuclear News*, reports

Gas-cooled reactors have always enjoyed an enthusiastic following and over the years a great many—perhaps too many—very imaginative design concepts have been developed. The international conference organised by the British Nuclear Energy Society in Bristol, from 20 to 24 September, still featured a large number of very interesting conceptual designs as well as providing an opportunity for status reports on the few development programmes which have got as far as experimental or demonstration projects. But another feature of the conference was the reporting of a mass of detailed technical information which has come out of the work in support of Britain's lone programme of commercial exploitation of gas-cooled reactors.

Of these two distinct sides to the meeting the latter, although less glamorous, was probably the more important. While, in their early stages of development, the natural uranium fuelled Magnox and the Advanced Gas-cooled Reactors (AGR) encountered more than their fair share of problems, a lot of the subsequent work has produced encouraging results which have restored confidence that, in the final analysis, these reactors will prove to be very profitable producers of electricity. In particular it now looks as if it will be possible to extend the useful life of the Magnox reactors beyond their twenty-year book life and there are good prospects for realising the full output performance of the AGRs. These successes may have come too late to prevent the change of direction in the country's thermal reactor policy but they are nonetheless very significant since gas-cooled reactors will account for the majority of Britain's nuclear energy production to the turn of the century, at least.

On the other side, the discussion of a multitude of different gas-cooled reactor concepts was certainly fascinating but was also tinged with a sense of unreality, for few of their enthusiastic promoters could put their hands on their hearts and say that they were confident that the system would see commercial exploitation in their lifetimes, if at all. Of course, powerful arguments were presented, notably for the use of gas-cooled reactors beyond the electrical energy sector, and given a change in attitudes towards nuclear energy in general these applications could become very important in the long term.

In a general review of the status of gas-cooled reactors in the UK, Jim Southwood from the National Nuclear Corporation dealt with many of the encouraging developments which had been presented in the detailed technical papers during the conference. He recalled the gas-side corrosion which came as such a blow to the Magnox reactors in 1968 and led to lowering of the operating gas temperature with some consequent downgrading of the power output. The years have shown that this expedient was justified. Corrosion rates have been markedly reduced and the useful operating lives of the early Magnox reactors can now be extended well beyond the original 20-year design life. The discovery more recently of flaws in bellows units in the ducts of a number of Magnox reactors with steel vessels led to shutting down the reactors for extensive investigation using techniques which were not available at the time of manufacture. Again this expeditious action has proved to be a worthwhile exercise because with some remedial action

Hinkley Point B—the new AGRs are proving easy to operate

Favourable trends

"There is a lot to be said for gas-cooled reactors—over 160 papers from nine countries to this conference alone," Dr Tom Marsham, a member of the UKAEA and managing director of the Northern Division, said at the opening session of the conference reported here.

It was true, he said, that only in the UK—despite their worldwide involvement—did gas-cooled reactors represent a substantial and increasing component in commercial nuclear power programmes. First generation Magnox reactors in the UK are where necessary receiving attention to allow their operation to continue beyond their original design lives because of their high reliability and low generation cost; and whatever is decided in the future about the UK nuclear programme, AGR stations now complete and those under construction will, on presently published assessments by UK generating boards, contribute something like four-fifths of the country's nuclear electricity between now and the end of the century and will be the main factor in stabilising electricity prices. "We have all seen the consequences of higher energy costs on prosperity and employment, so our commitment to get the best out of our investment in this technology is complete," said Dr Marsham.

"Experience from the earliest days of our first plant at Calder Hall has been that gas-cooled reactors are based on a very amenable technology," he said. "Even after they are built they respond well to efforts to improve their performance, load factor and particularly their fuel life. I am glad to say that our AGRs are following the same path—a path smoothed by new organisational arrangements coordinating development and technical support for the full range of work from esoteric nuclear aspects to the practical engineering problems of components. This co-ordinated programme covers work carried out by the generating boards, British Nuclear Fuels, NNC and UKAEA, and include a vigorous supporting programme covering realistic longer-term prospects."

The final outcome of the interaction of various factors on generating costs of gas-cooled reactors compared with other systems is unknown, he suggested: "It will depend how effectively the full potential of the different systems in terms of life, reliability and performance can in practice be achieved.

"As a keen sailor and former reactor operator I would like to make a personal unquantifiable point. Certain boats prove in practice to be sea-kindly—they react well to difficult or unexpected conditions. My experience of the different thermal reactors leads me to the view that gas-cooled reactors are operator-kindly, and this must be worth something."

He hoped the conference would answer two questions: first, was the operating experience they had had with gas-cooled reactors encouraging; and secondly, do gas-cooled reactors represent a real option for the future? "I think we will find the answer is 'yes', and if so I think more co-ordination of our efforts is timely." □

and a better appreciation of the extent of the flaws it has been possible to return the reactors to service with satisfactory margins of safety for extending operation beyond the original design lifetime of the plants.

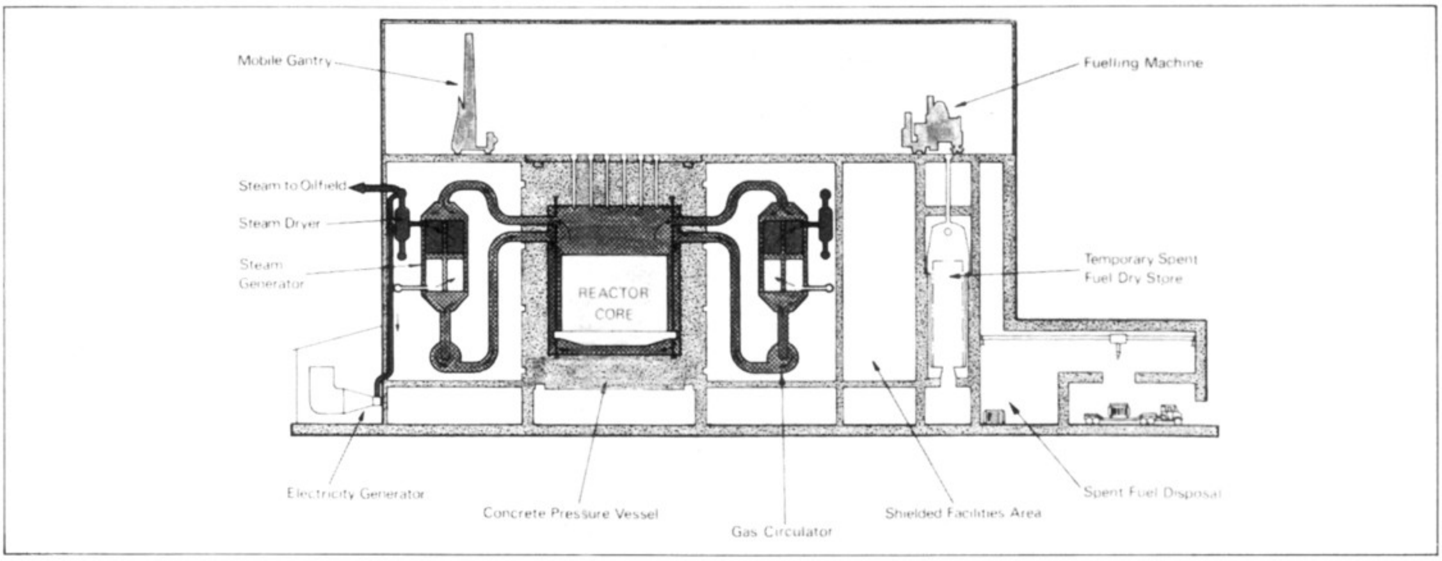
But perhaps the most outstanding success of the Magnox reactors has been the performance of the fuel. When they were first introduced into commercial service the target irradiation limit for the fuel was 3 000 MWd/te but progressive improvements have raised this to 5 500 MWd/te with a consequent large improvement in fuel economy. In some 200 reactor years of operation over a period of twenty years, approximately two million fuel elements have been loaded into Magnox reactors and the failure rate has been less than 0·1 per cent.

Operating experience is now building up with the first two AGR stations at Hinkley Point B and Hunterston and they have shown themselves to be easy plants to operate. The main problem accounting for between 15 and 25 per cent loss of availability has been associated with on-load refuelling. During part of the fuel-charging cycle when the graphite sleeve around the fuel assemblies becomes internally pressurised and when gas buffeting can cause impact on the charge tube, it was found that there was a possibility of fracture of the graphite sleeve which had not been identified during earlier rig testing because the number of tests had been statistically insufficient. The short term solution has been to introduce both eddy-current crack detection techniques and proof pressure testing of the graphite sleeves to eliminate those cracks which were not detected by the previous visual testing. Just before the start of the conference it had been announced that on-load fuelling could now be resumed since all the fuel inspected to the earlier lower standards has now been cycled through the reactors. A longer term solution to eliminate the risk of sleeve fracture during on-load fuelling is a stronger sleeve. This is being achieved with the adoption of stronger graphite and a change from the present double sleeve arrangement with an insulation gap to a single thicker sleeve.

Southwood also reviewed the design and construction progress of the two new AGR stations now being built at Heysham B and Torness while Phillip Warner from Northern Engineering Industries described the very substantial progress that has been made with the increased factory fabrication of components for these reactors. By courtesy of his co-author from Whessoe, Warner was able to show a slide of the first of several 1 000 tonne fabrications—a gas baffle for Heysham—being shipped on a special roll-on/roll-off barge. The journey from Teesside to Heysham—only 80 miles by land but over 1 000 miles by sea—had been successfully completed on the eve of the conference.

Among the crop of new design concepts described at the Bristol conference, not all were in fact so new. Considerable interest has been aroused in the possibility of re-introducing a Magnox reactor based closely on the Oldbury design as a small power reactor that could well meet the needs of developing countries. The work that has been carried out by the National Nuclear Corporation to re-examine and update the Oldbury design was described in a paper by J.O. Joss. Although in its day the Oldbury power station was considered to be large, Joss pointed out the 300 MWe unit size of the individual reactors fell right in the middle of the 200 to 400 MWe ranges used by the International Atomic Energy Agency in market assessment studies of small and medium power reactors for developing countries. It had the virtue of being a successful and very well proven reactor design and with the improvements that have been obtained in fuel performance, it could be economically attractive in the small size range. Examination of the design had shown that with very modest changes it would meet modern safety standards and Joss noted that Magnox reactors able to withstand earthquakes had already been built in Japan and Italy. The design offers the possibility for a reasonably large proportion of local construction work requiring, in the words of Joss: "no more than good quality agricultural engineering". Dry storage of spent fuel is another feature, successfully demonstrated at the Wylfa power station, which could be offered to potential customers in developing countries to eliminate the need for early reprocessing of the Magnox clad fuel.

Another variant on the same theme has evolved from studies undertaken by GEC Energy Systems and Taylor



A cross-section through a conceptual Magnox reactor for oil recovery

Woodrow and described in a paper by P. Dawson. It has been found that not only the size of the Oldbury type Magnox reactors but also the steam conditions it produces are ideally suited to the requirements for steam injection for recovery of very heavy oil reserves. The idea of injecting steam to mobilise heavy—almost solid—oil deposits is well known but the economics of its use are limited to situations where the cost of burning some of the oil produced to generate the required steam does not exceed the value of the residual product. An alternative nuclear heat source could not only make it economical to recover a lot of existing marginal reserves but could lead to more extensive exploration and exploitation in previously rejected regions. In this case, an Oldbury size of reactor with a thermal power of 1 000 MW would be contained in a wire wound pre-stressed concrete pressure vessel, but instead of the integral boiler concept, first introduced at Oldbury, it would use a cluster of 24 rugged boiler units in external circuits around the outside of the concrete vessel. These external boilers are more in line with those currently used for steam injection and would use a once through flow of raw feed water.

At the other end of the spectrum of gas-cooled reactor technology is the high temperature reactor with coated particle ceramic fuel embedded in graphite moderator which is capable of operating with coolant outlet temperatures of nearly 1 000°C. But here too the latest design concepts from Germany are harking back to the early, and very successful, experimental pebble bed reactor—AVR—which has operated at the Jülich research centre since the end of 1967. The idea is a small modular reactor with a thermal power in the range of 250 to 400 MW which could be incorporated in a narrow steel pressure vessel not much bigger than the one used for the original AVR with its thermal power of 50 MW. One of the virtues of the tall narrow configuration for the novel pebble bed type of reactor core, is the fact that adequate control can be provided without the need for control rods to be inserted directly into the core but only in the surrounding graphite reflector. The concept has also been shown to have great inherent safety with the ability to deal with complete loss of power for forced coolant circulation and it is thought to be suitable for siting close to an industrial complex.

This modular concept of high temperature gas-cooled reactor was featured in a number of papers by German authors at the conference. Two similar versions have been developed by design teams at Hochtemperatur Reaktorbau, the company led by Brown Boveri, and Hochtemperaturreaktortechnik (GHT) which is a subsidiary of Kraftwerk Union. They are envisaged in a number of different configurations either with integral steam generators for electricity or process steam production or with associated modules in connected steel vessels. One such module is a steam reforming unit suitable for production of synthesis gas—a mixture of carbon monoxide and hydrogen which is a chemical feed material for many processes including the production of the secondary fuel, methanol. An alternative module could contain a helium-to-helium intermediate heat exchanger which would be used to supply energy to a natural gas cracking unit or for processing the products of hydrogasification of lignite. The sort of industrial applications that are being considered would make use of four or more modular reactor units linked to processing modules all contained in concrete vaults in a single containment building.

Interest still persists in the larger high temperature gas-cooled reactor concepts in sizes up to 1 000 MWe using either the German pebble bed core or the prismatic block design developed in the US. Operating experience was reported to the conference from the 330 MWe demonstration plant at Fort St Vrain in the US which, after early difficulties, has now been operated up to its full power level. There was less to report on the German THTR 300 which has been suffering from protracted delays, mainly due to licensing procedures, and is currently at the centre of a major political struggle for funding to meet the increased cost of completion. In the final panel discussion at the conference, Derek Griffith from the US Department of Energy and Peter Engelmann from the Jülich centre in Germany both conceded that they could no longer make a case for government support to launch a large HTGR system purely for electricity production in competition with the well established and, in their view, perfectly satisfactory light water reactors.

Nonetheless, Griffith reported that the US Congress had voted funding for 1983 in support of the HTGR development programme and the intention was to seek continued funding in the 1984 budget. But the emphasis has switched to potential multi-purpose applications. The latest studies have identified 19 locations in the US where there is a requirement for more than 4 million lb/hr of process steam within a ten mile radius which could conceivably be supplied by an HTGR with a thermal power of 1 750 MW, and a substantially larger number of potential locations for co-generation of process steam and electricity. But while there may be prospects on paper for large HTGRs supplying industrial complexes in the US, there is also considerable interest in the small modular concept from Germany. Griffith said that a preconceptual design had been developed for preliminary economic comparisons and these had shown that the trade-off of availability against higher capital costs could be favourable if the target costs can be achieved. □

Fifty years of the neutron

Sir James Chadwick's epochal paper describing his discovery of the neutron, published in the *Proceedings* of the Royal Society in May 1932, was "the essence of lucidity, economy of phrase, and modesty . . . illustrated by very primitive looking diagrams." But the consequences of that discovery have been tremendous.

Lord Sherfield, who as Sir Roger Makins was chairman of the UKAEA from 1960 to 1964, recalled some of the history of the man and of his discovery when he opened a five-day conference in Cambridge in September called to mark the "50th anniversary of the neutron."

The immediate result of Chadwick's discovery was to put particle physics back on the beam. It completed the picture of nuclear structure which, all subsequent refinements notwithstanding, is still broadly accepted. This in turn led to the many advances in nuclear physics between 1932 and the outbreak of the Second World War, and in particular to the understanding of atomic fission.

Lord Sherfield noted that in 1939 Chadwick, who was by then Professor of Physics at Liverpool University, drew the Government's attention to the possible use of fast neutrons for military purposes. He was made an original member of the Maud Committee, which reported to the Government on the feasibility of an atomic weapon, and he organised important work at Liverpool on fission cross-sections in support of the enquiry.

"The outbreak of war had made it inevitable that the emphasis should be on the military rather than on the civil applications of neutron physics," he said. "But it should never be forgotten that the Maud Committee's report was in two parts, one dealing with military and the other with civil uses, and that the distinction between them was sharply drawn at the outset of the nuclear age.

"The nuclear industry, civil and military, is the most far-reaching consequence of Chadwick's discovery. But the discovery also led not only to important advances in fundamental physics, nuclear and astro-physics, but also to major developments in the study of the physics of the solid state and the properties of materials. For this purpose a high-flux reactor now operates at Grenoble and, in the UK, a Spallation Neutron Source is being built at the Rutherford Appleton laboratory. Applied neutron physics has contributed to advances in many branches of science and technology and has led to neutron therapy in medicine, which held a particular interest for Chadwick."

Neutron, *n.*—An elementary particle with mass of 1 AMU (approximately $1{\cdot}67 \times 10^{-27}$kg), about the same as that of the proton. Together with protons, neutrons form the nuclei of all atoms. Being neutral, a neutron can approach a nucleus without being deflected by its positive electric field and can therefore take part in many types of nuclear interaction . . .

The wide ramifications of the discovery were well illustrated in the "crowded" programme of the conference, said Lord Sherfield. "It is given to few men to inaugurate a new branch of science."

Reflections

He offered four personal reflections on the past fifty years' advances in the physical sciences—not all directly connected with Chadwick's work.

- The first was that Chadwick's discovery was a classic example of the value of pure basic research, and it was salutary to be reminded of this. "Today great emphasis is placed on the demands of the customer, whether it is a government department or the manager of an industrial concern, who is naturally looking to his own immediate need in applied research and technology. With the shortage of funds at the disposal of the universities and the research councils there is a real danger that, with the pressure to meet short-term objectives, basic long-term research will be starved of resources, and also that branches of science and technology not immediately popular or in current demand will be neglected or fall between particular departmental interests. This is a matter which needs constant vigilance within the scientific community, and an intelligent understanding on the part of government."
- Secondly, C.P. Snow's theory of the two cultures "in my experience . . . has been proved a misconceived and misleading generalisation. I have never found any lack of appreciation and understanding of the humanities among scientists, and I have been immensely impressed by the way in which my own scientific mentors, beginning with Chadwick and Cockcroft, have been able to communicate the essential basic scientific concepts and information to a scientific illiterate like myself.

"The boot may indeed be somewhat on the other foot; and perhaps there is a reluctance on the part of some arts graduates to try to understand science and the scientific point of view."

- "However, my third reflection is that, looking back over the last half century, there has been—there still is—a discontinuity, not between C.P. Snow's two cultures, but rather between the scientific community and the political arena: in two words, between science and government. After all, when Snow finally arrived in the corridors of power he soon lost his way. There has been a similar, though lessening, gap between the scientists in the universities and British industry. In this context I speak not just about science, but about science and technology, including engineering."

History in persons: from the left, Prof. E.T.S. Walton, Prof. E. Amaldi, Prof. W.E Burcham, Dr J.A. Ratcliffe, Dr M. Goldhaber, Lord Sherfield, Sir Harry Massey, Sir R. Peierls and Sir Denys Wilkinson

It is a truism, said Lord Sherfield, that the speed of scientific and technological advance in the last few decades has outpaced the capacity of the average citizen to absorb it, and that in consequence a reaction has developed against certain effects of science and technology and even against the scientist as such.

"The outstanding example of this lies in the nuclear field," he said. "It is an international misfortune that the military applications of nuclear fission preceded its civil use. If the electron is now accepted as man's best friend since the horse, the neutron has given applied nuclear physics a bad name. There has been almost universal failure in the public mind to distinguish, as scientists did from the outset, between the sinister and the beneficent uses of the neutron. This has consequences which may prove to be very serious for future generations in the energy field, and in other fields too if, to take one example, the so-called 'greenhouse effect' proves to be a global hazard."

- His fourth reflection was concerned with what could be done to bring the scientist and engineer more directly into politics—the policy and decision-making process. The organisation by which scientific and technological advice can be fed into the machinery of government has been the subject of long debate. "It is not a subject on which to dogmatise," said Lord Sherfield. "The organisation has to suit the personalities and views of the government of the day and its principal advisers. But it is of the highest importance that the solution satisfies the scientific community as well as the administration. Otherwise the public interest in matters vital to the welfare of future generations may be lost in the welter of public debate. This is too often emotional and ill-informed, and needs strong and authoritative guidance which can finally only come from a well-informed government."

The first stages of the civil and military nuclear programmes were an outstanding success. "But then, alas! dither and indecision took over on the civil side and the lead in nuclear technology which we had established has been lost. Now the issues are squarely in the political arena. If Chadwick has been watching from some galactic vantage point a few of the recent antics, he will, I believe, have regarded them with a pretty jaundiced eye."

Lord Sherfield returned in conclusion to the man and his discovery. "There is in the archives of the Royal Hammersmith Hospital a manuscript note by Chadwick on his discovery," he said. "In it he reproaches himself for not finding the solution earlier. 'I had failed', he wrote, 'to think deeply enough about those properties of the neutron which would furnish evidence of its existence. . . . I console myself,' he goes on, 'with the reflection that it is much more difficult to say the first word on any subject, however obvious it may later appear, than the last word—a commonplace observation, and perhaps only an excuse'.

"Such objectivity and self-criticism are the marks of a great scientist. Today, we salute his memory." □

The formation of public attitudes to nuclear power

The media have caused the nuclear industry a great deal of difficulty and involved them—and hence the public—in a great deal of additional expense. But it is not all their fault.

Sir John Hill, FRS, chairman of British Nuclear Fuels Ltd, noted in a paper presented at the Uranium Institute annual symposium in London in September that while it has always been the role of the universities to question "conventional wisdom" and suggest alternative solutions, changes in public attitudes in recent years have led the media also to adopt this questioning approach to a much greater extent than hitherto. "From many points of view this can be seen as a proper extension of the education of the public, and as such is entirely to be welcomed," he said. "The question we have to ask, however, is whether this objective is being achieved or whether the public's appetite for drama and excitement, and the extent to which writers and producers bend to these populist pressures, result in the system failing to do what it set out to do and the public, far from being educated, are being misinformed.

Sir John

"In some fields the record is very good. In others it leaves much to be desired. Let me give one example, I think it would be generally accepted although it is not invariably true that doctors know more about medicine and pilots know more about flying and geologists know more about the rocks than the average man in the street. By analogy I would think it fair to claim that those who are professionals in the field of safety and have spent their professional lives studying hazards and risks to the public should, in general, be better able to judge what is safe and what is not than those who have not been so trained or applied themselves to this particular science or discipline."

Study and analysis enable the professional safety analyst to predict with reasonable, but not absolute, accuracy the frequency with which accidents of any particular type are likely to happen and the probable consequences of these accidents when they occur, said Sir John. It also enables him to point to the most important areas where additional care or tighter procedures or duplication of equipment can be expected to be most effective in reducing the frequency or the severity of accidents in the future.

"These people both in this country or abroad do not rate nuclear power as a hazardous industry either to the employees or to the public," he said. "They know as well as anybody that accidents can and do happen but their judgment is that nuclear power for electricity generation can be regarded as a safe industry. The regulatory authorities who are themselves safety analysts or at least have immediate dialogue with them, set operating standards for nuclear plant at a level that will ensure that the nuclear industry is bracketed with other 'safe' industries from the point of view of the workforce. As far as the public is concerned they are satisfied that nuclear power is 'as safe or safer than the other methods available for generating the electricity we require'."

The public, however, does take a different view. Sir John recalled that in an analysis carried out in the United States thirty different hazards to life from smoking to spray cans were tabulated according to the best statistical evidence, in decreasing order of importance. Three separate groups of people from different walks of American society were then asked to put the same hazards in the order of importance they attributed to them.

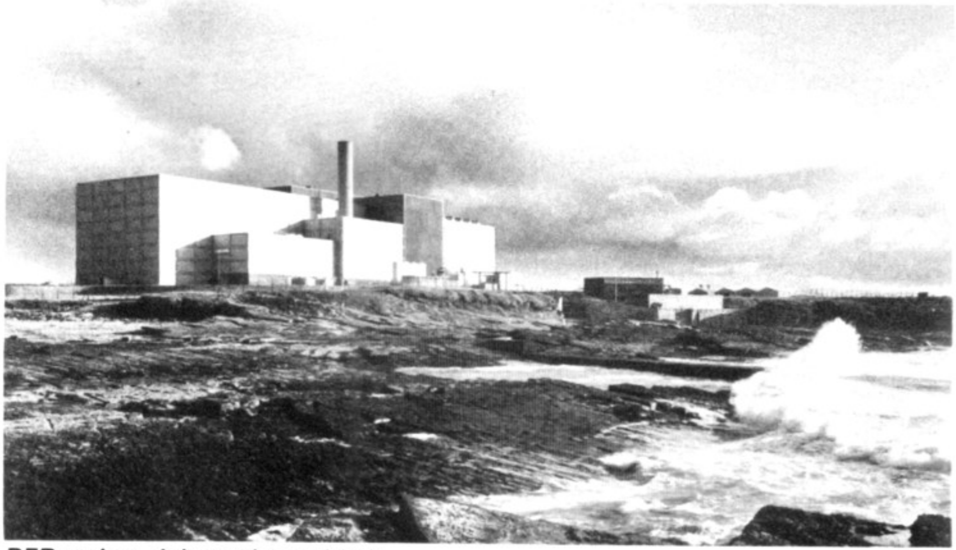
"Of the hazards that the public were able to judge on their own account—motor vehicles, handguns, power mowers—their guess as to importance accorded well with the statistical evidence," Sir John reported. "In other areas, where the public is in no position to use its own common sense to judge importance—nuclear power and aerosol sprays—the public perception bore no relation to the statistical facts.

"The degree of inaccuracy is disturbing. The groups of the public . . . were over-estimating the risks of nuclear power by factors in excess of 10 000 to 1: a figure that would be much greater still if uranium mining were excluded [from the statistical base]. Some other hazards such as the use of pesticides and aerosol sprays are similarly over-estimated by very large factors.

"We would be concerned if our children came back from school convinced that the great ice age finished about a year ago or the world was only a mile in diameter, and yet this is what a factor of 10 000 means. Those who have been involved in creating these public attitudes to nuclear power in the United States should be concerned that as a result of their efforts there is this vast gulf between the public perception of nuclear safety and the best statistical information that is available. There is also the same gulf between public attitudes and the view of the professional safety analyst."

Sir John said he did not think the British public took such an extreme view as he had quoted. "Nevertheless, I am sure it is true that a significant proportion of the British public, and women in particular, are very much—and I mean very much—more frightened about the effects and potential effects of nuclear power than those who have spent their professional careers studying public safety in general and nuclear safety in particular."

It is not only in nuclear power that there are such distortions, he acknowledged. The public greatly under-estimates the risks of diabetes, heart disease and smoking, and over-estimates the risks of genetic engineering and new drugs. "The public attributes a much higher risk to things that have been drawn to their attention recently than things they have heard about in the past. These factors are characteristics of the public, and not the media. But their effect is that if some new risk is brought to public attention, even if the risk is described with *perfect objectivity*—not an easy task at any time—the public will over-estimate the risk because it is new, because it has been brought to their attention, and they have no first-hand experience to form their own judgment."



PFR: what risk to the public?

Sir John continued: "There can be no doubt that in many countries and particularly the United States and Germany public concern about the safety of nuclear power has prevented rational decision-making in the industry. In Britain it has forced Governments to agree to a public inquiry procedure which is extremely slow and time-consuming. Public concern has resulted in the costs of the nuclear industry and hence the cost of electricity to the consumer being higher than is necessary or would result from more objective decision-making.

"Perhaps the passage of time will apply its own correction. Certainly, the public will not remain frightened forever unless the nuclear industry actually does them some harm. We must work meticulously to ensure that we do not have an accident that harms the public. We must not relax our vigilance. Of course there will be minor abnormalities, small accidents, and near-misses. Nothing in this world is perfect and no industry can operate without something going wrong. We must hope that these inevitable difficulties will be reported objectively.

"The nuclear industry must realise that once the outside world gets an interest in some incident the truth will come out, and it is better for it to come out cleanly than be dragged out after what will be seen as a cover-up. Our handling of the dissemination of information by the nuclear industry at the time of an incident has not in general been good and we must do better. The nuclear industry must act with complete integrity at all times. The penalty of the unearthing of anything that can be described as a cover-up is immense in public relations terms. To the media, I would ask that they should obey the same rules and be strictly objective.

"The misunderstanding of the public about the real issues in nuclear power at least in this country stem in part from the weapons history of the industry, in part from the public's dislike of bigness intruding on the countryside, in part from the argument that if there is that amount of energy in a piece of uranium it would do an awful lot of damage if it got out of control.

"Finally, it must be said that a small number of people have not acted with the integrity of their colleagues and have used the tricks of editing or of the cutting room to replace the integrity of genuine research. Their tactics are well-known: the hypothetical question to get the opposite reply to that intended, the deliberate omission of very relevant information, one side always being given the last word and the 'mole' being accorded unjustified high status. . . . Fortunately, people who do these things are few in number and no walk of life is free of those who let you down. Discipline imposed by colleagues is the most effective remedy.

"I believe that the very nature of a free society will, from time to time, result in the public getting a distorted view of some issues even with the highest standards of integrity in the media. That a balanced view will eventually emerge I have no doubt. The practical difficulty is that until this balanced view is widely accepted the industry will operate in a more difficult environment and thus less effectively than it should.

"I think if I could make one request to the media it is that we should not be over-exposed by comparison with other industrial activities. This in no way implies concealment, but only that the public should not be deluged by the nuclear safety debate which can only unsettle the public even if the safety case is rock solid and the reporting totally objective." □

Peaceful nuclear uses and nuclear weapons

Confusion exists and is growing in the public mind between peaceful nuclear uses and nuclear weapons. This is not surprising in light of the fact that the opposition to nuclear weapons is generally described as "anti-nuclear." The important question to ask is, "Anti-nuclear what?" Is it anti-nuclear weapons, anti-nuclear power, anti-nuclear medicine, or anti-nuclear agricultural and industrial uses?

This confusion undermines the Non-proliferation Treaty (NPT), first signed in 1968 and now concurred in by 116 nations. This Treaty specifically endorses peaceful uses of nuclear energy provided they are conducted under the safeguards of the International Atomic Energy Agency (IAEA), and any movement that tends to cast doubt on the legitimacy of nuclear power undermines the Treaty's fundamental basis.

The essence of the bargain struck in the Treaty is that non-nuclear weapons states agree to forgo nuclear weapons in return for two undertakings by nuclear weapons states. The first undertaking is to make real progress in arms control negotiations. The second, consistent with the Treaty's call for restraint in the development of nuclear weapons, is to cooperate with the non-weapons states in making available the peaceful uses of nuclear energy, with due consideration to the needs of the developing countries.

The ANS Board of Directors in its meeting on June 10, 1982, restated its support for the Non-proliferation Treaty, including effective measures to control and reduce nuclear armaments while making the peaceful nuclear benefits accessible to all peoples of the world.

President Kennedy used to speak fearfully of the prospect that a President of the United States in the 1980s might have to face a world in which as many as 25 nations would have nuclear weapons. That this gloomy prospect has not materialized is attributable in large part to the NPT and to the work of the IAEA.

An attempt to link nuclear weapons and nuclear peaceful uses is based upon the assumption that there are no effective barriers or controls to assure that materials used in the peaceful programs are not diverted to military purposes. Quite the contrary is the case. The control of peaceful nuclear materials is approached with increasingly sophisticated safeguards techniques and physical security. Institutional protections, including IAEA inspections, are in place, and additional arrangements will be added as they are needed for the enjoyment of peaceful nuclear uses.

Countries that have developed nuclear weapons to date have not done so through materials produced in a peaceful nuclear power program. The clear lesson of this is that we cannot eliminate the risk of proliferation by eliminating nuclear power. On the contrary, if we eliminate nuclear power, we lose an important means of persuading countries to confine their nuclear activities to peaceful purposes.

This statement by L. Manning Muntzing, President of the American Nuclear Society, appeared in the August 1982 issue of *Nuclear News*, the journal of the ANS, whose permission to reprint it here is gratefully acknowledged.

A fundamental point that must be kept in mind is that the most important step to peace and stability throughout the world is to remove the motivation for war. One such possible motivation stems from the fact that nature did not distribute oil, gas, coal, or uranium evenly around the world. Most nations do not have sufficient energy sources of their own. One of the ways to remove this motivation for war is to have assured supplies of energy. Nuclear power, rather than being a contributor to war, will help to achieve peace through providing energy to resource-deficient countries.

This leads to two fundamental conclusions. First, a good bargain has been reached in the world between nuclear weapons nations and non-weapons nations: namely, that nuclear weapons are to be controlled and reduced while nations receive peaceful nuclear benefits. It is the renowned concept of "swords into plowshares." Second, peaceful nuclear benefits can help remove one of the motivations for war and be a force for nuclear weapons control. The anti-nuclear weapons forces should be in the forefront of advocating peaceful nuclear uses, and the supporters of peaceful uses should look to controls and reductions of nuclear arsenals. □

IEA review World Energy Outlook

Today's surplus in the world oil market conceals underlying medium- and long-term trends, the Secretariat of the International Energy Agency conclude in their second *World Energy Outlook*.

The report says energy markets and the oil market in particular are likely to remain deceptively stable through the mid-1980s, but the results of the IEA's projections all point to a tightening in the oil market later in the decade.

The IEA suggests in the report, published in Paris on 12 October, that market forces and the price mechanism should be used to their full extent and supplemented where necessary to check underlying energy demand trends and to encourage domestic energy production. Continued energy efficiency gains at the end-use level must be achieved by both appropriate pricing policies and government action to remove institutional barriers to the normal play of market forces in the energy sector; and prices and price differentials between fuels must be allowed to play their role in inter-fuel substitution.

"Further penetration of electricity should be recognised as one of the major avenues for the use of non-oil fuels, and utilities should be encouraged to invest in new non-oil based generation capacity," the IEA says. "To widen the scope for public acceptance of nuclear power satisfactory schemes for final disposal of radioactive waste should be elaborated and implemented as quickly as possible. The outlook for investment in nuclear power plants must be improved by rationalising licensing systems to shorten costly lead-times."

The IEA suggests that to ensure sustainable conditions for the greater use of natural gas careful attention must be given to the issues of price and security of supply. Gas prices should reflect the cost of production, and be competitive in consumer markets.

Coal, the Agency says, should receive particular attention as an effective substitute for oil through policies that encourage conversion to coal and at the same time development of production capacity and transport infrastructure.

Scenarios

Using a number of assumptions, scenarios developed by the IEA secretariat foreshadow slackening overall energy demand together with relatively high levels of domestic oil production contributing to a decline in OECD oil import demand over the next few years. Therefore, the IEA says, increased oil demand expected from OPEC and other developing countries is likely to be absorbed by the oil market without major strains in the short term.

However, the *World Energy Outlook* projections show that from the mid-1980s onward the oil market is likely to move into disequilibrium as growing oil demand, especially in OPEC and other developing countries, runs up against falling production in North America, the North Sea, the Soviet Union and reduced exports from some OPEC countries. If these developments occur, together with limited progress in substituting other fuels for oil, then the stage could be set for renewed erratic oil price movements. The *World Energy Outlook* reiterates that unpredictable events in the Middle East remain a major risk that could precipitate another oil price "shock", especially in a finely balanced oil market.

In the shorter term, the report indicates that energy and oil prices may decrease significantly in real terms during the balance of 1982 and in 1983. There is however a danger that falling oil prices will send misleading signals to those involved in the energy market, resulting in complacency among consumers and hesitancy among investors. As a result, actions necessary to overcome difficulties foreseen for the late 1980s and the 1990s may not be taken in time.

To avoid this, the study underlines the necessity for a concerted effort by governments and the private sector to continue the movement toward a more balanced structure of energy supply and demand in which the share of imported oil is reduced and other fuels are made available to replace it.

The analysis contained in the *World Energy Outlook* points to a number of trends: among them, a continuing dependency in OECD countries on imported oil, with imports expected to range around 21 million barrels a day over most of the 1980s. Thereafter, they could range as high as 30 mbd or as low as 17 mbd by 2000. The share of natural gas in total energy use is unlikely to grow over the next 20 years beyond its current 20 per cent level; with the existing price advantage of coal over oil, the share of coal is projected to grow from 21 per cent to 30 per cent of OECD primary energy requirements.

By the year 2000, nuclear energy might reach a 10 to 11 per cent share in OECD total energy production, providing nuclear capacity grows from its present 120 GWe to at least 400 GWe. Other energy sources, including hydroelectricity, are estimated to cover no more than 10 per cent of projected energy demand by 2000—a figure more than twice present levels.

The *World Energy Outlook* is available from the IEA and OECD sales agents including HMSO. □

Oil from the North Sea: production will eventually fall

Energy saving exhibition

British industry and commerce is wasting more than £3 billion a year on unnecessary energy bills: savings could contribute noticeably to improving Britain's economic performance in increasingly competitive world markets.

This is the message of an exhibition entitled 'Energy conservation—design for efficiency' at the London Design Centre in October and November. The exhibition will be staged at the Industrial and Maritime Museum in Swansea from 9 December to 15 January, then at the Glasgow Design Centre from 3 February to 5 March.

Studies carried out during the past seven years have indicated that the practical potential for energy savings in industry is about 30 per cent of total consumption, and that some 45 per cent of the energy costs associated with offices and other commercial and public buildings could be saved. Improvements in the energy efficiency of building and industrial processes can often pay for themselves in two or three years.

The Design Council exhibition covers a wide range of energy saving developments from the use of sewage-generated methane gas in a diesel-engined lorry and the computer control of complete building services to a variety of methods of drying everything from glued furniture joints to printing inks. □

NERC ANNUAL REPORT

Geological research halt "regrettable"

The Government's decision to stop geological field work on the assessment of the feasibility of deep geological disposal for highly radioactive waste was "regrettable but understandable", Sir Hermann Bondi, chairman of the Natural Environment Research Council (NERC), told journalists at a press conference held to present the Council's annual report on 26 October.

Up to a few weeks before the decision the Council had been recruiting scientists into the geological group and had brought together a "most excellent team". Sir Hermann regretted that although none of the scientists had become redundant some had decided to go elsewhere.

He said only part of NERC's research into the disposal of highly active waste had been concerned with the land burial option; there had been no change of policy and no lessening of financial support for work on the feasibility of disposal on or under the sea bed.

Sir Hermann said that the Government announcement referred to two factors. One was advice that radioactive waste should be stored for up to 50 years before disposal and the other was the volume of work being done in other countries. Clearly, the longer the waste was stored on the surface the less urgency there was for a decision. More time would be available to get the information relevant to a final decision; but a scientist could never get enough information, certainly never too much, and regretted any delay in the process of finding out. In politics and particularly if matters that upset some parts of the electorate did not have to be brought to a conclusion in a hurry, then there was no requirement to do things before they were necessary.

"For us who had been doing this work at the high volume asked of us the decision creates management problems," said Sir Hermann. "It is always a pity when work which is not only useful but also of great scientific interest has to be stopped, so you cannot expect us to cheer. The work was of great interest: for example, the migration of liquids in rocks is something we would want to study anyway."

He said the Council attracted the finest scientists because it offered a stimulating intellectual atmosphere, a stimulating field of work and whatever financial support was necessary. Although good scientists would always have plenty of work to do people of high quality had decided to leave NERC and that was to be regretted.

The annual report showed that in 1981-82 NERC's net expenditure was £83·5 million of which £54·4 million was funded by the Science Budget administered through the Department of Education and Science, and £29·1 million from commissioned research.

The Natural Environment Research Council report for 1981-82 is available through HMSO, price £4·25; ISSN 0072 7008. □

Government "welcomes" inquiry examination

The Government welcomes the examination of the issues which is to take place at the Sizewell Inquiry, which starts next month, the Department of Energy said in a proof of evidence published in October.

The Department's statement notes that as with other fuels the Government's objectives for electricity are that there should be secure supplies, provided to the consumer at the lowest possible cost.

"The Government's approach to achieving these objectives differs in some respects from its approach to the other energy industries," the Department says. "With electricity it is more difficult—and will continue to be so—to sell surpluses, or make good shortfalls in supply, since the scope for international trade is limited to sales through interconnectors between adjacent national grids; and there are a number of uses where electricity is not interchangeable with other fuels."

The proof of evidence recalls that the CEGB have a statutory duty ". . . to develop and maintain an efficient, co-ordinated and economical system of supply of electricity in bulk for all parts of England and Wales . . .". So too does the Government in considering the industry's capital programme.

Against this background, the Department says, the Government seeks to ensure that the electricity supply industry makes as thorough and realistic an appraisal of future demand as possible; that its plans offer the prospect of meeting that demand as economically as possible while assuring security of supply and making an adequate return on investment; and that public expenditure considerations are properly taken into account.

"The energy crises of the last ten years have shown the danger of over-dependence on one fuel, and the wisdom of a sensible degree of diversity of supply," says the proof of evidence. "Despite considerable research work in the UK and internationally on alternative and/or renewable sources of energy, on fast reactors, and on nuclear fusion, and the Government encouragement of increased private generation and economic combined heat and power schemes, the Government considers that the only available and economic options for new secure base-load generating capacity at present are coal-fired or thermal nuclear power generation.

"In 1981-82, 83 per cent of the CEGB's generation was from coal—which also dominated base-load generation. By comparison nuclear accounted for some 12 per cent. The nuclear output will increase, probably to around 20 per cent, when those nuclear stations now under construction are fully commissioned. However, unless new stations are ordered in the 1980s the nuclear power component will progressively decline as older nuclear stations are retired."

As was made clear in the 1981 White Paper on Nuclear Power (Cmnd.8317, published in July 1981), the Government considers it prudent for the UK to have a range of supply options, the proof of evidence says. "In this context it sees an important and necessary role for nuclear power which will develop in the years ahead as older electricity generating plant is retired. The Government accordingly expects the electricity supply industry to pay due regard in its planning to the need for diversity and security in supply, including an appropriate nuclear component.

"Nuclear power has the potential to produce electricity more cheaply than fossil fuels provided that new power stations can be built to time and cost. This is of importance, not only to individual electricity consumers but—through its influence on industrial competitiveness—to the economy as a whole.

"Safety is paramount. The operational responsibility rests with the CEGB. It is the responsibility of the Nuclear Installations Inspectorate as part of the Health and Safety Executive to decide whether or not a new power station has been designed and built to the necessary standards and can be operated safely.

"Government policy is to encourage the electricity industry to ensure that there is a reliable, safe and cost-effective reactor system available for ordering as necessary. In 1977, the CEGB declared its intention of establishing the PWR as a valid option; this intention was endorsed by the previous administration; and the present Government, in confirming its agreement to this in 1979, took the view that subject to the necessary consents and safety clearances, a PWR should be the next nuclear power station order.

"This general statement of policy in no way pre-empts the particular decision on the proposed Sizewell B power station."

The proof of evidence is supported by projections exploring a "reasonably" wide range of possible developments in the UK energy demand into the first decade of the next century. The Department notes that the assumptions made and the projections developed from them are necessarily very uncertain. In electricity supply, in particular, the Department acknowledges that there are very real uncertainties and cautions that "the reader should not be misled by the apparent mathematical precision of the figures: they can only have a broad indicative value. They represent neither programmes nor predictions." □

PLUTO is 25

PLUTO, the second of Harwell's high-flux, heavy water moderated Materials Testing Reactors, celebrated its Silver Jubilee on 28 October.

PLUTO was commissioned in 1957 and together with its sister reactor (DIDO, commissioned in 1956) has played a key role in testing the materials and components for UK reactor systems. The current emphasis of reactor work in PLUTO is continued support for the AGR programme—a role which is likely to expand following the recent close-down of the UKAEA's experimental AGR at Windscale. The experimental irradiation facilities in PLUTO are being extended.

For many years PLUTO has been a major producer of radioisotopes sold throughout the world by Amersham International plc. Its products include isotopes for medical research, diagnosis and treatment, and gamma-ray sources used to sterilise medical equipment and pharmaceuticals. A more recent commercial application of Harwell's MTRs has been the irradiation of silicon crystals used in the manufacture of semiconducting devices: during irradiation a small fraction of the silicon is transmuted into phosphorus, conferring semiconducting properties.

Progressive developments and improvements to fuel elements, safety circuits and control systems have enabled the operating power of PLUTO to be increased in stages from 10 MW in 1959 to 25·5 MW today, with little modification to the basic plant. The reactor's cumulative load factor—defined here as the percentage of the time it has operated at its full permitted power throughout its life—is 81 per cent.

Further information about PLUTO may be obtained from Alec Chenery, Research Reactors Division, Building 775, Harwell Laboratory, Didcot, Oxon. OX11 0RA; tel. 0235 24141, ext. 5122. □

The organisation and role of the NII

The Health and Safety Executive has published a detailed paper on the role and work of the Nuclear Installations Inspectorate in relation to the safety of nuclear power stations—particularly the pressurised water reactor.

The paper has been written to give further assistance to the public inquiry into the CEGB's application to build a PWR adjacent to the existing Magnox station at Sizewell, Suffolk. The main inquiry hearings begin next month.

Announcing the new publication, the HSE recalled that in mid-July the NII published a review of the CEGB's Pre-Construction Safety Report (PCSR) for the proposed PWR station. Should planning consent be granted following completion of the inquiry, the Board would still require a licence from the HSE under the Nuclear Installations Act 1965 to install and operate the station. This, the HSE said, would not be granted until the NII was satisfied with the safety case put forward.

The paper says the duty of the Inspectorate in relation to all nuclear power stations under the Act is to see that the appropriate standards are developed, achieved and maintained by the licensee, to see that necessary safety precautions are taken, and to monitor and regulate the safety of the plant by means of its powers under the licence granted.

"This duty is carried out by assessment of the safety of proposed sites and nuclear plant designs, by the establishment of safety requirements for the protection for both operators and members of the public, and by inspection for compliance with these requirements at all stages from construction to operation and eventual decommissioning," the booklet says.

The system for ensuring nuclear safety provided by the relevant Acts in the UK is one which places the responsibility for safety squarely on the operator or licensee, requiring them to formulate the design safety criteria and standards, construction, commissioning and operating arrangements and procedures which will be used.

The paper describes the NII's safety philosophy and assessment work, licensing, siting, the Inspectorate's earlier generic review of the PWR, regulatory control of the construction and commissioning of the plant and its operation and decommissioning. There are three appendices, one comprising a typical set of conditions attached to a nuclear power station licence.

The paper is published as *The Work of HM Nuclear Installations Inspectorate;* 48 pp; ISBN 0 11 883664 1. HMSO, price £3·50 plus postage. ☐

RAPSODIE withdrawn from service

RAPSODIE, the first French experimental sodium-cooled fast reactor, in service at the Cadarache research centre since 1967, is not to be returned to service.

The reactor had been shut down since January 1982 following discovery of a small nitrogen leak in the double envelope surrounding the principal reactor vessel. The decision not to return the reactor to service was taken following detailed study of the means, cost and time it would take to repair the fault. Repair would have been technically possible though complicated; and the reactor was 15 years old and had fulfilled its design objectives.

RAPSODIE marked the first important step in the development of fast reactors in France, with an initial thermal power of 24 MW (raised to 40 MW in 1970). It was conceived in the early 1960s with a view to demonstrating on a significant experimental scale the concept, safety and reliability of fast reactor, proving principal components in sodium and aiding fuel development. Its successful operation gave the Commissariat à l'Energie Atomique the confidence necessary to go on to build the 250 MWe Phénix fast reactor, using components whose design was extrapolated from RAPSODIE.

After the start-up of Phénix, RAPSODIE was used principally for fuel development work, as much as to establish performance limits as to support work aimed at achievement of higher burn-ups, with Phénix serving as a demonstration plant at industrial scale. In turn, the success of these two reactors permitted the launch of the Super-Phénix project.

The CEA says its experience with RAPSODIE was wholly satisfactory. Since its initial start-up its availability had been 73·5 per cent and its load factor 54·4 per cent. It produced $1\,827 \times 10^6$ kWth, and recorded 2 703 days at full power. More than 30 000 fuel pins were irradiated.

The experimental programme will now be continued in Phénix and in other CEA reactors and in collaboration with other countries.

The CEA says the dismantling of RAPSODIE will yield much valuable information on component and materials properties, and will also shed light on the nature of the nitrogen leak discovered in January. RAPSODIE personnel will be re-deployed on fast reactor work, principally at Cadarache.

REVIEW

Energy deskbook

By Samuel Glasstone; 453 pp; US Department of Energy, Technical Information Centre, Oak Ridge, Tennessee 37830; available as DE82013966 (DOE/IR/05114-1) for $12·50 from National Technical Information Service, US Department of Commerce, Springfield VA 22161.

This is a remarkable book. First, it is very cheap (though would-be users outside North America may find it hard to lay their hands on it). Secondly, it has been produced—albeit with generously acknowledged assistance from people within the US Department of Energy and its contractors—by Samuel Glasstone.

My review could end there, but for those who are not yet familiar with this man's incredible output I will add some words of explanation. The latest edition of his standard *Nuclear Reactor Engineering* (produced with Alexander Sesonske) makes the point in the Library of Congress "Cataloguing in Publication Data" on the reverse of the title page: "Glasstone, Samuel, 1897-..." Most men would by now, after some 38 books on various scientific subjects, be unplugging their typewriters. Not Glasstone. Here he is, instead, embarking on an oeuvre whose stated purpose is "to serve as a convenient reference to definitions of energy-related terms and descriptions of current and potential energy sources and their utilisation. The material is presented at a low technical level with emphasis on general principles, which are not difficult to understand, rather than technology."

There is no index: the purpose is served by an expanded contents listing in alphabetical order. The entries, too, are presented alphabetically with abundant cross-referencing. It would be petty to look for inconsistencies* or errors; rather, I am content to report that this is a book for reference, and for browsing in during quiet moments. The flavour is North American; the utility of the book is indisputable.

—James Daglish

*As an editor, I have long been attracted by Emerson's dictum: "A foolish consistency is the hobgoblin of little minds. . .With consistency a great soul has simply nothing to do."

NDT award

Derek Pullen, of the Non-Destructive Testing Centre at Harwell, has been awarded the John Grimwade Memorial Medal of the British Institute of NDT for the "best paper of the year" (1981) published by the Institute.

The award is made annually by the Institute, and commemorates the services to NDT of the late E.J. Grimwade, a pioneer in industrial radiography.

The award-winning paper was "The Radiography of Swaythling Bridge", co-authored by Ron Clayton of the Environmental and Medical Sciences Division at AERE Harwell. It appeared first in the *British Journal of NDT* and was reprinted in ATOM **301**, November 1981. The paper describes the successful application of high-energy radiography, using a mobile linear accelerator, in the examination of concrete structures up to 1·6 m thick. The Swaythling Bridge, in Hampshire, was built in the 1920s and no construction plans were available to help engineers determine its ability to carry modern heavy traffic; the Swaythling study therefore provided important engineering information for the Bridge Engineering Departments of Hampshire County Council and the Southampton City Council.

Mr Pullen has worked on the development of NDT technology at Harwell since 1958. He led the Harwell team in the joint Harwell/Rolls-Royce programme to develop the dynamic radiography of jet engines, which in 1978 received the Queen's Award for Technical Achievement. He is currently a consultant and adviser to industry in the Advanced Applications Unit of the NDT Centre. □

STATUS goes east

With three new franchise agreements the marketing of STATUS—Harwell's free text information retrieval software package—will be expanded in the UK and Europe and extended into the Far East.

Asian Computer Services Pty Ltd (ACS) of Singapore have been granted a Far East franchise and will provide STATUS on IBM, DEC, Prime and Hewlett Packard computers. ACS, which forms the Computer Services Division of the Haw Par Group, will market STATUS throughout the region, covering Singapore, Malaysia, Hong Kong, Indonesia, Thailand, the Philippines, Brunei and China.

Under a second agreement IAL Gemini Ltd are to market STATUS to Data General computer users in the UK. IAL Gemini, which is based in Middlesex, was formed three years ago by International Aeradio Ltd and Cap Gemini Sogeti, and specialises in the provision of commercial and industrial software.

In addition, Computer Technology Ltd (CTL) of Hemel Hempstead have been awarded a franchise enabling the company to provide the STATUS package on CTL computers in Europe and selected overseas countries.

STATUS has now been adopted by more than 80 organisations in Britain, Europe, Africa, Australia and New Zealand, and the package is used in a number of 'public access' databases as well as for specialist technical, commercial and administrative in-house applications. An active STATUS Users' Group was formed two years ago to exchange information on applications and to assist Harwell in developing and enhancing the package. Further information may be obtained from Derek Matkin, Commercial Manager, STATUS, Marketing and Sales Department, B.329, Harwell Laboratory, Didcot, Oxon. OX11 0RA; tel. (0235) 24141, ext. 2704. □

NEA to sponsor nuclear safety project

The OECD steering committee for nuclear energy—the governing body of the Nuclear Energy Agency (NEA)—has agreed to sponsor a programme of safety related studies at the Loss of Fluid Test (LOFT) facility under an NEA international consortium. LOFT is a 50 MWth reactor in Idaho, USA, which simulates a commercial PWR and is the only large-scale thermo-hydraulic nuclear test facility in the world.

The NEA has led an effort towards formation of the new three-year, $100 million international project. The US and ten other countries have pledged financial support in principle: they are Austria, Finland, the Fed.Rep. of Germany, Italy, Japan, Spain, Sweden, Switzerland, Turkey and the UK. In addition, the Commission of the European Communities intends to participate, and other countries may join at a later date according to the announcement from the OECD.

The US Nuclear Regulatory Commission has been performing a safety research programme at LOFT since 1978. This programme has yielded substantial information confirming the ability of emergency core cooling systems to cope with loss of coolant accidents. With this programme nearing completion, the US Government offered participation in the LOFT facility to the international community.

The OECD says an experimental programme has been developed which consists of some ten experiments investigating a number of topics including transient events, loss of coolant and fission product behaviour. A management board consisting of leading experts from participating countries is to be formed to administer the project; operations are scheduled to start early in 1983. □

CALL FOR PAPERS

NDT for the engineer

The theme of the British Institute of Non-Destructive Testing's annual conference to be held at Keele University from 19 to 21 September 1983 is Non-Destructive Testing for the Engineer. Contributions relevant to the theme are invited.

The publications and technical committee of the Institute are particularly interested in papers concerning the practical uses of existing inspection testing in the engineering industries, especially those showing a novel or unique application and new or improved techniques which could solve industrial problems and should therefore be brought to the attention of the engineering industries. Many examples are expected from the heavy engineering industries, but contributions from light and consumer product engineering would also be welcomed.

Any person who could make a significant contribution, representing engineering firms, service industries, equipment manufacturers or research organisations is invited to contact the Secretary, British Institute of NDT, 1 Spencer Parade, Northampton NN1 5AA; tel. (0604) 30124/5. □

Radiological protection

The Society for Radiological Protection is organising two meetings in the early months of 1983.

The first, on 'Radiological Protection—future research requirements: what we know and what we need to know', is to be held at Middlesex Hospital, London, on 25 January; and the second, 'Monitoring—environment and personnel', will take place at Imperial College, London, on 29 March. Enquiries about both meetings should be addressed to the programme committee secretary, Prof. J.H. Martin, Department of Medical Biophysics, Blackness Laboratory, University of Dundee, Dundee DD1 4HN. □

Radioactive fallout in air 1981

The amount of radioactive fallout in the atmosphere trebled in 1981 compared to the previous year, as a result of the Chinese nuclear test of 16 October, 1980. However, levels measured in the air and rain in the United Kingdom were only two per cent of the peak levels recorded in 1963-64.

A United Kingdom Atomic Energy Authority report, *Radioactive Fallout in Air and Rain: Results to the end of 1981,* published on 9 September, says that about two-thirds of the caesium-137 in air near ground level in the United Kingdom was attributable to the Chinese test. The average concentrations of long-lived fission products in air and rain were about three times those in 1980 and about two per cent of the maximum of 1963-64.

In the southern hemisphere fallout continued to decrease in 1981 and was about two-thirds of the 1980 level.

The programme of continuous sampling of airborne dust and rainwater, and their analysis for various fission products and radioactive nuclides, has been carried out by the Atomic Energy Research Establishment, Harwell, for more than 25 years. The results are published annually from locations in the United Kingdom and overseas.

The report, by Cambray, Playford and Lewis, of Environmental and Medical Sciences Division, Harwell, AERE R-10485, is available from HMSO price £3·00. □

1983 Pacific Conference

Five themes will be explored at the Fourth Pacific Basin Nuclear Conference, to be held in Vancouver, B.C., from 11 to 15 September 1983: the need for nuclear power; the fuel cycle; seismicity and seismic design; isotopes for medicine, agriculture and industry; and issues affecting nuclear goals.

The conference, which will be hosted by the Canadian Nuclear Association, is sponsored jointly by nuclear societies in countries bordering the Pacific Ocean. Earlier conferences were held in Honolulu, Tokyo and Acapulco. The programme committee consists of 40 representatives of ten Pacific countries; the honorary chairman of the conference is Mr Robert Depres, chairman of Atomic Energy of Canada Ltd and the chairman is Mr William Walker, chief engineer of B.C.Hydro. The technical programme chairman is Dr A. Mooradian, executive vice-president of Atomic Energy of Canada Ltd.

Further details may be obtained from the Canadian Nuclear Association at 111 Elizabeth St, 11th floor, Toronto, Ontario, Canada M5G 1P7. □

Radiation and the worker: Where do we go from here?

A public one-day meeting, organised jointly by the British Association for the Advancement of Science, the National Radiological Protection Board and the Health and Safety Executive, is to be held at the Scientific Societies Lecture Theatre at 23 Savile Row, London on 7 January 1983.

Under the Health and Safety at Work Act 1974 new regulations, an approved code of practice and notes for guidance were to be published in draft form as consultative documents in the closing months of 1982, and thus symposium is intended to promote understanding of their contents and to stimulate informed debate.

The central purpose of the proposals is to assume the risk of adverse effects at any level of radiation dose, however small, and to try to control its level: radiological protection of the worker necessarily involves the acceptance of some level of risk, and in deciding this level consultation is essential. The organisers hope that the BA/NRPB/HSE meeting will assist in this process.

Tickets are available from the Press Office, British Association, at £10 including VAT. Further information may be obtained from Ursula Laver at the BA, tel. 01-734 6010, ext. 377. □

'Nuclear power exhibition' at Harwell

A new exhibition centre at Harwell is the permanent home for the Nuclear Power Exhibition, which for the past two years toured the UK. The centre will also be used to exhibit aspects of Harwell's nuclear and non-nuclear programmes.

The new centre and the Nuclear Power Exhibition were opened on 18 October by Sir Peter Hirsch, chairman of the UKAEA, at a small ceremony attended by representatives of local authorities, neighbouring laboratories and local schools and colleges.

The Nuclear Power Exhibition was sponsored by the Nuclear Power Information Group, which comprises the AEA, the Electricity Council, the electricity generating boards, BNFL and the Nuclear Power Company. It was launched in 1979, and during its touring days was displayed in 20 cities and towns throughout the UK and was seen by more than 100 000 people. Its aim is to increase public awareness and understanding of nuclear power, its costs, safety and reliability.

Organisations wishing to arrange a visit to the Nuclear Power Exhibition may obtain further details from Mrs Linda Jones, PR Group, Building 329, Harwell Laboratory, Didcot, Oxon. OX11 0RA; tel. (0235) 24141, ext. 3285. □

Welding and brazing

The American Society of Mechanical Engineers and the UK-based Defence Customer Services are jointly presenting a three-day seminar on welding and brazing in accordance with Section IX of the ASME Boiler and Pressure Vessel Code on 25-27 January 1983 at the Beaufort Hotel, Bath.

The course is designed to appeal to welding engineers, quality assurance engineers and auditors who require an insight into the procedures and techniques involved in welding and brazing to nuclear standards. Delegates will receive the latest edition of ASME Section II, Part C: welding rods, filler metals and electrodes; section IX, welding and brazing qualifications; and extensive course notes.

The fee for the course is £450 + VAT. Enquiries should be addressed to the Seminar Registration, Defence Customer Services, 12 Gray Street, Bath, Avon; tel. 0225 335 666. □

Tribology courses

Pump problems in the process industries

25 January 1983

This course is intended to appeal to engineers concerned with the selection, maintenance and use of rotodynamic pumps. Information will be presented by pump manufacturers and users and by specialists on seals and bearings with emphasis on industrial problems. Fee: £103·50 inclusive of VAT, refreshments and course notes.

Gears: Design, lubrication and failures

24 March 1983

The aim of this course is to help the practising engineer who wishes to incorporate gears in his design or who needs to have sufficient understanding to analyse failures in plant. The topics covered are an introduction to all important aspects of the subject. Fee: £103·50 inclusive of VAT, refreshments and course notes.

The programme and application forms for both courses can be obtained from The Course Organiser, National Centre of Tribology, UKAEA Risley, Warrington WA3 6AT; tel. (0925) 31244, exts. 2640/3232. □

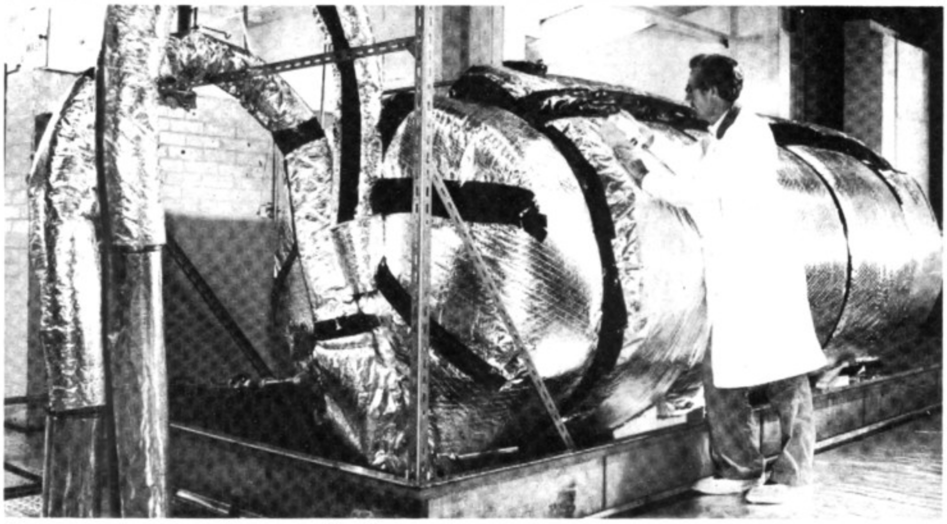
Research agreement signed

An agreement between the International Atomic Energy Agency and the Ges. für Strahlen- und Umweltforschung (GSF) on a joint research programme for the application of isotopic techniques in hydrological and geothermal investigations in Latin America was signed in October.

The aim of the programme is the promotion of isotopic techniques, especially those based on environmental isotopes, in the development of groundwater resources for human and agricultural use and of geothermal resources for power production. Isotopic techniques are especially useful in investigations into the origin of groundwaters; the rate of groundwater recharge; the age or residence time of groundwater bodies; the movement of groundwater; the relationship among groundwater systems; and the temperature and availability of geothermal fluids.

The individual projects will be carried out largely by Latin American institutions in response to local conditions and requirements, with advice and cooperation from the IAEA and the GSF Institute of Radiohydrometry.

The new agreement, which will last until the end of 1986, follows another joint IAEA/GSF programme, also funded by the Federal German Ministry for Research and Technology, which terminates in 1983. It consists of basic research into the mechanisms of groundwater recharge. □



Decontamination technique proven

A new technique for radioactive decontamination has been demonstrated successfully at the Winfrith establishment of the UKAEA during the overhaul of a 50-tonne fuel transport flask. Used for the first time, the technique removed residual radioactive contamination from the interior of the flask before the overhaul began.

The 20-foot (6 m) long flask is used to ship spent fuel elements from the Winfrith reactor to the BNFL reprocessing plant at Sellafield. The flasks are tested and overhauled regularly to ensure that they continue to meet stringent safety standards. The new technique required the fitting of a special lid to the flask so that pipes could be attached and the decontamination reagent pumped throughout the flask to wash interior surfaces.

To help ensure that the reagent was kept at the correct temperature throughout the five-day operation, the flask was thickly insulated and wrapped in aluminium foil. After decontamination, the flask's heavy lead lining was lifted out of the 4 in. (100 mm) thick steel outer sleeve and all surfaces were prepared for painting by wet sandblasting. A special paint spraying apparatus mounted on a telescopic arm was to be used to ensure that even the most inaccessible areas were treated.

Winfrith expects the successful use of this technique to be of considerable interest to the nuclear industry. By decontaminating equipment effectively before maintenance work begins, technicians may have easier access and therefore be able to give a faster, more efficient service. □

AEA REPORTS

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

AERE-M 3252 *A gamma doserate surveillance system.* By A.T. Rolls, G.F. Snelling and F.D. Seymour. July 1982. 13pp. HMSO £2·00. ISBN 0 70 580975 7

AERE-R 10032 *Random number generators for the normal and gamma distributions using the ratio of uniforms method.* By I. Robertson and L.A. Walls. December, 1980. 58pp. HMSO £3·00. ISBN 0 70 580643 X

AERE-R 10470 *Determination of rare earth elements in geological materials by neutron activation analysis using a group separation and high resolution gamma-ray spectrometry.* By T.W. Sanders and S.J. Wright. September, 1982. 21pp. HMSO £2·00. ISBN 0 70 580646 4

AERE-R 10554 *The simultaneous measurement of particle size, velocity and mass transfer in a pulsed two-phase flow field.* By M.L. Yeoman, N.S. Lightfoot and A.P. Morse. June, 1982. 21pp. HMSO £2·00. ISBN 0 70 580546 8

AERE-M 3258 *A beta-in-air monitor surveillance, alarm and record system.* By G.F. Snelling and F.D. Seymour. August, 1982. 26pp. HMSO £2·00. ISBN 0 70 580596 4

AERE-M 3261 *A process plant cooling water monitor for fission product breakthrough.* By A.T. Rolls, G.F. Snelling and F.D. Seymour. August, 1982. 17pp. HMSO £2·00. ISBN 0 70 580606 5

AERE-R 9066 (rev) *Initial experience of manufacture and property measurements on piezoelectric cable.* By B.H. Broomfield. November, 1981. 23pp. HMSO £2·00. ISBN 0 70 580944 7

AERE-R 10496 *Selection of low-activity elements for inclusion in structural materials for fusion reactors.* By O.N. Jarvis. June, 1982. 46pp. HMSO £4·00. ISBN 0 70 580885 8

AERE-R 10631 *Computer modelling studies of photochemical air pollution formation in power station plumes in the United Kingdom.* By R.W. Derwent. August, 1982. 54pp. HMSO £3·00. ISBN 0 70 580626 X

ND-R 461(S) *The Auger spectra of some ternary lithium compounds.* By I.F. Ferguson, D.R. Masters and M. Turek. September, 1982. 19pp. HMSO £2·00. ISBN 0 85 356157 5

ND-R 803(W) *A comparison of measured fission gas releases for Windscale AGR fuel irradiated above 18 GWd/tU with those predicted using the computer code MINIPAT D.* By N. Beatham, R. Hargreaves, R.D. Walker and R. Kirkbride. August, 1982. 26pp. HMSO £2·00. ISBN 0 85 356150 8

IN PARLIAMENT

BY OUR PARLIAMENTARY CORRESPONDENT

Sizewell inquiry

18 October 1982

Mr Kenneth Carlisle asked the Secretary of State for Energy what decision he had taken on the funding of objectors at the Sizewell PWR inquiry.

Mr Nigel Lawson: The Government will not be providing public funds to objectors at the inquiry. I have explained the reasons for this decision in my reply to a letter from Sir Frank Layfield, QC, the inquiry Inspector, in which he set out the representations made to him in favour of funding. Copies of both letters have been placed in the Library of the House. [ATOM **313,** p247].

Site monitoring

22 October 1982

Mrs Renée Short asked the Secretary of State for the Environment what monitoring of sites on which low and intermediate radioactive waste is dumped takes place.

Mr Giles Shaw: Where necessary, monitoring of sites at which disposals of low-level radioactive waste have taken place is carried out either by the Department's Radiochemical Inspectorate or by the site operator as a condition of the authorisation. In the great majority of cases monitoring is not necessary because the radiological hazards involved in the disposal are negligible. Disposal facilities for 'intermediate' radioactive waste as defined in the recent White Paper *Radioactive Waste Management* (Cmnd 8607) have yet to be constructed and the monitoring arrangements have not yet been determined.

Representation

22 October 1982

Mrs Renée Short asked the Secretary of State for the Environment if he would ensure that local authorities were in future represented on the Government's Radioactive Waste Management Advisory Committee.

Mr Giles Shaw: When appointments are made to the committee Mrs Short's suggestion will be borne in mind.

● Mrs Short also asked whether the Secretary of State would consult local authorities on the question of dumping of radioactive waste to give them the option of public hearings.

Mr Giles Shaw: My Department consults local authorities and water authorities about disposals from UKAEA sites and sites licensed under the Nuclear Installations Act 1965 and about all other landfill burials involving special precautions, and thus goes beyond the requirements of the Radioactive Substances Act 1960. The Radiochemical Inspectorate is always willing to discuss such a case with the local authority if requested. Other authorisations under the Act are very numerous and of much less significance radiologically, and in such cases consultations would not be justified. Copies of all certificates of authorisation are sent to the relevant local authorities.

The Act makes provision for a formal hearing only where the applicant requests it. However, if a case arose in which no such request was made by the applicant but the circumstances nevertheless seemed to warrant it, the Department would explore the possibility of including a hearing in its consultations.

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JANUARY
The Assessment of the Risks of Energy
The 49th Melchett Lecture given by H.J. Dunster to the Institute of Energy in London.

Fast Reactor Fuel Cycles
Dr. T.N. Marsham at the opening of an international conference on fast reactor fuel cycles, in London.

Coal and the Environment
A review of the Commission on Energy and the Environment's report by Dr. P.M.S. Jones.

The Pursuit of the Ideal
Dr. Sigvard Eklund to the General Assembly of the United Nations.

FEBRUARY
The WAGR Concluding Experiments
by R.E. Mrowicki, C.P. Greef, J.H. Leng and M. Kendal.

CONFORM
by Cliff Etherington.

MARCH
The Sizewell B PWR
Dr. Walter Marshall to a press conference.

High Technology for the Future
by Dr. S.J. Sanderson.

Danish Research Reviewed
by Dr. M.H. Bradbury.

Domestic Energy Conservation and the UK Economy
Reviewed by G.V. Day.

Nuclear Power in Europe
Foratom report.

APRIL
The New AGRs
by Simon Rippon.

The Windscale Nuclear Laboratories
by Dr. David Phillipson.

Geography, prospects, problems
David Fischer on the IAEA safeguards system.

The Bases for Decision Making
Report by Peter Curd of a seminar of the All-Party Group for Energy Studies.

Book Reviews:
Nuclear Energy: the real costs
Nuclear Waste Disposal—Can we rely on bedrock?

MAY
A PWR for the UK
A report of a seminar on the design of the PWR by Simon Rippon.

Book Reviews:
Comparative risks of electricity generating fuel systems in the UK
Lasers: Theory and applications

JUNE
Pressure Vessel Integrity
The Marshall Study Group report.

Design for Safety: PWR pressure vessel integrity
by John Collier, Myrddin Davies and Lynne Garne.

Fusion: the European Scene
A report by James Daglish of a British Nuclear Forum Symposium at Culham.

JULY
The Case for Sizewell B
The Central Electricity Generating Board's Statement of Case.

Engineering for a safe PWR
Report by James Daglish of a conference at the Institution of Mechanical Engineers in London.

Interest in the "Classics" Revives
Report by Simon Rippon of the Third European Nuclear Conference held in Brussels.

Book Reviews:
Nuclear Energy: the real costs
The Nuclear Industry Almanac

AUGUST
Living with Nuclear Energy
The Dulverton Lecture given by Lord Sherfield at International Students House in London.

The Radioactive Waste Management Committee Annual Report

IAEA Safeguards Review

SEPTEMBER
Energy: Boon or Birthright
The eighth Foratom Congress reported by Simon Rippon.

NIREX established

PWR Safety Issues to be Resolved
Nuclear Installations Inspectorate Review.

Electricity Council Annual Report

CEGB Annual Report

Nuclear Energy Prospects to 2000
Report of an OECD Study

NEA Activity Report

Amersham International Annual Report

Book Reviews:
Nuclear power in perspective
World energy needs and resources
Nuclear issues: International control and international cooperation

OCTOBER
Talking about Accidents
Sir Walter Marshall to the IAEA International Conference on Nuclear Power Experience in Vienna.

UKAEA Annual Report

Commissariat à l'Energie Atomique Annual Report

IAEA Annual Report

NOVEMBER
Decomissioning the WAGR
Dr. H. Lawton to the 1982 International Decommissioning Symposium in Seattle, Washington.

Nuclear Power Experience
A report by James Daglish of the international conference convened by the International Atomic Energy Agency in Vienna.

Good Progress
The UKAEA annual press conference chaired by Mr. A.M. Allen.

BNFL Annual Report

IAEA General Conference

Three Mile Island
Herbert Feinroth to the British Nuclear Energy Society in London.

DECEMBER
Electrification, economic growth and uranium power
Dr. Chauncey Starr, vice-chairman of the Electric Power Research Institute to the Seventh Annual Symposium of the Uranium Institute in London.

Building on Success: The Development of AGR fuel
by R.A. Shaw.

Gas-cooled reactors today
A report by Simon Rippon of a conference held at Bristol.

Fifty years of the neutron

Book review:
Energy deskbook