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ATOM

PROLIFERATION AND THE RECYCLING OF PLUTONIUM

GEOTHERMAL ENERGY AND THE UK

SEPTEMBER 1978 NUMBER 263

ATOM contents

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Front Cover: Natural steam "gushers" during pressure tests at a power plant 75 miles north of San Francisco, USA.

PROLIFERATION AND THE RECYCLING OF PLUTONIUM

In February this year the Authority's Deputy Chairman, Dr. Walter Marshall, CBE, FRS, gave the Graham Young Memorial Lecture on the subject of nuclear power and the proliferation issue (ATOM, April 1978). In a lecture given to the Uranium Institute's International Symposium on uranium supply and demand and related subjects held in London in July, Dr. Marshall develops some aspects of his previous lecture and of papers given by other scientists at the Fifth Energy Technology Conference in Washington.

I do not have to tell this audience that the proliferation issue has become of major importance in determining the future of the nuclear industry and therefore the future use of uranium in the world. This last year has seen a good deal of controversy on this topic and my purpose today is to discuss this topic as I see it.

Active world-wide interest was stimulated by President Carter's initiative in calling for a new examination of the risk of proliferating nuclear weapons capability through the growth of nuclear power. The sense of his initiative has been well summarised by Joseph Nye, in the April 1978 issue of Foreign Affairs[1], and by Victor Gilinsky, in his article of November last year on Nuclear Energy and Nuclear Proliferation[2]. My first step must therefore be to summarise their argument.

In brief, they argue that if plutonium is to be present in the world, several factors have to be taken into account when considering its use and safekeeping. Neither governments nor regimes are guaranteed to be long-lived and, sadly, regions of the world are not guaranteed to be stable in the future. We cannot even rule out the possibility of "terrorist groups being in league with maverick states"[1] to divert or misuse plutonium. They therefore argue it is important to decrease the general availability of weapons-usable materials — in particular, plutonium. The US Administration has therefore advocated that, at least as a temporary measure, plutonium should neither be recycled nor separated, but should be left in fuel discharged from the reactor because spent reactor fuel is such an intimate mixture of uranium, plutonium and fission products that the intense radioactivity of the latter would prevent the fuel from being easily "reprocessed" to separate out the plutonium. But if there is to be no reprocessing there can be no recycle of plutonium in either thermal or fast reactors and automatically, therefore, in the USA the fast reactor is delayed. This US initiative has, in turn, led many countries who are uranium producers to have renewed concern about the use made of their uranium if exported, but again, for this particular audience, it would be unnecessary for me to dwell on those matters.

You must all be conscious that these concerns have elevated the export of uranium ore to a high political level, so much so that the geological availability of uranium is nowadays of less concern than its political availability. These concerns about weapons proliferation are complicated in many countries by a less well-articulated concern about the so-called "plutonium economy". It seems to me that much of this general concern about plutonium is emotional and non-factual and I shall, therefore, concentrate solely on the proliferation arguments because those are ones amenable to analysis.

I must say at the outset, that I have some sympathy with the intent of the US arguments and, certainly, it is disappointing and distressing to observe that, taken as a whole, the world is not becoming a more sane, more civilised, more stable place. However, it also seems to me that the arguments being made are a significant, over-simplification of a complex position. In particular, I am unhappy at the concentration of attention upon the availability of plutonium to the exclusion of almost any other consideration. I do not accept that the diversion of plutonium from a civil nuclear power programme is the main proliferation danger facing the world; there are so many other and easier ways of making nuclear weapons that I am puzzled by the large amount of attention given to the former to the almost total exclusion of the latter. I would, myself, prefer to see more thought put into purely political actions designed to reduce tension in the world and, even if we confine ourselves to technical issues, I would think the growing availability of easy enrichment techniques, the future possibility of uranium 233 being available from the irradiation of thorium, the development of sophisticated expertise in the use of high explosives and the acquisition of delivery systems capable of deploying nuclear weapons, were all more important questions to consider than the mere availability of plutonium. There is, therefore, a real danger that a concentration on the dangers of plutonium will merely divert attention from more important matters but, despite that danger, I have no alternative but to address myself to the narrow plutonium question today if only because that is the issue which has aroused so much uninformed apprehension.

In thinking about the availability of plutonium, I discovered that my thoughts were closely parallel to those of my American colleague, Dr. Chauncey Starr, of the Electric Power Research Institute and, therefore, many of the points I have made previously and which I will make today, have been worked out in joint discussions with him. Some of our earlier thoughts were summed up in the Graham Young Memorial Lecture which I gave at the University of Glasgow on 24th February 1978[3] and in a series of four lectures given by Dr. Starr and staff members of EPRI and of the United Kingdom Atomic Energy Authority, during the course of a special session on non-proliferation at the 5th Energy Technology Conference in Washington DC on 27th February 1978[4]. Today, I first propose to remind you of the arguments which we made in those lectures at the end of February and then to tell you something of the way our ideas have evolved since that time as a result of comments we have received and further work within our two groups.

Any discussion of plutonium availability must start by considering the initial production of that material. As you all know, it is produced in thermal reactor fuel by the neutron irradiation of uranium 238. When a spent fuel element is removed from a thermal reactor, it contains fission products that are so radioactive that we can safely regard it, and the plutonium it contains, as "inaccessible" to all except the few experienced nuclear fuel companies in the world. I believe it is primarily for this reason that some American spokesmen have urged consideration of the once-through fuel cycle where the spent fuel elements are simply stored and left unreprocessed so that the plutonium is left locked up in an intimate mixture of radioactive fission products and unburnt uranium.

However, the radioactivity associated with a typical fuel element falls off rapidly with time as shown in Figure 1, which is reproduced from the Graham Young Memorial Lecture. It can be seen from this figure that it falls by a factor of 300 over the first year and a factor of 2000 over the first 10 years. The hazard presented by the radioactivity to anybody attempting to handle the fuel element depends, of course, on the amount of radioactivity, the knowledge of those handling it, the sophistication of their equipment, and the operational time at their disposal. Even given the decay of radioactivity with time, it is still extremely difficult to perform all the steps necessary to extract the plutonium. But, though difficult, it is certainly not impossible and, therefore, as time goes on, the plutonium becomes "extractable" by organisations with progressively less experience and expertise.

This, by itself, would not be very significant if all the spent fuel could be gathered together on just a few sites in the world so that it could be adequately safeguarded and controlled. However, with light water reactors, it is common practice to store spent fuel at the reactor site itself for many years and there is no technical difficulty to increasing the storage capacity to cover about ten to fifteen years' production. Therefore, if we promote the once-through cycle,

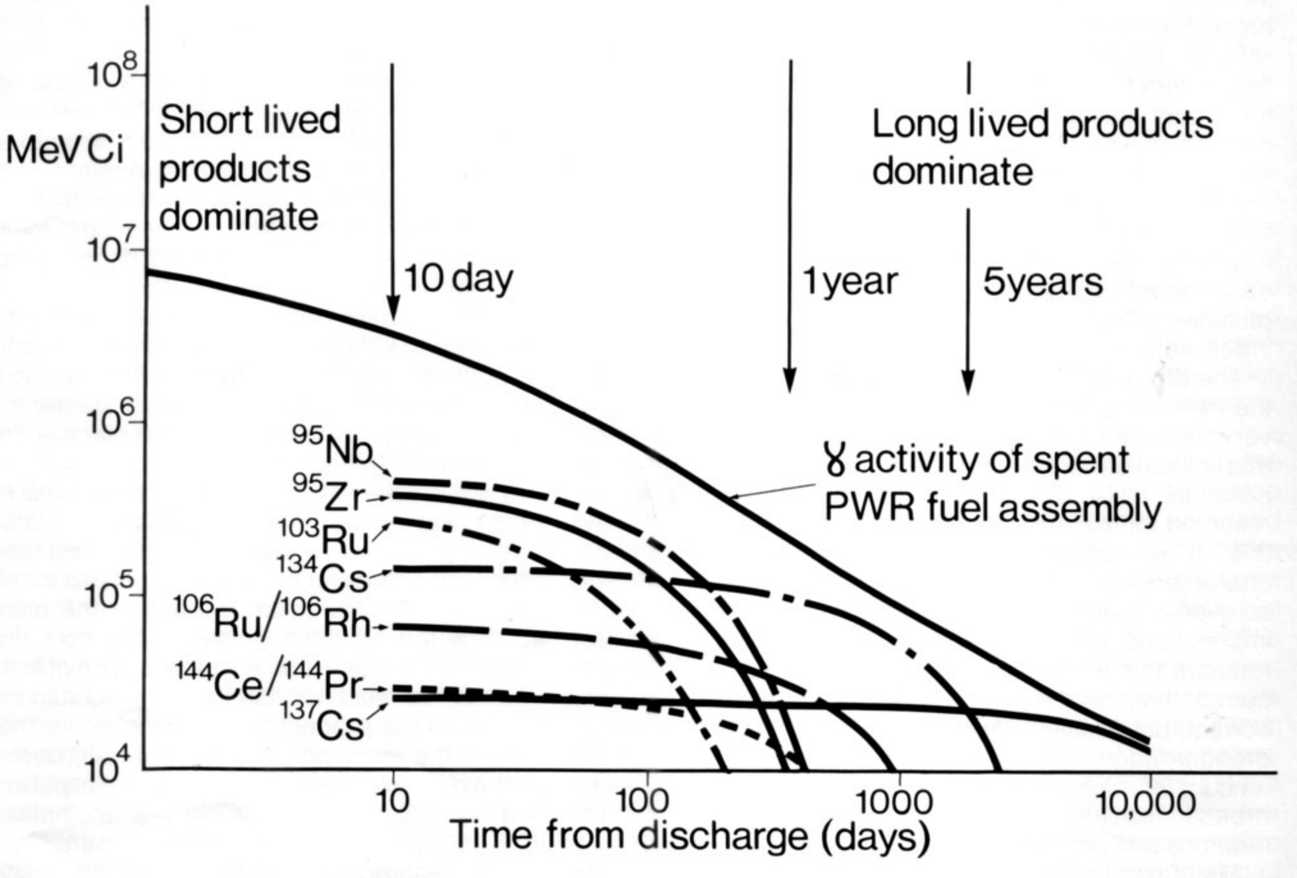

Figure 1 — The gamma activity of a spent PWR fuel assembly as a function of time and the contribution made to that activity by several key isotopes.

THERMAL REACTOR (P.W.R)

1000 MW — **Kilograms/Year Plutonium**

				Input	=	0
Create	=	710				
Incinerate	=	380				
		330	=	Output	=	330
				Production	=	330

Figure 2 — Production of plutonium in a PWR (for each GW(e) year).

it is my judgement that the chances are very low of gathering together that spent fuel at just a few locations. I feel that that particular proposal will lead to the distribution of plutonium in spent fuel in a wide number of locations throughout the world, and the need for physical protection and safeguards would grow correspondingly as the amount of stored fuel increased and the number of sites increases. In this way I argued in the Graham Young Memorial Lecture that every reactor and every fuel storage facility would become a "plutonium mine", becoming steadily more accessible with time, thus setting off a proliferation time-clock, with every nuclear power plant and storage facility in every nation becoming a potential target for plutonium diversion.

I do not think that this is a very attractive proposition for us to look forward to indefinitely. Above all else, I must reiterate a very simple point: thermal reactors produce plutonium each and every year of operation and, therefore, if the plutonium is not used the amount of it in the world must grow indefinitely.

Therefore, I argued in my lecture that the proper step for the moment is to retrieve spent fuel into a small number of very large reprocessing plants. In practice, this would mean that plutonium would be stored in as few locations as possible. I also suggested that the plutonium should be reserved for use in fast reactors and, in order to understand this, it is necessary to review briefly the operational characteristics of fast reactors. I do not apologise for doing so even to this informed audience because so many wrong impressions have been given to the public about fast reactors that we should take every possible opportunity to correct those wrong impressions. For example, it is factually correct, but consistently misunderstood, that the use of fast breeder reactors instead of thermal reactors decreases the amount of plutonium in the world. This is because fast breeder reactors do not breed fast, they simply use fast neutrons and breed rather slowly.

May I remind you of some typical production figures for plutonium. A typical thermal reactor (a 1000 MW PWR) produces about 300 kgs of plutonium each full operating year. If that plutonium is not used, then it must be regarded as a waste product and it accumulates indefinitely. That was never the intention of the nuclear industry. That is why, in many countries throughout the world, fast reactors were planned to follow on after thermal reactors to make use of and to incinerate that plutonium. (An alternative is to use plutonium in thermal reactors and I shall discuss that later.)

A typical fast reactor (1000 MW and sodium-cooled) has a core which contains the plutonium fuel and a blanket region which surrounds that core. The core of the reactor produces heat, and therefore electricity, by incinerating some of the plutonium fuel which is put into it. The core fuel also contains a good deal of uranium 238 and, therefore, additionally plutonium is both created and incinerated in the core *in-situ*. The exact balance between the creation and incineration in the core needs to be calculated carefully to understand the heat production of the reactor, but, for our purposes, we can ignore all those complications. We simply need to know that, if the fuel is taken out of the core at the end of one full year's operation, it will contain about 200 kgs of plutonium less than it contained when that same fuel was put into the reactor. In effect, therefore, the core of the fast reactor is an incinerator of plutonium and incineration takes place at a rate of 200 kgs for every GW(e) year.

It would be entirely possible to operate fast reactors in that simple way as incinerators of plutonium, but by making use of the blanket region, we can make the fast reactor flexible to either an increasing or decreasing need for electric power. When depleted uranium is put into the blanket region, it absorbs the neutrons which escape from the core and is converted to plutonium. A typical design of fast reactor might produce as much as 450 kgs of plutonium in a year in the blanket. That production of plutonium in the blanket outweighs the incineration in the core but, depending exactly on the design of the reactor and material put into the blanket, one can affect the balance between the optional production in the blanket and the inevitable incineration in the core so that the reactor as a whole is, overall, either a net producer or a net incinerator. Using the figures quoted above, the blanket production of 450 kgs, offset by core incineration of 200 kgs, gives a net production of 250 kgs. This is somewhat less than

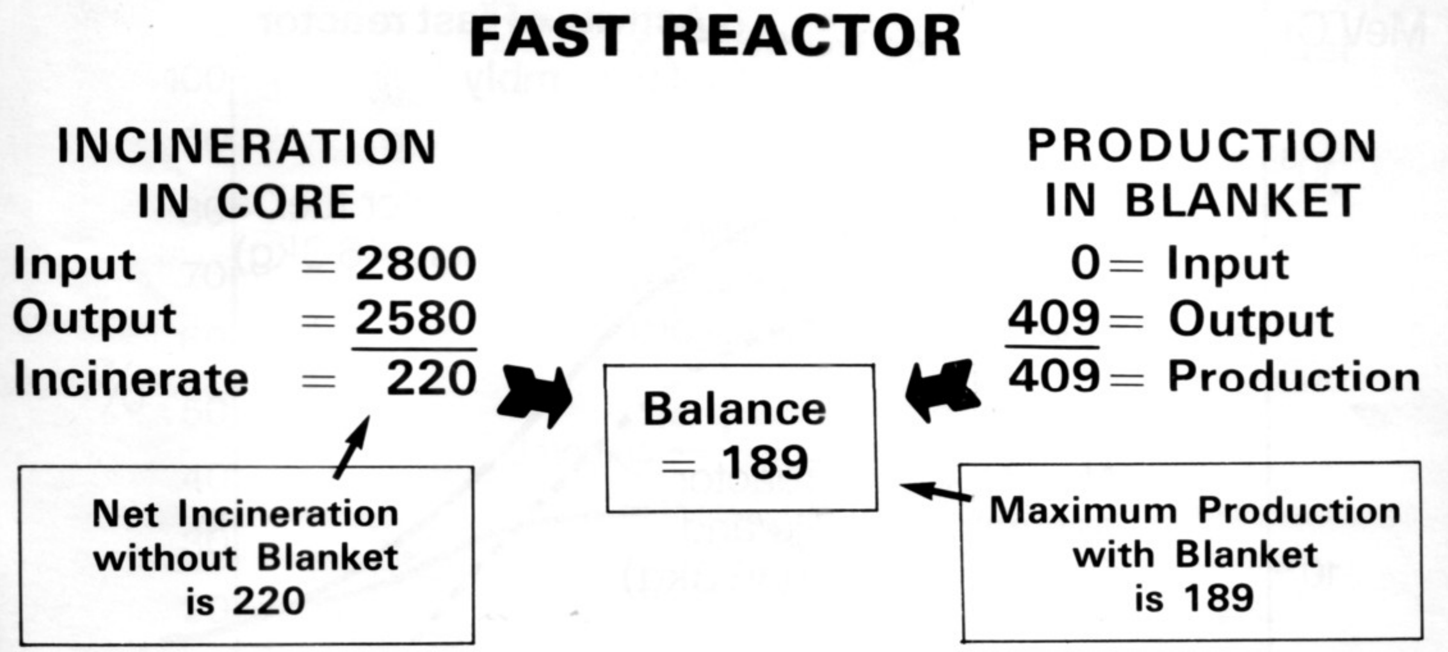

Figure 3 — Plutonium incineration and production in a specific design of fast reactor (all figures are per GW(e) year).

the production from a PWR and considerably less than the production (per unit power) from our Magnox stations. These calculations concerning plutonium production are summarised simply in Figures 2 and 3. They demonstrate that, once the fast reactor has been launched, it only needs a steady supply of depleted uranium to keep it going. It does convert that depleted uranium to plutonium but it also incinerates plutonium simultaneously. At one extreme, the fast reactor can be an overall producer of plutonium at a slower rate than in thermal reactors and, in the other extreme, it is overall an incinerator of plutonium. In this way, the total amount of plutonium in the world can be controlled by the use of fast reactors. These figures for plutonium production are summed up using particular reactor designs in Figures 2 and 3.

However, the main non-proliferation effect of the fast reactor is neither the opportunity to incinerate plutonium nor the option to control the total amount of plutonium in the world; it is the fact that, so long as plutonium is used, it becomes so associated with fission products that it becomes "inaccessible". It is, therefore, important to realise that fast reactors have advantages both for energy production and for non-proliferation objectives.

However, in order to realise these advantages, it is first necessary to reprocess the spent fuel elements of thermal reactors to extract the plutonium from them and it is then necessary to fabricate that plutonium into fresh fuel for the fast reactor. It is this prospect of separating plutonium from fission products and then handling it to make fresh fuel that has given rise to concern about the so-called "plutonium economy" and proliferation risks. Furthermore, it has been argued that, as the use of fast reactors grows, those risks must necessarily grow also. I do not accept the sense of this argument because I think it is based upon a misunderstanding of the ultimate nature of the fast reactor fuel cycle which will be operational in the future.

Any discussion of plutonium fuel cycles must appear complex to the non-expert. The difficulty of presentation is inevitably increased when we recognise that there are at least three types of plutonium-bearing fuel we need to consider. First, we need to consider the fuel needed to launch fast reactors. Next, we need to consider the fuel required to maintain them in operation and, finally, we need to consider a different opportunity altogether, namely the use of plutonium-bearing fuels in thermal reactors. I shall, therefore, devote the remainder of this lecture to a discussion of these three fuels, paying particular attention to the proliferation aspects of each.

We should first note that, within the fast reactor programmes throughout the world, overwhelming attention has been given to the first step, namely the launching of fast reactors. This must, of course, start from the reprocessing of thermal reactor fuel, the extraction of plutonium and and the refabrication of that plutonium, together with depleted uranium, to make the initial charge for the fast reactor core. Once the plutonium has been separated from fission products, then it is no longer "inaccessible" and, therefore, we are obliged to acknowledge that these steps have, in a very general and philosophical sense, increased the availability of plutonium from the time that it was separated up to the time it is placed inside the fast reactor core (and thereby rendered "inaccessible" very rapidly). All countries with fast reactor programmes have planned to use some form of PUREX plant for reprocessing the thermal reactor fuel and planned to fabricate the new fast reactor fuel by a suitable extrapolation of techniques for the fabrication of uranium oxide fuel for thermal reactors. I have not been able to see any reasonable alternative to these ideas to launch fast reactors but, as I understand the views of those people who fear the so-called "plutonium economy", they are not concerned so much with this phase of launching fast reactors — because that necessarily must be an interim phase — but they are concerned about the prolongation of risks from plutonium into the indefinite future. However, these fears, if I have correctly represented them, have not sufficiently recognised that the fuel cycle to maintain fast

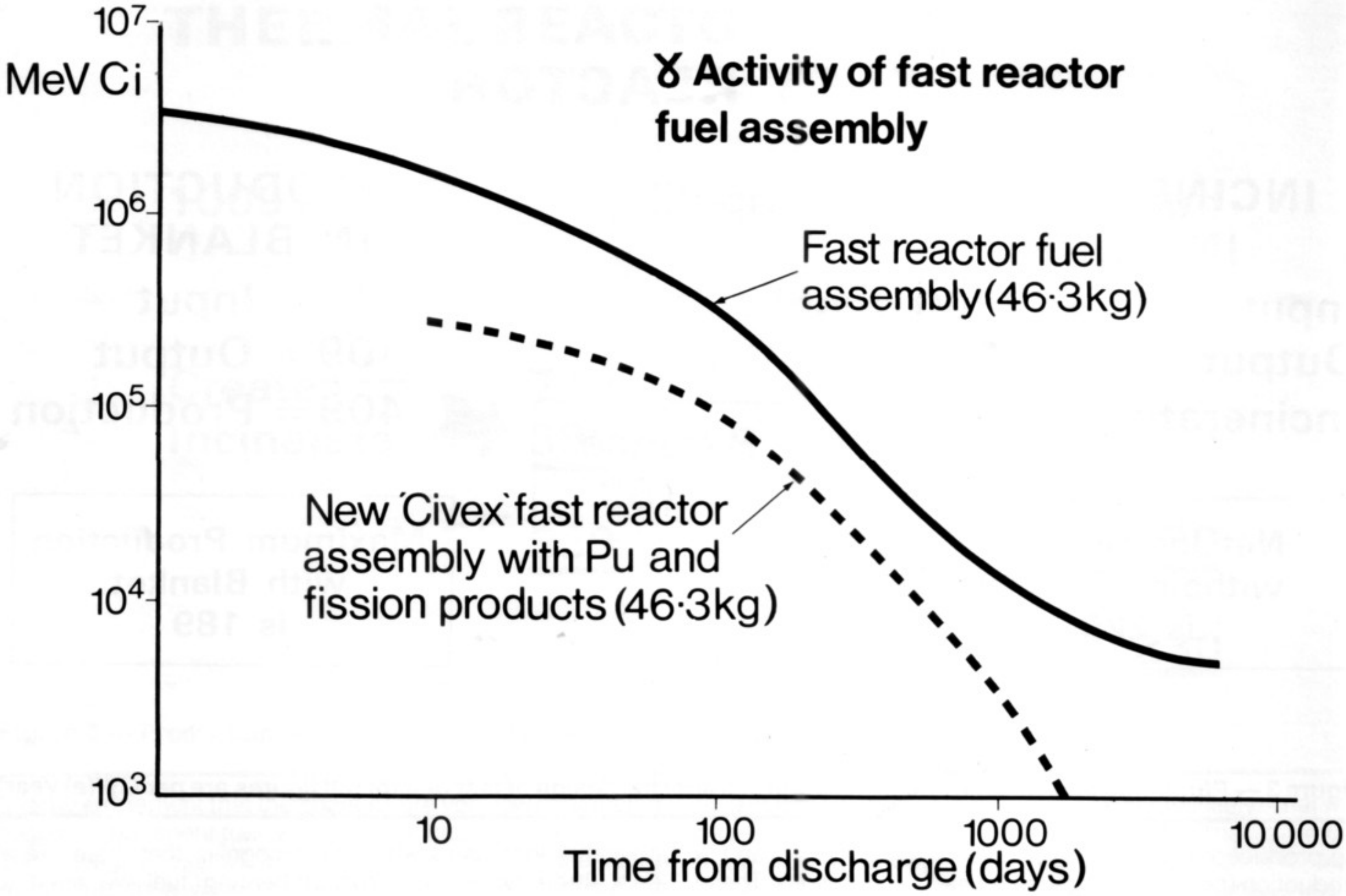

Figure 4 — The gamma activity of a fast reactor fuel assembly and a new CIVEX assembly.

reactors in operation will be very significantly different from that which is required to launch them and the main theme of the papers given by my colleagues at the Washington Conference in February was to point out that there are good reasons to suppose that, throughout the fuel cycle to maintain fast reactors, we can retain plutonium in such a form that it is very hard to divert it or misuse it and, if necessary, we could introduce a modification of existing plans to render the plutonium "inaccessible" throughout the entire process. This modified proposal was named CIVEX by Dr. Chauncey Starr to emphasise the difference from the conventional PUREX plant and I would now like to describe to you a CIVEX plant as I envisage it at the present time.

I would like to start by drawing attention to a very simple point. It is conventional to store thermal reactor fuel for about 10 to 20 years before reprocessing it because there are no strong economic reasons why it should be reprocessed more rapidly than that, and the longer it is left in storage, then the easier it is to handle. However, the fuel cycle to maintain a fast reactor in operation must necessarily recycle fissile material more rapidly and the spent fuel and blanket elements taken out of a fast reactor must be reprocessed, mixed with the fresh depleted uranium and returned to the fast reactor, ideally within about one year. This is absolutely necessary to keep the total plutonium inventory at an acceptable economic level. This means that the technology for handling plutonium which comes from a fast reactor and goes to a fast reactor, will be significantly different from that which is handling plutonium that has come from a thermal reactor and going to a fast reactor.

Figure 1, which shows the gamma activity of a spent thermal reactor fuel element, also shows beneath the main curve the contribution made to that activity by the various fission products present in it. Those curves illustrate clearly how the activity is dominated in turn by short-lived products, a key group of isotopes with half-lives of several months, and a longer-lived group of fission products and actinides with half-lives of many years. The curve for a fast reactor fuel assembly would have the same shape but there is clearly a big difference between reprocessing either of these within the first year, when the radioactivity of the fission products is very high, or reprocessing after 10 to 20 years when the radioactivity of the fission products has substantially decayed. In particular, we can note that, if the fuel is reprocessed within the year, then the radioactivity is dominated by the presence of several short-lived radioactive isotopes namely zirconium, niobium, ruthenium, cerium and praseodymium whereas, after five years, these very active fission products have decayed and the radioactivity is then at a lower level and dominated by caesium, strontium and the actinides. In a conventional reprocessing plant and in the fast reactor reprocessing plant as at present planned, it is customary to include several stages of the plant to eliminate all the fission products from the final uranium and plutonium products. However, for the fast reactor, there is no technical reason why we are obliged to do this and, if the reprocessing flowsheet were simplified, then those fission products could be made to accompany the final plutonium uranium product at any designed level. In that case, the plutonium would be accompanied by such highly radioactive fission products that it would be "inaccessible" when it came out of the reprocessing plant as well as when it went into it. The fabrication of this highly radioactive mixture into fresh fast reactor fuel would be difficult, certainly more

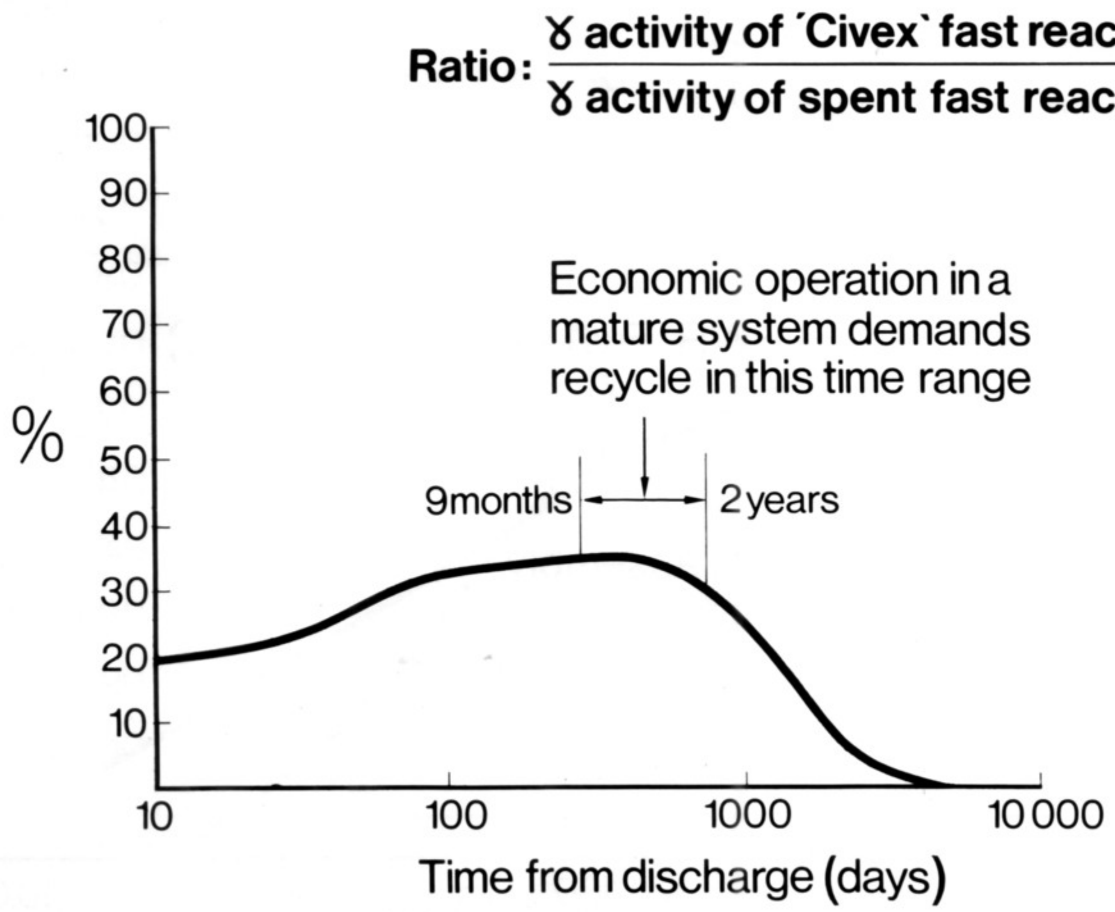

Figure 5 — The ratio of gamma activity of CIVEX fast reactor fuel to spent fast reactor fuel as a function of time.

difficult than if the fission products had been separated out in the reprocessing plant. Nevertheless, my colleagues and I are confident that fabrication techniques can be developed, especially if we choose to fabricate the fast reactor fuel using the gel route which my Harwell colleagues have been working on for several years. This gel route fabricates fuel into perfect spherical particles which can then be loaded automatically and remotely into the fast reactor fuel pins. Once that process has been developed successfully for straightforward plutonium/uranium oxide fuel, we would not anticipate great difficulties in extrapolating it to deal with fission products simultaneously. We will have available, therefore, technology which is capable of retaining plutonium in an "inaccessible" form throughout its entire lifetime once it is both being created and used for fast reactors and that fast reactor programme has reached a mature state.

It is this idea which is the core of the CIVEX proposal which Dr. Chauncey Starr and I have put forward with our colleagues. In our view, it very largely eliminates proliferation dangers from the fast reactor in the longterm, but I would like to reiterate that no technical "fix" by itself can be a solution to proliferation dangers. It is always possible for a suitable sophisticated organisation — and that certainly includes many governments — to manufacture nuclear weapons if it is really determined to do so. All the CIVEX proposal has done, therefore, is to ensure that it is, roughly speaking, just as difficult and just as time-consuming to divert plutonium from the fast reactor cycle as it would be to divert if from freshly-discharged thermal reactor fuel. In my view, we should leave it to future generations to decide whether that is a worthwhile objective. It is not obvious to me that it necessarily is so, but I

TABLE 1

Key Fission Products for CIVEX Process
(450 kg assembly)
PWR Sub-assembly — 10 days After Discharge

Fission Product	Activity Ci MeV × 10^5	½-Life Days	Percentage Recycled
95_{Nb}	4.38	35	30
95_{Zr}	3.85	64	30
103_{Ru}	2.60	39	50
$106_{Ru}/106_{Rh}$	0.64	368	50
$144_{Ce}/144_{Pr}$	0.29	285	11

think it is worthwhile to identify the options that we will have in the future if we remain concerned about this matter in the next century.

Table 1 gives a list of the important fission products which matter for the application of this CIVEX process. The table shows the gamma activity and half-life for each of the isotopes and the final column gives a percentage of each which can be recycled together with uranium and plutonium by suitable modification of the reprocessing flowsheet. These last estimates are due to my colleagues at Harwell and have been described in the paper which Dr. R.H. Flowers gave at the Washington Conference.[4].

Figure 4 shows the results of that particular technology if applied to the recycle of plutonium in a mature fast reactor system operating next century. The first curve in Figure 4 shows the activity of a fast reactor fuel assembly as a function of time after removal from the reactor and the second curve shows the activity of the fresh fast reactor fuel if prepared by a CIVEX process which recycles isotopes to the percentage described in Table 1. Clearly, if that recycle were a leisurely

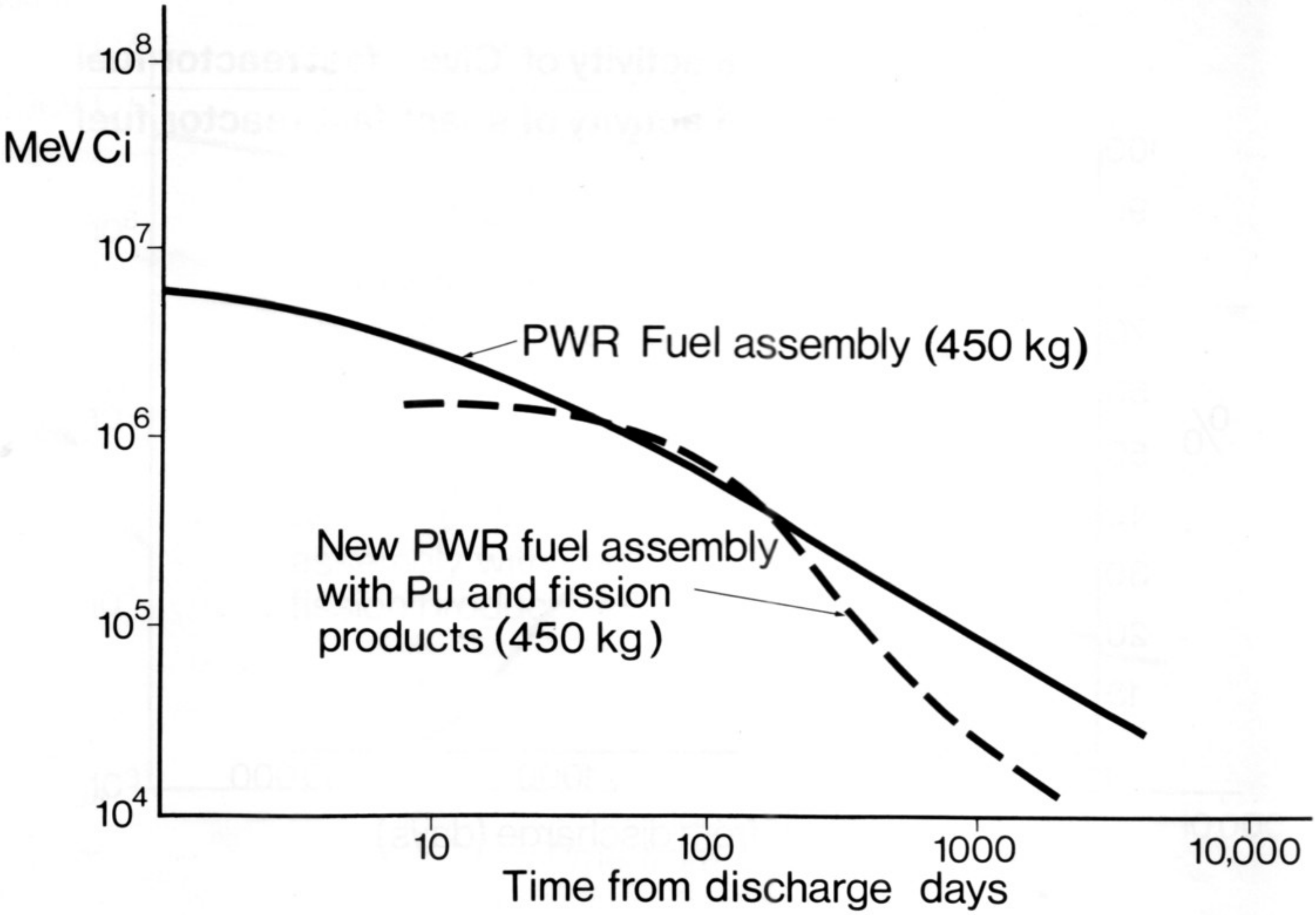

Figure 6 — The gamma activity of a PWR fuel assembly and a new CIVEX assembly for a PWR.

one, then the activity in the recycled fuel would be small because these isotopes would have had time to decay. However, if the recycle time is shorter than or comparable to one year, then the activity of the fresh fuel is comparable to that of the old fuel. This is shown as a percentage plot in Figure 5 and, because Figure 5 is shown to an arithmetical scale rather than the logarithmic scale of Figure 4, it is easy to see that the opportunity to recycle a high degree of radioactivity has a maximum at around about the same time that we must achieve for fast reactors in order for them to be economically viable.

Since the presentation of these ideas at the end of February, most comments and questions have concerned the prospect for applying the same idea to the recycle of plutonium in thermal reactors. This was, in fact, mentioned by Drs. Levenson and Zebrowski of the Electric Power Research Institute during the course of the Washington meeting and I agree that it is a matter which deserves attention. However, it is my present view that close examination will show that this is not really worthwhile and I would not, therefore, wish to advocate it. There are several reasons why that is my view and I would now like to review them briefly.

First, I must acknowledge that some of the advantages of the fast reactor fuel cycle are shared with thermal reactor recycle of plutonium. Both make plutonium "inaccessible", both can incinerate plutonium and both control the total plutonium population. Furthermore, thermal reactors are immediately available. But they do not give independence of uranium supply and thermal recycle of plutonium only adds about 20 per cent of energy value to our uranium resources and therefore, in my judgement, thermal recycle will be undertaken only in a few advanced countries for a relatively limited interim period before fast reactors are commercially available.

For this rather limited application, let us now see if the CIVEX idea can be used.

I am satisfied that, from the technical point of view, the same ideas proposed for CIVEX in the fast reactor fuel cycle could be applied also to plutonium recycle in thermal reactors. Using the results of Table 1, we can calculate the amount of activity which can be returned to thermal reactor fuel. The results, which are again due to my Harwell colleagues are plotted in Figures 6 and 7. These correspond exactly to Figures 4 and 5 but are applicable to thermal reactors rather than fast reactors. Apart from unimportant details, the figures are similar to those for fast reactors. They do demonstrate, therefore, that it is possible to retain plutonium in an "inaccessible" form in thermal reactor recycle provided that recycle is done rapidly.

But I do not think there is any practical possibility of rapid recycle being done. There is, at the moment, worldwide a vast surplus of unreprocessed fuel compared with reprocessing capacity. There is no prospect of that trend being rapidly reduced and, in my judgement therefore, we shall have throughout this century more plutonium than can possibly be used, either in thermal or fast reactors. Furthermore, a large fraction of that plutonium will be old plutonium which might well be closely associated with long-lived actinides but cannot possibly be associated with the fission products listed in Table 1, because they will all have decayed. Therefore, I see no practical opportunity for

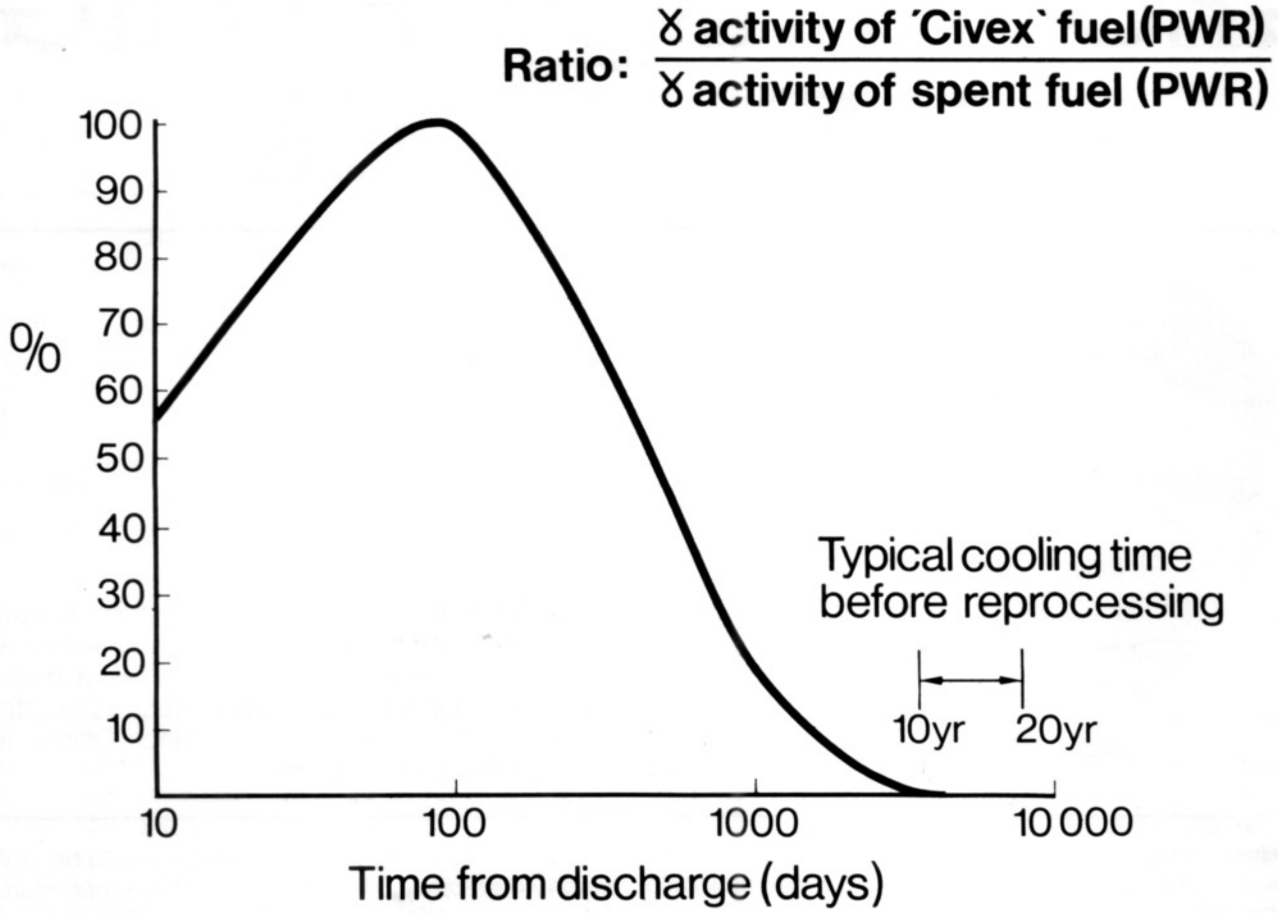

Figure 7 — The ratio of the gamma activity of CIVEX fuel for a PWR to that of spent fuel from a PWR.

recycling "new" plutonium into thermal reactors in this century. Indeed, I cannot envisage a situation in which significant quantities of thermal reactor fuel would be reprocessed either in a conventional or CIVEX type plant before it has been in a cooling pond for a number of years. Furthermore, even if a CIVEX project for thermal recycle was launched today, it would be at least ten years before the fuel cycle would be fully proven and available on a commercial scale. Finally, the use of plutonium recycle in thermal reactors can only be an interim measure until fast reactors are available and therefore, as I see it, even if it was judged desirable to recycle plutonium in a thermal reactor using a CIVEX type plant, the opportunity to do so on any scale would, in practice, be overtaken by the arrival of fast reactors — which are needed to tap the energy resource of uranium-238.

To sum up: CIVEX could be used for thermal recycle of plutonium but it would take more than a decade to launch it and it would not be fully operational with "inaccessible" plutonium for several decades after that.

But, in my opinion, thermal recycle will only be worthwhile in a few advanced countries with large nuclear programmes and those are exactly the countries likely to get fast reactors at an early date. The arrival of fast reactors will therefore, in my opinion, overtake the opportunity to use CIVEX for thermal recycle of plutonium.

For all these reasons, I believe that where thermal reactor recycle is done at all, it will be done with careful institutional and conventional safeguarding techniques. Therefore, if CIVEX withstands the technical scrutiny of the international community, I recommend that we concentrate on preparing it as an option for use with fast reactors if it turns out to be required.

To conclude, I have reviewed the use of plutonium in three types of situations: to launch fast reactors, to maintain fast reactors and for recycle into thermal reactors in the interim period. I have pointed out that, in a mature fast reactor economy of the next century, a technical evolution of the fuel cycle can make it very difficult to divert plutonium from the CIVEX fuel cycle itself and that, therefore, if there really are proliferation dangers from handling plutonium, they are likely to be larger during the interim period of some decades before fast reactors arrive than they will be ultimately. Let us hope that a general consensus develops to this point of view quite soon because the present uncertainty concerning the future of nuclear power and the stimulus it gives to every nation to preserve its nuclear power independence, is itself a proliferating trend. We ought to be building up interdependence and confidence between nations and that, in my view, would be a more significant contribution to non-proliferation objectives than the technical ideas which I have outlined here today.

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2. Victor Gilinsky (Nuclear Regulatory Commission). Nuclear Energy and Nuclear Proliferation. Chemical and Engineering News. 28th November, 1977.

3. Atom 258 April, 1978.

4. Atom 259 May, 1978.

GEOTHERMAL ENERGY AND THE UK

In this article,* Dr. J.D. Garnish of the Energy Technology Support Unit (ETSU) at Harwell, reviews the current status of geothermal energy research and its prospects in the UK. Dr. Garnish, as a member of ETSU is responsible for supplying technical advice to the Department of Energy on geothermal matters and is the Project Officer for the Department's geothermal R & D programme.

To a great extent, the technology of extracting and using geothermal energy already exists and is in widespread use elsewhere in the world (Armstead 1977; Barbier & Fanelli 1977). The problem is to assess how far this overseas experience can be extrapolated to the UK. The exploitation of geothermal resources is more often limited by the cost of an operation than by unsolved technical problems, and the cost of a particular project is very dependent on local conditions. While it is possible, therefore, to obtain quite good cost data from overseas projects, it is far less easy to predict what the costs would be in the UK situation. We know that the thermal resource is very large — in the limit, indeed, it can be regarded as the entire heat content of the crust at all depths within reach of drilling technology (8 to 10 km). In the UK this heat content exceeds 10^{18} J/km²† (Garnish 1976). How much, if any, of this resource will ever be exploited in the UK is controlled almost entirely by the final cost of the energy which could be made available to users relative to that from other energy sources. Work in the UK is at far too early a stage to make any positive predictions; the object of this paper is simply to present some preliminary indications.

Power generation

Much of the experience gained overseas has originated from the use of natural steam fields for power generation. An idea of the extent of such activity can be judged from Table I. While such evidence is useful in demonstrating the amount of experience that is accumulating in the use of geothermal sources and the resulting confidence in their use, it must be recognised that natural steam fields are likely to be found primarily in the vicinity of active tectonic plate boundaries (Figure 1 — see also Haenel 1977). As the UK is remote from any such boundary, the possibility of finding such a field within the UK can be discounted. It is conceivable, however, that other (dry rock) sources in the UK could be developed which would provide heat at comparable temperatures (200-250°C) and in this case the overseas experience on the use of water resources at these temperatures could be of interest. Currently, the cost of the *surface* equipment for generation of electricity from such sources is of the order of \$400-500/kW(e) (Leardini 1977) and there is no reason to suppose that costs would be significantly different in the UK. Plant for generation from lower temperature sources may be more expensive, however, — around \$1000/kW(e) — and this coupled with the lower thermodynamic efficiency could make power generation from lower grade sources unattractive. The costs of extracting heat from UK sources will undoubtedly differ from those reported from, say, the USA or New Zealand and it is important to note that boreholes up to 5000m deep would be required to reach the higher temperature range in the UK. Such boreholes may well cost up to £2 million each. As an order-of-magnitude estimate, therefore, the *resource* cost of geothermal heat suitable for power generation in the UK may add another \$500-1000/kW(e) leading to *total* capital costs of \$1000-2000/kW(e).

Direct use of heat

Of more direct and immediate interest to the UK is the work that has taken place in France over the last seven or eight years. In the context of geothermal energy, the geology of northern France is comparable with that of much of the UK. The geothermal gradient in both countries, the rate of increase of temperature with depth, is about that expected in a tectonically stable area i.e. about 30°C/km. The city of Paris lies close to the centre of a large sedimentary basin, a region where potentially water-bearing rocks can be found at depths of several thousand metres. At such depths, therefore, water at temperatures of 60-100°C may be encountered and useful heat extracted from such waters. Several installations have been built around Paris within the last few years which are using these geothermal waters to

*This article appears also in the September issue of the Institute of Physics publication "Physics Education". The views expressed are those of the author.

†10^{18} J is equivalent to the heat content of 37 million tonnes of coal.

TABLE I

The Present State of Geothermal Development

Country	*Electrical generating capacity (MWe)* Installed (1976)	Estimated (1985)	Estimated (2000)	*Non-electrical uses in 1976 (MWt)* Residential & Commercial	Agricultural	Industrial
USA	522	6,000	20,000	15	—	—
Italy	421	800	—	—	1	20
New Zealand	202	400	1,400	215	small	125
Mexico	78.5	400-1,400	1,500-20,000	—	—	—
Japan	70	2,000	50,000	10	5	small
Philippines	—	300	—	—	—	—
El Salvador	60	180	—	—	—	—
Nicaragua	—	150-200	300-400	—	—	—
Iceland	2.5	150	500	350	39	50
Costa Rica	—	100	—	—	—	—
Guatemala	—	100	—	—	—	—
Honduras	—	100	—	—	—	—
Panama	—	60	—	—	—	—
Taiwan	—	50	200	—	—	—
Portugal (Azores)	—	30	100	—	—	—
Kenya	—	30	60-90	—	—	—
Guadeloupe	—	30	—	—	—	—
Spain	—	25	200	—	—	—
USSR	5.7	20	—	114	5,011	—
Turkey	0.5	10	—	100 (planned)	—	—
Canada	—	10	—	—	—	—
Hungary	—	—	—	770	363	—
France	—	—	—	40	—	—

provide a major portion of the space-heating needs of a number of apartment complexes (Clot, 1977).

The method of use is illustrated in Figure 2. In its simplest form, only one well is required, extracting hot water from the reservoir rocks in exactly the same way as an oil well taps an oil-bearing formation. In practice, the use of a second well to dispose of the waste fluids is becoming more and more common. These deep ground waters invariably contain significant quantities of dissolved solids and reinjection provides an environmentally acceptable method of disposal. It is important, of course, to ensure that the reinjected cool water does not find its way back to the point of extraction too

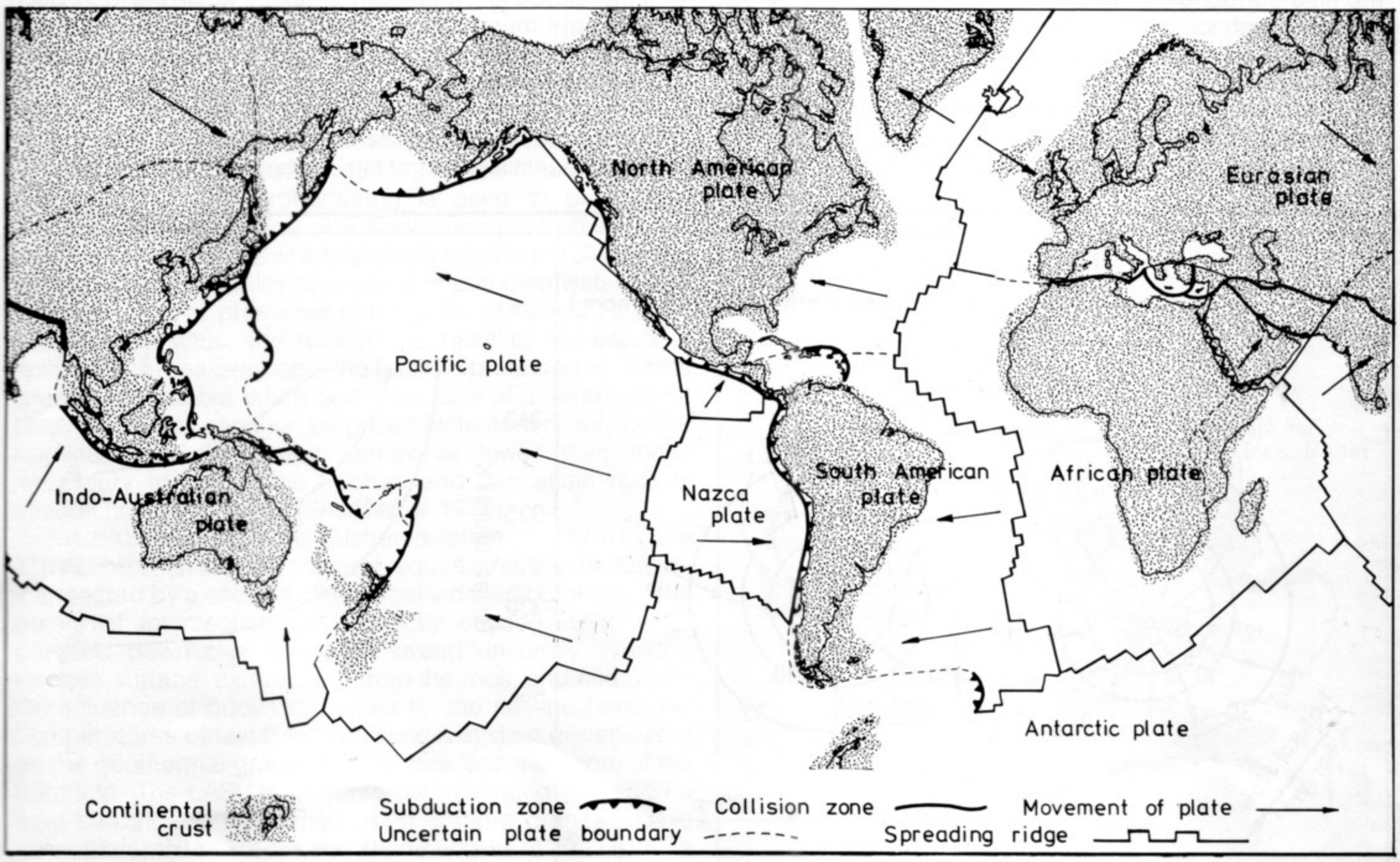

Figure 1. The Earth's crust consists of a set of rigid plates which are moving relative to one another. The resulting stresses at the plate boundaries give rise to earthquakes and volcanos. Heat flow and geothermal gradient in these regions is higher than average.

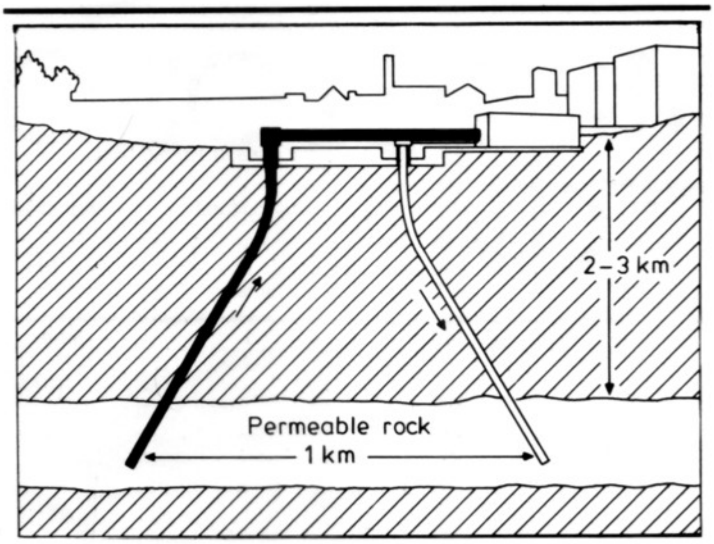

Figure 2. Typical scheme for the exploitation of thermal waters. In practice, the wells may be deviated as shown or drilled vertically and connected by surface pipeline.

soon because if it did it would reduce the life of the system. The precise layout of wells will depend on the detailed geology of the reservoir but a typical separation of the wells would be 1000m. The principles of such a system are illustrated in Figure 3, which shows the results off a computer simulation of one layout considered for a particular installation. It will be seen that this model was testing the possibility of using three production wells and two injection wells. As will be seen, one of the proposed production wells (P_2) would have been too close to a reinjection well, so that cool water would have reappeared at the production well within eight years. Note, however, that the predicted life of the field surrounding the other two production wells should be very much longer.

A point to note here is that geothermal energy is, in practice, a non-renewable resource. Exploitation at useful rates is equivalent to mining the heat stored in the crust; the rate of heat flow through the crust — or rate of replenishment — is extremely low. The average rate of crustal heat flow for a tectonically stable area is about 60mW/m^2 (Lee & Uyeda 1965), so that the heat extracted from a given field would not be replaced in human timescales.

For the particular example illustrated in Figure 3, the scheme finally adopted uses two production wells and two reinjection wells; peak production rates of 200m^3/h of water at 65°C are achieved. These can supply a peak power of 13 MWt, which is about 50 per cent of the peak demand of the space heating system, but over a year they provide nearly 80 per cent of the total energy required. (The peak demands of the system are met by auxiliary fossil-fuel boilers). The total cost of the geothermal components of the scheme was about £2.5 million (in 1975). The French authorities estimate that the overall running costs of the system (including amortisation of capital) are about 15 per cent lower than for a comparable oil-fired system at current fuel prices. Preliminary calculations suggest that the overall cost of heat extracted is relatively insensitive to well depth between 2000m and 3500m as a deeper well, though more expensive, will tap higher temperature fluids and can therefore produce a greater thermal output. Much more work needs to be done in the UK before we will know the extent to which this information is relevant but the French experience must be regarded as encouraging.

The 'hot dry rock' problem

All commercial exploitation of geothermal energy so far has relied on the presence of naturally heated ground water. Since the occurrence of such waters is limited both in its depth range and its extent, this places a very considerable restriction on the fraction of the thermal resource which may be exploited. More than 90 per cent of the accessible crustal rocks are of such low permeability that they can be regarded as dry. Furthermore, certain igneous rocks such as granite tend to contain high concentrations of radioactive elements (U, Th and K) which contribute significantly to the heat flow and therefore the temperature gradient within the rock. Such rocks might therefore be expected to be prime targets for geothermal exploitation, were it not for the fact that their permeability is so low.

The problem is that rocks are, in general, very poor thermal conductors. In order to extract heat at an economic rate it is necessary to circulate the heat transfer medium (i.e.

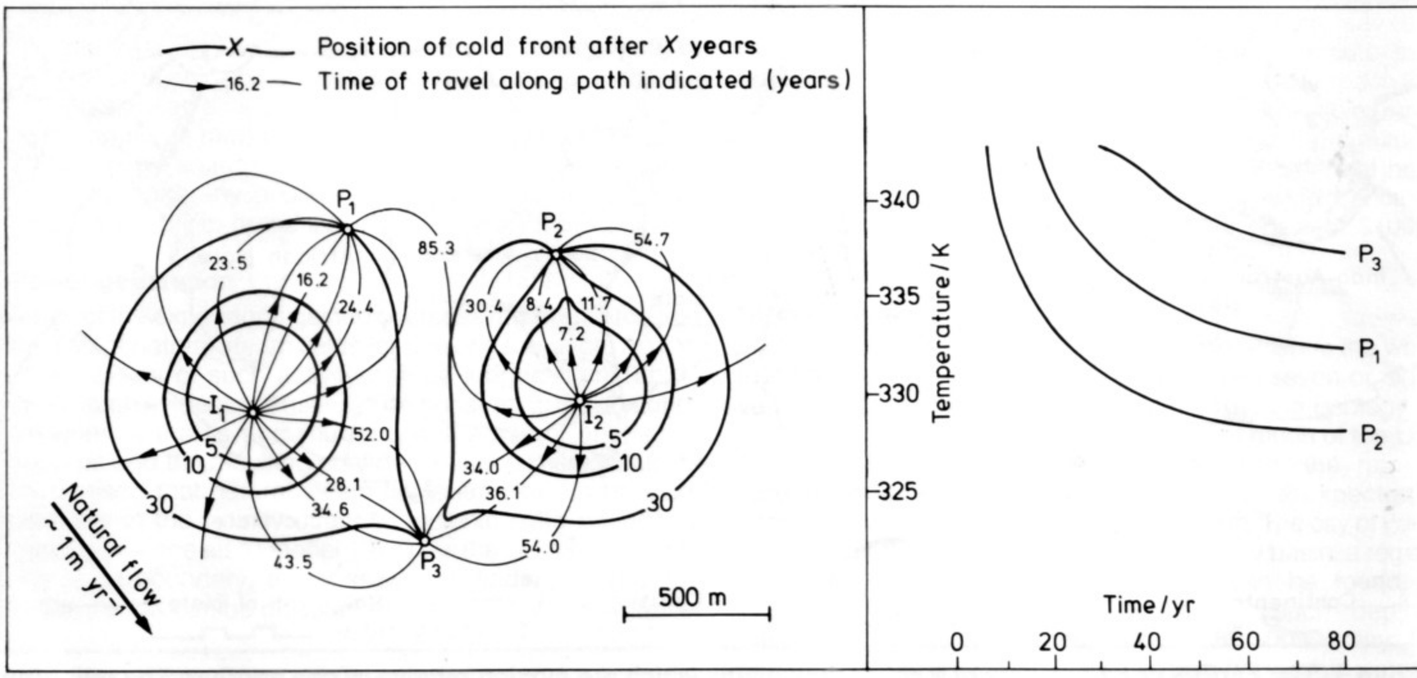

Figure 3. Computer modelling of a particular pattern of production (P) and reinjection (I) wells considered for a scheme in Paris. Note the way in which the output temperatures are predicted to vary with time.

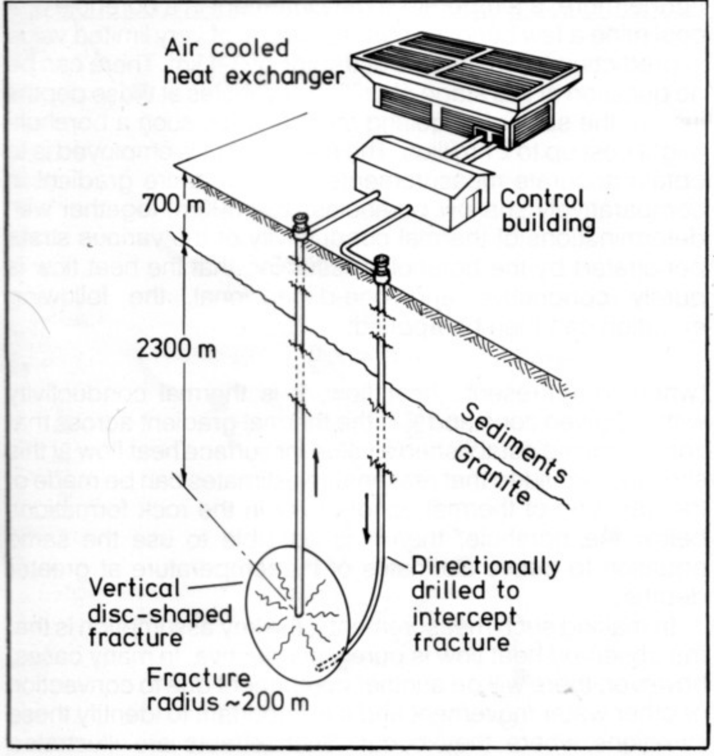

Figure 4. Schematic diagram of the 'hot dry rock' experiment at Los Alamos.

water) over a very large heat transfer surface. Such a condition occurs naturally in porous rocks such as sandstone, but exploitation of the heat content of impermeable rocks will require the artificial generation of heat transfer surface. The problem reduces, then, to one of finding acceptable methods of generating such a surface. Nuclear or chemical explosions large enough to produce an adequate volume of fractured rock would in general be unacceptable because of the seismic effects they would produce (Berman 1975). World interest at present is centred on a 'proof-of-concept' experiment being carried out by Los Alamos Scientific Laboratory (LASL) in New Mexico, USA. In this experiment, hydrofracturing is used to produce a suitable fracture surface. (Hydrofracturing is in principle a very simple technique which is widely used in the oil industry to improve permeability. It consists of pumping water into a borehole until, at pressures of the order of 100-200 kg/cm^2 above hydrostatic, the rock at the base of the borehole splits). In its idealised form, the fracture produced at depths greater than about 600m takes the form of a large vertical disc. This crack can then be grown quite controllably by the application of pressures somewhat lower than those necessary to initiate the fracture and can attain radii of several hundred metres (Smith *et al.* 1975).

The LASL experiment is illustrated schematically in Figure 4. It will be seen that the concept requires that the fracture be intersected by a second, directionally-drilled borehole. If the points of intersection are correctly chosen, cold water pumped down one hole will sweep uniformly over the fracture surface, extract heat from the rock, and rise under the influence of buoyancy forces up the second borehole. Temperatures obtainable from such a system depend only on the geothermal gradient in the rock and the depth of the borehole. The LASL team have demonstrated that such a loop can indeed be formed deep within a granite (in this case, at depths of 3000m and a temperature of 200°C) and a thermal extraction test is now under way. This experiment is being run as an international project under the auspices of the NATO Committee on the Challenges of Modern Society, and a number of scientists from other countries, including one from the UK, have participated. Similar though smaller scale projects are now being initiated in a number of countries, to gain experience and to develop the relevant techniques.

Work in the UK

Although a number of UK universities and the Institute of Geological Sciences have been involved for many years in various aspects of geothermal development overseas, work directed towards the prospects for the UK itself has been in hand for only a couple of years. Following the publication of Energy Paper No. 9 (Garnish 1976), which summarised the information then available, the Department of Energy instituted a national programme of research. The current first phase of the programme is aimed at acquiring an overall, 'broad-brush' view of the geothermal resource in the country, with more detailed data collection in the areas of greater apparent interest. For any part of the country considered for geothermal development, answers are being sought to the following questions:

(i) how does the temperature vary with depth? i.e. what is the heat flow and thermal conductivity of the different strata, are there complicating factors such as ground water circulation or radioactive heat production which will distort the pattern of surface heat flow and lead to errors in extrapolating to temperatures at depth?

(ii) what is the nature of the rock at depths of interest? i.e. is water present in a rock that is sufficiently permeable to permit economic rates of water withdrawal or, conversely, is the rock sufficiently impermeable to allow a Los Alamos type of development?

(iii) finally, but almost as important, does an appropriate market exist for the heat produced? Initial calculations

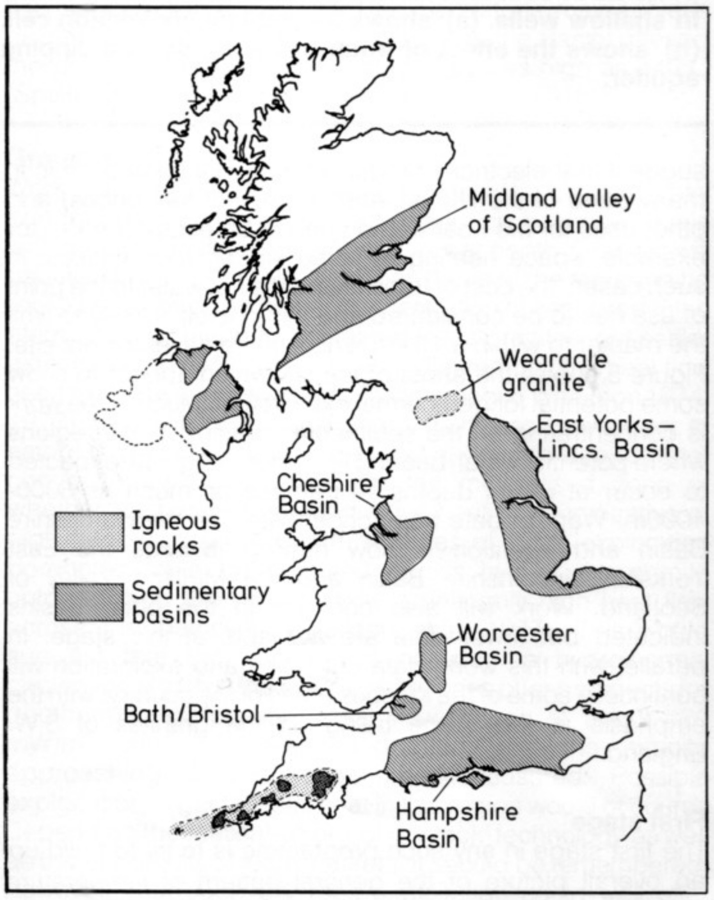

Figure 5. Areas of the UK already identified as of potential geothermal interest.

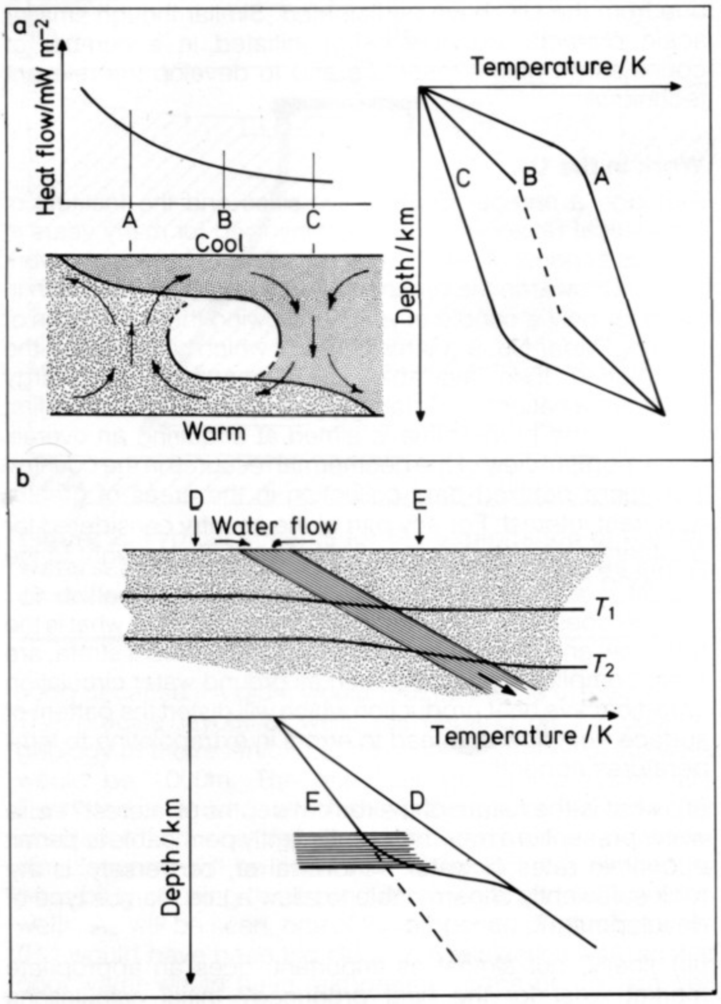

Figure 6. Movement of ground water will distort the patterns of observed heat flow and temperature gradient in shallow wells. (a) shows a complete convection cell, (b) shows the effect of water travelling down a dipping aquifer.

suggest that electricity production may not be economic in many parts of the UK (at least at present fuel prices) and other uses for the heat would need to be established — for example, space heating or some industrial processes. In such cases, the cost of transmitting the hot water to the point of use has to be considered and this in itself is likely to limit the market to within a 10 km radius of the development site. Figure 5 shows the areas of the UK which appear to show some potential for geothermal exploitation. Much of the work is concentrating on the sedimentary basins, those regions where potential water-bearing formations might be expected to occur at useful depths — perhaps as much as 3000-4000m. Work to date has concentrated on the Hampshire Basin and attention is now moving towards the East Yorkshire/Lincolnshire Basin and the Midland Valley of Scotland. Work will also continue in the other basins indicated but fewer data are available at this stage. In parallel with this work, data collection and exploration will continue in some of the igneous areas of the country, with the emphasis at this stage being on the granites of S.W. England.

First stage

The first stage in any such programme is to try to build up an overall picture of the general pattern of temperature variation with depth across the country. Prior to this work, some temperature data were available from the mining areas but other regions were almost completely undocumented. Furthermore, a temperature measurement in a borehole or a coal mine a few hundred metres deep is of very limited value in predicting temperatures at depths of 3-4 km. There can be no question at this stage of drilling boreholes at those depths just for the sake of acquiring thermal data; such a borehole might cost up to £1 million. The method that is employed is to obtain accurate measurements of temperature gradient in comparatively shallow boreholes (200-300m) together with determinations of thermal conductivity of the various strata penetrated by the borehole. Assuming that the heat flow is purely conductive and one-dimensional, the following equation can then be applied:

$$q = k.\frac{dT}{dz}$$

(where q represents heat flow, k is thermal conductivity within a given zone and $\frac{dT}{dz}$ is the thermal gradient across that zone). Having established a value for surface heat flow at this site, and provided that reasonable estimates can be made of the variation of thermal conductivity in the rock formations below the borehole, then it is possible to use the same equation to derive estimates of the temperature at greater depths.

In making such measurements, the key assumption is that the observed heat flow is purely conductive. In many cases, however, there will be another component due to convection or other water movement and it is important to identify these situations where they occur. Such effects are illustrated qualitatively in Figure 6 (see also Haenel 1977). For this reason, the data from the upper 50m of a borehole are rarely any use because of the complicating effects of shallow water circulation. Problems arising at deeper levels can sometimes be identified from observed distortions in the temperature v. depth curve, but more commonly they have to be inferred from other geophysical or geochemical measurements. Because of these uncertainties, data from a single borehole can rarely be regarded as definitive but a clear pattern can usually be discerned from an assemblage of boreholes across a given area. With this end in view, a team from Oxford University has been taking over and measuring temperatures in boreholes drilled for other purposes in various parts of the country, and is now beginning to build up a picture of the heat flow in the UK.

The first results

The first results suggest that the heat flow and temperature gradients are about those expected for a tectonically stable country like the UK, i.e. a mean heat flow of about 60 mW/m^2 and gradients of 25-30°C/km. There is, however, some evidence of zones of enhanced heat flow — perhaps 20 per cent greater than normal (Oxburgh *et al* 1977). There are in addition a few sites where heat flow seems to be considerably greater. If these findings are confirmed, then the significance is that higher temperatures could be achieved at a given depth and the cost of any exploitation would be correspondingly reduced. In parallel with this work the Institute of Geological Sciences have been examining old mining records, borehole logs, etc, in order to compile measured temperature data in those areas where such work has been undertaken (Burley 1977). Particularly for the Hampshire and East Yorkshire Basins, it has been possible to compile data from quite a number of boreholes, some as deep as 2500m. Admittedly the data are of very variable quality — in most mining and drilling operations the measurement of temperature receives rather cursory attention — but put together they provide a fairly coherent picture. Figure 7 shows some of the results of the work of these two teams applied to the East Yorkshire Basin. It will be seen that borehole temperature measurements do exist down to 1500m but the data are of variable quality. (For

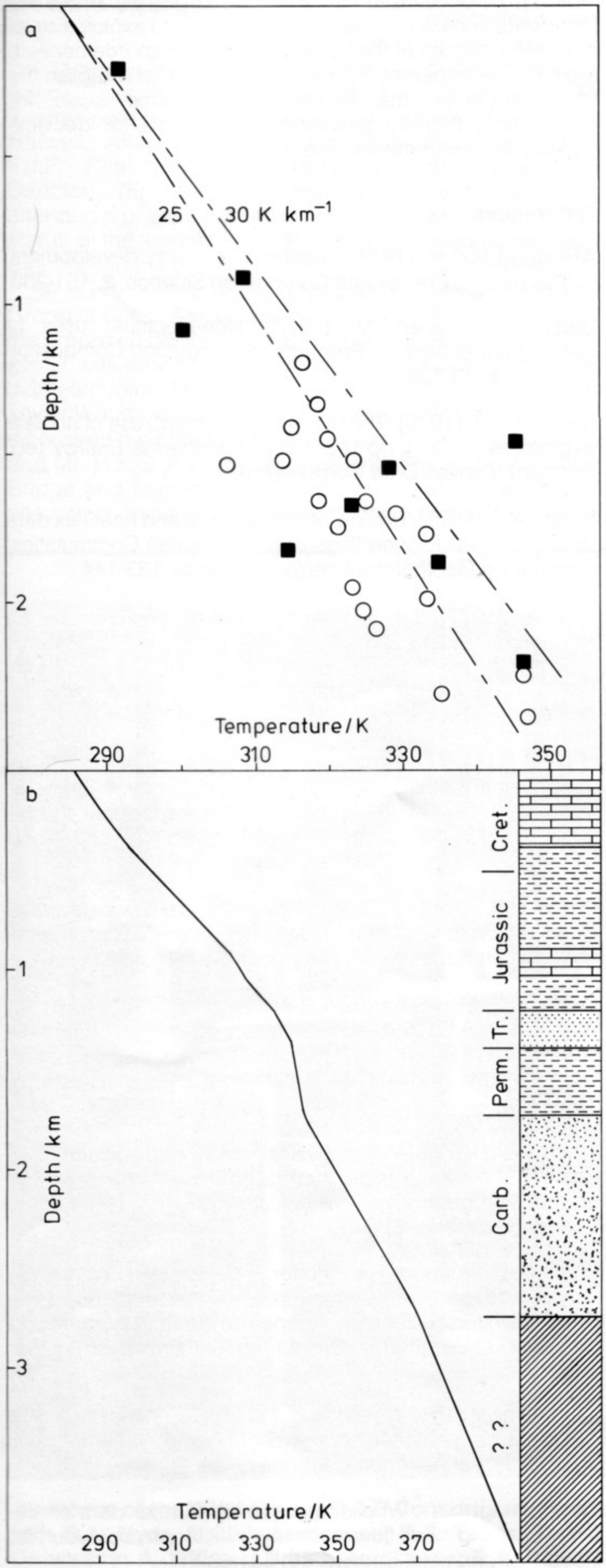

Figure 7. Thermal conditions in the E.Yorks/Lincs Basin. (a) temperatures observed in boreholes (from Burley 1977); (b) temperature profile predicted from heat flow measurements (from Oxburgh et al 1977).

technical reasons, however, it is anticipated that the data indicated by square symbols in the Figure will be more reliable than those indicated by circles). The second part of the Figure shows the predicted variation of temperature with depth, based on heat flow measurements. From this, it may be anticipated that temperatures up to 100°C may be achieved at depths of around 3000m. The next stage in the process will be to determine at what levels in the Basin water-bearing formations occur.

Hampshire Basin

Much more attention has been given to the western part of the Hampshire Basin where a considerable number of oil exploration holes have been drilled. The temperature data are shown in Figure 8, from which it will be seen that the mean gradient in this Basin is 30°C/km, only slightly less than that observed in the Paris Basin. Early in 1977, a borehole was drilled at Winterborne Kingston, Dorset, to more than 3000m. The primary purpose of this borehole was to provide geological data for the Department of Energy's offshore oil exploration programme, but it also proved extremely valuable to the geothermal programme. It not only enabled temperature predictions to be confirmed but permitted positive identification of water-bearing formations. The results of temperature-logging in this hole to a depth of 2400m are also shown in Figure 8. Two possible geothermal aquifers were penetrated, the Bridport Sands at about 1000m and the Bunter Sandstone at about 2300m. The observed temperature in the Bridport Sands at this site was a little over 40°C, probably too low to be of major interest, while the water in the Bunter Sandstone was at 85°C. The permeability of the sandstone proved to be good but the water is a very concentrated brine which may well prove difficult to exploit. Nevertheless, as the first test of geothermal predictions in a UK sedimentary basin, the results must be regarded as encouraging. It may also be noted that other geophysical work carried out in the Basin by IGS suggests that the New Red Sandstone may achieve depths in excess of 4000m elsewhere in the Basin, offering the possibility of obtaining temperatures as high as 140°C (Smith 1977).

Granites

Work so far in the granites of SW England has concentrated on measurement of surface heat flow, again with a view to predicting temperatures at depth. Granites will usually show higher heat flow than those of the surrounding rocks because of the higher concentration of heat-producing elements (U, Th and K) contained in the granites, but earlier work in the tin mining areas had indicated that the heat flow seemed to be unusually high (Tammemagi & Wheildon 1974, 1977). The aim of this first year's work has been to try to establish whether these were local anomalies due to water convection within fractures in the mineralised zone or whether they were true conductive heat flows indicative of high temperatures at depth. A series of 200m exploration boreholes have been drilled across two of the granite outcrops and the results show a uniformly high heat flow across the batholith (Wheildon *et al* 1977). This would suggest that the anomaly is not due to hydrothermal circulation and that the granite really does offer prospects for geothermal exploitation. Heat flow values of about 120 mW/m^2 and temperature gradients in the granite approaching 40°C/km have been measured. Possible exploitation of geothermal heat in this region would of course depend on the realisation of 'hot dry rock' technology as well as the availability of local markets. It should be remembered, however, that such dry rock exploitation could well offer temperatures of 200°C or more and that applications could include both process heating and electricity generation. It

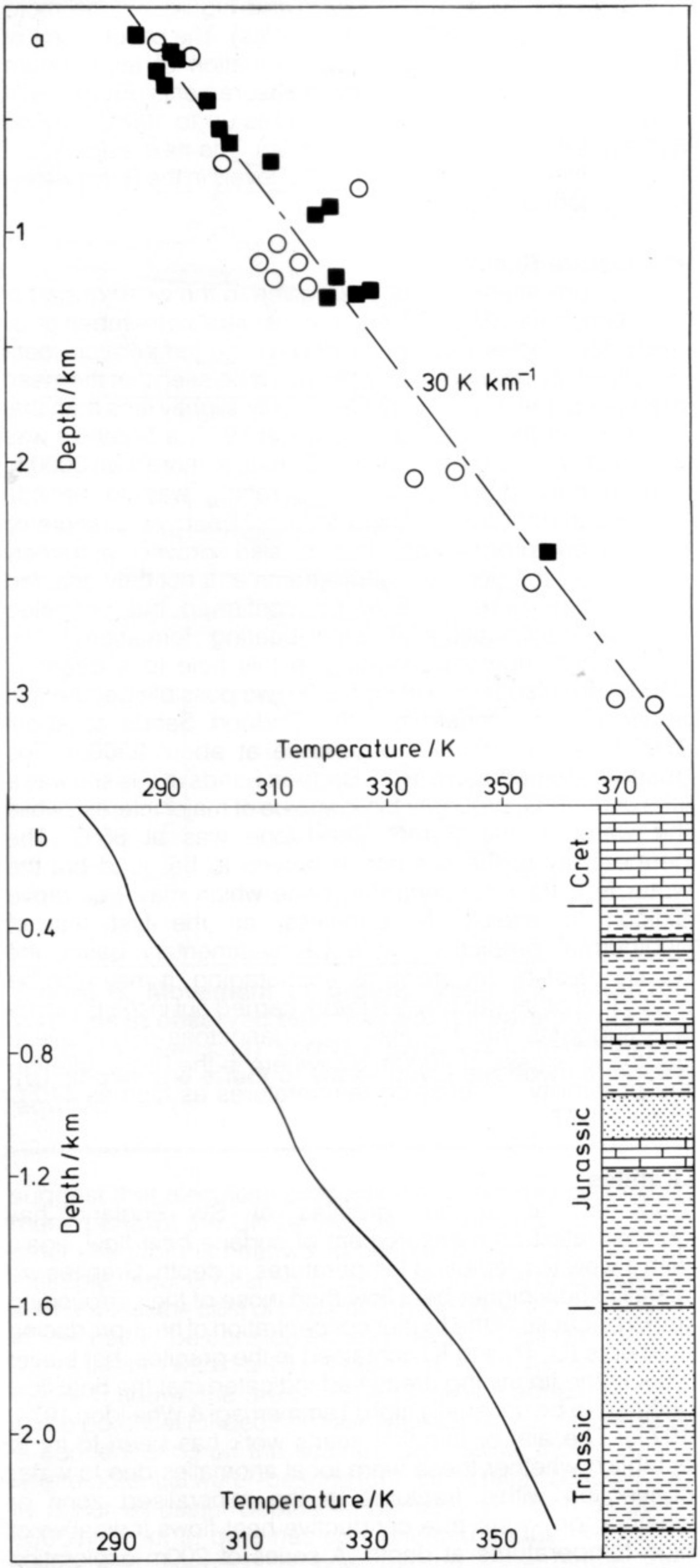

Figure 8. Thermal data from the Hampshire Basin (a) temperatures observed in boreholes (from Burley 1977); (b) temperature profile measured in the Winterbourne Kingston borehole, Dorset (from Oxburgh et al 1977).

seems unlikely that power generation from such sources would prove economic in present-day terms, but it may well be competitive with generation from fossil fuels at some later date. Unlike the other 'alternative' energy sources, geothermal energy does offer the possibility of generation of 'firm' (i.e. continuous) power.

Conclusions

It may be concluded that, while it is too early to make any firm predictions, it may well prove possible to exploit a small but useful fraction of the huge geothermal resource beneath the UK. The experimental programme aims to establish the technical facts, the economics and time scale for exploitation, thereby providing a firm basis for decision making by government or industry.

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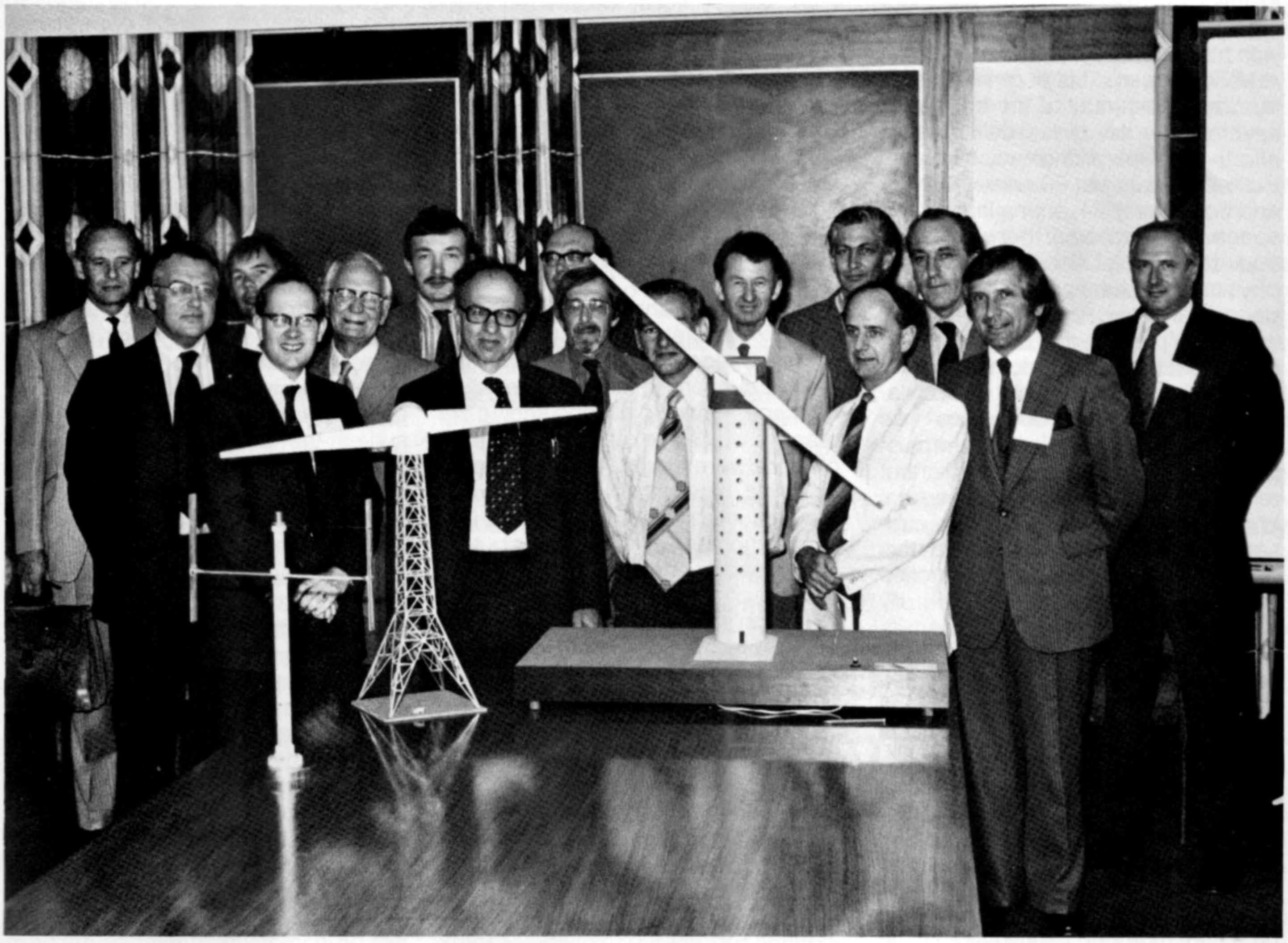
Chief Scientist sees work on wind energy

On 31st May, Professor Sir Hermann Bondi, Chief Scientist, Department of Energy, paid one of his regular visits to Harwell. After discussions with Dr. F.J.P. Clarke, Harwell's Research Director (Energy), Sir Hermann attended a presentation on the current status of the aerogenerator R & D programmes in the UK.

Mr. G.R. Ketley of the Dynamics Group of British Aerospace described the proposed design of a 3·8 MW horizontal axis aerogenerator with a 60m diameter rotor. Mr. R.E.D. Burrow of Taylor Woodrow Construction Limited, discussed the concrete tower support and Mr. H.S.G. Knox of the Cleveland Bridge and Engineering Co. Ltd., the alternative metal lattice support: for environmental reasons it is necessary to develop both types of support. The electric generator would be at the top of the tower. Approval is at present awaited for a detailed design study funded by the Department of Energy, to enable a prototype to be built. Dr. P.J. Musgrove of Reading University described the principles of his concept of a vertical axis aerogenerator while Dr. T.A. Willmer outlined the wind-tunnel testing programmes and mathematical modelling currently being undertaken by British Aerospace. They work to aircraft reliability standards and are considering using titanium blades to avoid corrosion on marine sites. Taylor Woodrow Construction Limited are responsible for the tower design for this device which has the advantages of not needing to be oriented into the wind, (a feature which may reduce capital cost) and of variable geometry which permits speed control. This programme is funded by the Department of Energy. Sir Hermann said he was very pleased with the presentations and that every effort must be made to make aerogenerators economic and to progress to higher power machines. There was a special interest, he added, in aerogenerators for isolated areas and for developing countries where reliability and minimum maintenance were vital. On a more general level, Sir Hermann said that it was necessary to work on all the renewable sources of energy. Britain was particularly well-placed for extracting power from waves and well-placed also (but not unique) for the exploitation of wind power. We were less in the forefront for solar and geothermal power but the utilisation of tidal power could be a front runner.



Members of the Wind Energy R & D Consortia who made presentations at Harwell. The photograph shows from the left: E.A. Hyde, British Aerospace; R.S. Taylor, Taylor Woodrow Construction Ltd; Dr. P.J. Musgrove, Reading University; A. Willmer, British Aerospace; R.A. Roach, Taylor Woodrow Construction Ltd; D.F. Warne, Electrical Research Association; Sir Hermann Bondi, Chief Scientist, Department of Energy; M. Whitelegg, South of Scotland Electricity Board; R.E.D. Burrow, Taylor Woodrow Construction Ltd; G.R. Ketley, British Aerospace; H.S.G. Knox, The Cleveland Bridge and Engineering Co. Ltd; D. Tyndal, The Cleveland Bridge and Engineering Co. Ltd; Dr. F.J.P. Clarke, Harwell; P. Rendell, British Aerospace; Dr. B. Lindley, Electric Research Association; R.G. Dancy, British Aerospace.

BOOK REVIEWS

The Self-Splitting Atom

A history of the Rutherford-Soddy Collaboration

by Thaddeus J. Trenn

Taylor and Francis, London 1977

It is not often in these pages that attention is drawn to a book concerning itself with a fundamental research topic, and an historical one at that. However in this case the work is of particular significance for scientists concerned with atomic energy: for here is where it really all began. This book provides a fascinating account of the brilliant, in several aspects unique, collaborative effort of two young scientists — Rutherford was just 30 when it began, and Soddy only 24 — who in the short space of 18 months, between 1901 and 1903, revolutionised the basic physical and chemical concepts of the period, and laid the foundations on which the present-day understanding of radioactivity and atomic disintegration is based. One of the collaborators' dramatic conclusions was that "the energy latent in the atom must be enormous compared with that rendered free in ordinary chemical change". That means would subsequently be found to release this latent energy on a large and controlled scale was not conceived by Rutherford and Soddy, but its existence was undeniably established. In these days of intense debate about the usage of this natural potential it is a rare opportunity to be able to go back to the grass roots, obtaining an insight into the scientific researches which led to the astounding initial discovery and to the controversial proposition that atoms were not fundamentally immutable.

Dr. Trenn has based his chronicle on a very thorough examination of the available documentation, including the original laboratory notebooks (some pages of which are interestingly reproduced in the text), and has carefully collated all the evidence to reconstruct the detailed story of the successive experiments, the difficulties in interpretation, sequences in the rise and decline of transitory concepts, and the logical stages by which the final theory evolved.

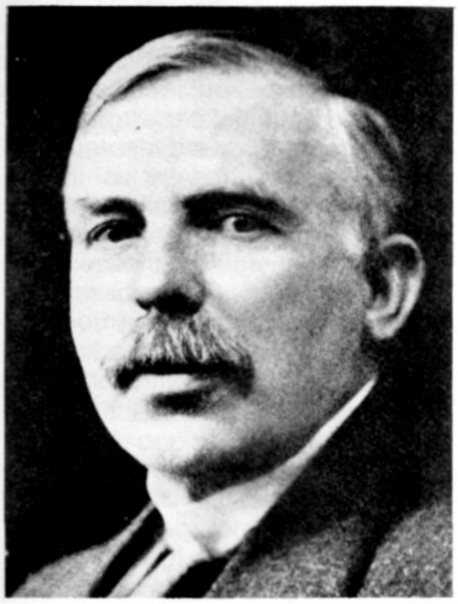
The book is undoubtedly a valuable contribution to the history of science. But it is not so much with the historian's approach to the work that the present reviewer is, or for that matter is qualified to be, concerned. Rather, this review is addressed to professional scientists and students. For all those familiar with the experience of undertaking exploratory experiments which give unexpected, often contradictory, and inexplicable results, the graphic account afforded in Dr. Trenn's book of the "classic" of such experiments is highly instructive and revealing. As Professor Feather remarks in his foreword to the book, Dr. Trenn has succeeded in discarding all that has been added by way of discovered fact and conceptual modification during subsequent years. "He writes as if looking over the shoulders of the young researchers as they worked — alternately encouraged and frustrated by the unexpected results of their experiments. He brings into sharp focus the successive phases of their theorising, when their picture was less than complete or coherent". The reader can follow the logic and motives of each step taken by the researchers, appreciating the clarity of their reasoning and the thoroughness of their approach; sharing in their excitement; understanding their perplexities; recognising the boldness of their deductions in the face of existing conceptual principles; and seeing the reasons why some of their interim conclusions were wrong. As with almost all scientific research in the real world, the final interpretation came, not in a single moment of inspiration, but as the steadily developing result of intense, concentrated effort. Thanks to Dr. Trenn's very clear style and direct approach, his account provides exciting as well as instructive reading. Each chapter seems to end with a mystery situation which leads the reader compulsively on to the next chapter until the final climax is satisfyingly reached. In these chapters all biographical material and asides not strictly relevant to the immediate scientific context are omitted; short biographies and a summary of the events leading up to the work to be described are provided in an introductory chapter. This proves to be a very satisfactory approach, enhancing the intensity and continuity of the scientific narrative.

Any summary of Dr. Trenn's account must inevitably lose something of the essential spirit of the presentation. However, the following may serve to indicate the main features in the collaborative research, and to bring out some of its interest and significance.

The formal collaboration of Rutherford and Soddy began in Montreal, at McGill University, in October 1901. At that time virtually nothing was established about the structure of atoms: physicists recognized that atoms could throw off rays or corpuscles akin to cathode rays, producing ionisation, but this did not affect the intrinsic nature of the atoms which, from the chemists' viewpoint, were the ultimate constituents of matter — above all, permanent and immutable. The nature and origins of the complex radiations emitted from substances such as uranium, first observed some five years previously by Becquerel, were a mystery. The Curies, for example, argued that they must arise through excitation by some unknown, perhaps cosmic, source of energy. Speculations were rife, and the mysteries deepened as observations proceeded.

Rutherford, a junior professor of physics at McGill, had been pursuing his interests in the ionising effects of the rays from radioactive substances, which he studied using an ionisation chamber and electrometer. He realised that he had need of assistance from a chemist and invited Soddy, then a demonstrator in the chemistry department, to join him. The close combination of physical and chemical viewpoints and techniques proved very powerful. Dr. Trenn makes the point that the two men appeared to consider each other equals in the research right from the start, and made equally vital contributions to the total collaborative work.

The first joint experiments were concerned with what was then called emanation: the mysterious production from thorium — perhaps a material substance, perhaps a form of radiation — which could activate the surrounding medium and produced an active deposit on nearby surfaces. The investigation of emanation by the two collaborators illustrates the kind of ups and downs which they encountered throughout their joint research. To what was the emanating power in thorium due? They found that it could not be completely destroyed by heat. Substitution of carbon-dioxide for air as the surrounding medium produced no change in the amount of emanation, so it could not be attributed to an activated state of the material atmosphere around the thorium. Moreover, the emanation was unaffected by chemical reagents. At this stage



Lord Rutherford

Professor Soddy

Rutherford and Soddy arrived at the conclusion that emanation must be an inert gas, a new member of the argon family. And since its production appeared to be a specific property of thorium, then the thorium was producing a material gas with non-thorium properties — a new element. "Rutherford", exclaimed Soddy, "this is transmutation". But the conclusion was premature. The question remained: was the emanation being produced by the thorium itself, as Rutherford and Soddy at the time believed, or did it arise from some "active constituent" of thorium? To investigate this vital question, chemical separation was used. From a thorium nitrate solution insoluble thorium hydroxide was precipitated out, the soluble filtrate being then free of thorium. Quite unexpectedly, the thorium precipitate had lost emanating power, but this and the radioactivity characteristic of thorium were found in the filtrate. Thus Rutherford and Soddy had to abandon the position that the activity was a specific property of thorium. There was a constituent of thorium, an unknown substance which was labelled thorium X, to which the properties of radioactivity and emanating power must be ascribed. So the initial suggestion of transmutation of one element (thorium) into another element (emanation) was for the time being dropped.

In this fashion the investigations proceeded with surprises and new puzzles accompanying almost every experimental observation. It was found that repeated chemical separation failed to remove a residual 25 per cent active constituent of thorium. And, after the 1901 Christmas vacation, Rutherford and Soddy were astonished to find that the thorium precipitate had *gained* in activity, while at the same time the filtrate (ThX) had *lost* activity. The first observation indicated that, in the thorium, ThX was being regenerated. But was this active constituent being induced by some inseparable agent in the thorium, or was the thorium itself producing the ThX? A series of chemical tests favoured the latter alternative; moreover the process was shown to be independent of the molecular condition of the thorium. Rutherford and Soddy concluded that this was a "sub-atomic chemical change". The thorium atom was transforming itself into another chemically distinct substance, Thorium X. So a transformation theory — the structural modification of individual atoms — was then put forward.

But at this stage transformation, or transmutation, was not recognised as involving a change in mass, and the radioactive rays were thought to be an after-effect of the transformation, a gradual dissipation of energy which the constituents had acquired by excitation during the transformation process. This approach could account for the decay in activity of the ThX filtrate, which was seen to be exponential, as was the recovery of activity in the thorium precipitate.

The next big step was laboriously reached through a series of studies, including the radioactivity and emanating power of ThX, these being found to be correlated, and attempts to ascribe the initial radioactive change in thorium to a so-called "inseparable active constituent". As this basis became more and more untenable, Rutherford and Soddy arrived at the conclusion that radioactivity (the emission of radiation) was an *accompaniment* of radioactive change (transmutation) rather than a subsequent effect. It was thus a property of the parent rather than the daughter; and this synchronisation was generalised to all the transformations.

Next, close attention was given to the nature of the radioactive radiations. It was recognised that the penetrating component (beta rays) consisted of electrons, akin to cathode rays, which were magnetically deviable. The readily-absorbed component (alpha rays) was not deviable, and was first considered to be non-corpuscular, like Röntgen rays, being a secondary radiation caused by the beta rays. But then it was found that a radioactive constituent producing beta rays could be chemically removed from a compound which continued to yield alpha rays. With this observation, and the new principle of accompaniment, the nature of the alpha rays was very much open to question.

A mass of indirect evidence gradually led Rutherford to the postulate that the alpha rays were charged bodies, with considerable momentum. In fact he wanted them to be negatively charged; this would have supported a theory he had developed concerning the behaviour in an electric field of the excited activity from emanation, which had been shown not to emit beta rays. A deviation chamber consisting of a set of parallel plates was constructed so that alpha rays from a radium source, located at one end of the plates, could be transmitted to an ionisation chamber and electroscope at the other end. Small deflections produced by a strong magnetic field led to a reduction in transmission. Deviations produced by an electrostatic field applied between the plates were also observed. To Rutherford's surprise, the particles turned out to have a positive rather than a negative charge, but the important fact was proved, that they had a large mass, similar to that of hydrogen, and high velocity. So the alpha rays were, in fact, ejected atoms of matter, and it followed that in the transformation process the parent atom was disintegrating into *two* products — a large daughter and the small alpha particle.

Thus the full disintegration theory started to emerge. The radiations were not merely *linked* with the disintegrating parent, as represented in the theory of accompaniment, but the alpha rays, being ejected constituents of the disintegrating substance, were part of the very *act* of disintegration. An atom was at this time assumed to be composed of a large number of positively and negatively charged electrons. The alpha particle, then, was a sub-atomic fragment similarly constructed. The expulsion of such a fragment from the parent atom could well be expected to produce changes in the chemical character of the atom.

The emission of beta rays was now considered a secondary phenomenon, since their loss from the atom, as in ionisation and similar processes, was not thought to affect the chemical character of the atom.

Was the alpha particle an element? A tentative connection was drawn between alpha particles and the helium known to be found occluded in uranium and thorium deposits. But it was too early to establish this. Nevertheless, the discovery of the alpha particle, observed in fact as a by-product of an experiment aimed at explaining an anomaly seen in the decay of emanation, provided Rutherford and Soddy with the connection between radioactivity and radioactive change, and advanced dramatically the understanding of the disintegration process.

The studies continued with a joint attack by Rutherford and Soddy on uranium and radium decays, and on further investigations of the emanations arising from radium and thorium. All the evidence conformed to their generalised disintegration theory. The exponential law of spontaneous radioactive change was propounded. And the energy released per disintegration was calculated. The radically new concepts were a serious sticking point for many scientists at the time: not only was the chemical atom — the basic unit of matter — claimed to be intrinsically divisible, but a vast store of internal energy was said to be released in the disintegration process, may be a million times as great as the energy of any molecular change. Dr. Trenn gives an interesting account of the initial scepticism which the disintegration theory aroused, and the various alternative hypotheses which were offered. But in the end the conclusions of the Rutherford and Soddy collaboration had to be accepted.

It is sobering to contemplate the total significance of the collaborative work of Rutherford and Soddy. It seems very likely that, but for that powerful alliance of a brilliant young physicist and an equally inspired young chemist, just after the turn of the century, the subsequent progress of nuclear science would have been delayed by quite a number of years. Would it have caught up by 1939? If scientific conditions had not been ripe for the discovery of fission just as World War II was about to break, the stimulus for its immediate intensive exploitation would have been lacking. Who can say how different the course of economic and political, as well as scientific history might have been?

Many steps and considerations have been omitted in this brief sketch, and scant reference has been made to Dr. Trenn's case for neglected recognition of Soddy's equal part in the collaboration. Dr. Trenn's full account is warmly recommended, to scientists and to all those interested in the scientific method as well as the history of science.

Joan M. Freeman

(Dr. Freeman worked at Harwell from 1951 until her retirement in January this year. From 1960 she was leader of the Tandem Generator Group and in 1976 was the first woman to win the Institute of Physics' Rutherford Award which she shared with Professor R.J. Blin-Stoyle of Sussex University for their work on β-radioactivity of complex nuclei).

Nuclear Power and Nuclear Weapons Proliferation.

Report of the United States Atlantic Council's Nuclear Fuels Policy Working Group (June 1978)

Non-Proliferation and International Safeguards.

Public Information Booklet prepared by the International Atomic Energy Agency (May 1978)

Two recent publications make a serious contribution to the important issue of minimising the risks of nuclear weapons proliferation while enabling nuclear power to play its essential role in meeting world energy requirements.

"Nuclear Power and Nuclear Weapons Proliferation" published in June 1978 was produced by the US Atlantic Council's Nuclear Fuels Policy Working Group under the chairmanship of Mr. John E. Gray, a Director of the Council and President of International Energy Associates Ltd. The Atlantic Council formulates policy recommendations for action on problems and opportunities shared by North America, Western Europe, Japan, Australia and New Zealand. The present report is the latest in a series of policy papers issued by the Council on the long-term energy supply position. The Council originally convened their Nuclear Fuels Policy Working Group to produce a report on nuclear fuels policy but brought it together again to focus on the relationship between the production of nuclear electric power and the proliferation of nuclear weapons capability.

The Working Group starts from the assumption that expanding nuclear power programmes are essential if a world energy shortage is to be avoided and draws attention to the commitment in the Non-Proliferation Treaty that adherents to the Treaty will be given access to the benefits of nuclear power. Proceeding from this standpoint, the report advocates acceptance of the fast breeder reactor as a necessary part of the nuclear economy.

The Group accept that plutonium reprocessing and uranium enrichment are the key technologies for the production of weapons grade nuclear material and press for an international regime to control production plants and storage facilities. In this and a number of their other recommendations they are fully appreciative of the factors which have led to President Carter's nuclear policies, but they are strongly critical of the idea that any one nation should seek to impose on other nations its own views on how to minimise the dangers of proliferation. American policy, they argue, should accordingly be to further internationally-agreed arrangements whereby existing and future plants capable of producing nuclear-weapons-grade fissile material would be segregated from national control, although not necessarily from national ownership, and would be operated in a multinational system which would safeguard the sensitive facilities and the fuel produced therein. The provision of spent fuel storage facilities and nuclear waste management should be an integral part of such arrangements. The US should proceed by example rather than precept: as one particular instance, the Group cited the firm view that the US should develop and demonstrate proliferation-resistant breeder technology. This would create a positive basis for close co-operation with other nations on breeders, with the intention of providing strong technological as well as political leadership internationally in the development and demonstration of this technology.

Other recommendations draw attention to the need for strengthening the IAEA's role in safeguards and suggest that the US should promptly implement their agreement with the Agency — proposed over ten years ago. The report also comes out in favour of full fuel-cycle safeguards as a prerequisite of any future supplies of nuclear fuel or equipment to countries which are not adherents of the NPT and recommends that the US should take a major role in providing and implementing a system of sanctions to be used against nations which violate non-proliferation commitments or safeguards agreements.

There is little new in these recommendations or, indeed, in the detailed arguments put forward in the report. But, while many analyses and examinations of proliferation problems befog this already misty area by endeavouring to cite every known fact or opinion and to qualify such conclusions as are reached by setting out the exactly opposing view, the Atlantic Council's Working Group are to be congratulated on having come out with the 17 clear-cut proposals listed in Chapter VIII, which certainly merit careful consideration not only by the US Government but, in many cases, by all Governments with a major nuclear power programme.

The Public Information Booklet on Non-Proliferation and International Safeguards prepared by the International Atomic Energy Agency in connection with the United Nations Special Session of the General Assembly devoted to Disarmament held in New York from 23rd May to 28th June 1978, although more limited in scope than the Atlantic Council report, provides a considerable service to all those concerned with the wider implications of nuclear power. This booklet explains the obligations assumed by States signing and ratifying the Non-Proliferation Treaty and provides a list of the 101 which have already done so. It sets out the text of the Treaty itself and of certain associated Resolutions and Declarations. Attention is drawn to the significant differences between NPT safeguards agreements and those concluded with States not party to the Treaty.

The main part of the book is devoted to a clear description of how the Agency safeguards system has evolved and how it operates, with some airing of the Agency's ideas about the ways in which the safeguarding of reprocessing and enrichment plants can best be achieved and about international plutonium management arrangements — areas which will of course be considered in detail by the International Fuel Cycle Evaluation studies.

All this provides most useful reference material. But despite mention of the need for further development of safeguards methods and techniques the lay reader might be left with the impression that the shaping of a safeguards system to prevent the proliferation of nuclear weapons is a problem to which there can be a unique and definitive solution. The objective of safeguards work is continuously to strengthen international confidence. The appropriate blend of materials accounting, process containment and surveillance techniques varies as the relative power of these techniques change, and for any particular type of plant the blend will be different. The equipment used by the Agency for inspection and analysis which is described in the booklet will itself need to be developed and replaced as time goes by. Moreover, considerations such as safety, radiation protection, quality control and operational efficiency must be given their due weight.

The report contains a section on international plutonium management which outlines some of the Agency's early thoughts on the future directions for plutonium and spent fuel storage and some form of international management. These ideas and the relative merits of increased supervision versus some degree of internationalisation remain to be debated.

Whatever basis for international agreement on plutonium management may prove practicable and acceptable to the States concerned, the Agency is certainly the logical and indeed the only possible pivot point. The Agency's role in international arrangements for the supervision of plutonium and spent fuel stores will ultimately be as vital as the one it plays in the operation of its safeguards system. The task of drawing up such arrangements, let alone reaching international agreement on them, will be formidable. In order to reach conclusions on the form of such arrangements and the nature of the Agency's role in them, much debate will be required in INFCE and beyond on the complex technical, economic and political issues involved.

B.D. Maclean

New Documents Guide

A sixth edition of the 'Guide to UKAEA Documents' has been published. The Guide, which first appeared in 1958 has been revised again to take into account recent organisational changes within the UKAEA as well as the inevitable corrections necessitated by the passage of time. The new edition lists reports available and gives details of where these may be seen or borrowed: the Guide also contains a general description of current report series, and a brief UKAEA bibliography.

(Guide to UKAEA Documents: Sixth Edition 1978. Edited by J. Roland Smith. Available from HMSO Price £1.00).

Energy from biomass

On 24th May, three Member countries of the International Energy Agency (Ireland, Sweden and the United States) signed a new agreement to set up an Energy from Biomass Technical Information Service. Two other IEA Member countries, Belgium and the United Kingdom, and the EEC signed the agreement in early June.

The Biomass Conversion Technical Information Service will be operated by the National Board for Science and Technology of Ireland, and will constitute a regular service providing the participants with scientific and technical data in such areas as production, harvesting, processing, transportation and conversion techniques of biomass. The initial period of the Service will be three years with a budget of £90,000.

This new agreement brings to a total of 32 the number of R & D projects launched since the IEA was established in November 1974.

Biomass (terrestrial and marine plant tissue and organic waste) can be converted into clean fuels by many conversion technologies. A ton of dry biomass, for example, when heated in the absence of air, will produce 1·25 barrels of oil, 1200 cubic feet of medium-Btu gas and 750 pounds of residues with a heat content roughly equal to that of coal.

Current research and development is directed to use the potential of biomass and to the development of cheaper and more efficient technologies for large-scale conversion of biomass to gas, oil, char and other products.

A first IEA co-operative research and development agreement in the biomass area was launched in April 1978. It includes the joint planning of national programmes of participating IEA countries* in forestry energy, i.e., the use of short-rotation forestry biomass and forestry residues to produce clean fuels, petrochemical substitutes and other energy-intensive products.

*Belgium, Canada, Ireland Sweden and the United States of America.

Waste disposal booklet

The British Nuclear Forum has recently published a new booklet entitled "Nuclear Waste Disposal". The booklet deals clearly and concisely with all aspects of this subject from transport and reprocessing to interim and long-term storage and disposal.

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

UKAEA PRESS RELEASES

Atlantic disposal of radioactive waste

A shipment of packaged low-level radioactive waste from Britain will be disposed of to the Atlantic deeps in July under international surveillance.

This means of disposing of low-level solid radioactive waste not suitable for land burial is considered the most suitable and has been used annually since 1949. The waste will be carried in the MV *Gem* of Glasgow which will sail from Sharpness (in Gloucester).

The total weight of the consignment will be 2066 tonnes and its radioactive content, together with that being disposed of by other countries, will be far below the levels recommended by the International Atomic Energy Agency and approved for the purposes of the Convention on the Prevention of Marine Pollution by Dumping of Wastes and other Matter (the London Convention). The disposal will be carried out under the surveillance of a representative of the Nuclear Energy Agency of OECD.

Note

The disposal site in the deep North Eastern Atlantic is a rectangle bounded by longitudes 17° 30'W (seventeen degrees thirty minutes West) and 16° 00'W (sixteen degrees zero minutes West) and by latitudes ten nautical miles north and south of latitude 46° 00' (forty six degrees zero minutes north). It is clear of shipping lanes, fishing areas and submarine cables. The ocean depth is some 2½ miles.

The waste disposed of is typically general trash and residues from the nuclear industry, medical therapy, research etc., and consists primarily of contaminated laboratory equipment and materials. It is packaged in concrete-lined containers, designed to meet international guidelines and to take the waste material to the sea bed.

1st July, 1978

Safeguarding nuclear materials

The European Association for Research and Development into the safeguarding of nuclear materials — ESARDA — is to hold its first Annual Symposium in Brussels on 25th-26th April, 1979.

Original technical papers are invited from nuclear plant operators, safeguards authorities and research organisations from any country.

ESARDA contains representatives of both safeguarding authorities and R&D organisations from a number of European states with the objective of assisting in the coordination of R&D in the safeguarding and control of nuclear materials. A valuable additional function is to collect and disseminate information on programmes carried out in various countries.

The symposium is seen as a further means of performing this role and also as a means of transferring experience and development knowledge. There will be an exhibition of instruments and equipment and there are plans for the simultaneous translation of all the oral contributions in up to six languages.

It is hoped to attract some hundreds of delegates to the symposium. Delegates are already expected from a number of countries, such as Canada, Iran, Japan and the USA and most European countries.

Enquiries about papers or requests for more details of the symposium should be addressed to one of the following: A.S. Adamson, NMACT, AERE, Harwell, Oxfordshire OX11 0RO; C. Beets, CEN/SCK Mol, 2400 Mol, Belgium; L.A. Stanchi, JRC 21020 Ispra, Varese, Italy.

7th July, 1978

NEA Activity Report

The OECD Nuclear Energy Agency (NEA) published on 30th June its Sixth Activity Report covering the year 1977. The Report reviews the work undertaken by NEA during the year and is prefaced by an analysis of the trends in nuclear power in the Agency's 23 Member Countries.

The Agency reports that during 1977 its role became more sharply focussed on those areas of nuclear development which determine the availability of the nuclear option, at the time and on the scale required and which are therefore of direct concern to governments. In particular the Agency has been seeking to achieve an accurate evaluation of the obstacles to the introduction of nuclear power and thereby to contribute to a better informed public discussion in this important field. The Agency has therefore continued, the report says, to give priority attention to economic and technical studies on nuclear energy development, including long term nuclear fuel cycle requirements and uranium resource availability and to questions of safety and regulation on both the policy and practical levels.

UK/IAEA/Euratom sign NPT Safeguards Agreement

An agreement between the United Kingdom of Great Britain and Northern Ireland, the European Atomic Energy Community (EURATOM) and the International Atomic Energy Agency (IAEA) for the application of safeguards in the United Kingdom of Great Britain and Northern Ireland in connection with the Treaty on the Non-Proliferation of Nuclear Weapons (NPT), was signed in Vienna on 6th September, 1976, and entered into force on 14th July, 1978.

In 1967, the Government of the United Kingdom stated that at such time as international safeguards were put into effect in non-nuclear-weapon States in implementation of the provisions of the NPT, the United Kingdom would be prepared to offer an opportunity for the application of similar safeguards in the United Kingdom subject to exclusions for national security reasons only.

Under the terms of the agreement, the IAEA has the right to apply safeguards on source or special fissionable material in nuclear facilities in the United Kingdom, subject only to exclusion for national security reasons.

Nuclex 78

The UKAEA will be making a major contribution to the 5th International Fair of Nuclear Industries — Nuclex 78 — which will be held from 3rd-7th October at the Swiss Industries Fair in Basle. This event takes place every three years and in 1978 will take the usual form of an exhibition accompanied by an extensive programme of technical meetings and special colloquia.

The theme of the Authority's stand at the exhibition will be that the benefits of the unique experience acquired by the Authority during 25 years' of operation as a research and development contractor to the nuclear industry at home and abroad, continues to be available to overseas customers. The presentation will emphasise that because of their key role in the UK nuclear industry, the Authority are able to offer services over the whole range of nuclear power activities.

The Authority's stand will form part of a British Overseas Trade Board 'joint venture' sponsored by the British Nuclear Forum, in which there will be about 25 British participants. The Authority and other UK nuclear organisations will also play a major part in the technical meetings associated with Nuclex 78.

CULHAM WELCOMES JET

On Tuesday, 30th May, the European Council of Ministers approved the Statutes establishing the JET (Joint European Torus) fusion experiment as a Joint Undertaking under the Euratom Treaty and as from 1st June, the Project exists with its new status.

JET will be built at the Authority's Culham Laboratory near Abingdon and to mark their welcome to the Project, the Culham Management Committee held a reception for the JET team on 5th June, at which representatives of Government Departments, local authorities and other parts of the UKAEA were present. Later, Dr. R.S. Pease, Director of the Culham Laboratory, and Dr. H.O. Wüster, Director of JET, watched by the JET team and other guests, unveiled a new notice-board outside the main gates which indicates the presence of the two organisations — the Culham Laboratory and the JET Project — on the same site.

The photograph shows the joint unveiling of the new noticeboard by Dr. H.O. Wüster, Director of JET (left), Dr. R.S. Pease, Director of Culham (right), accompanied by Dr. D. Palumbo, Director of the Euratom Fusion Programme (centre) and Mr. A.M. Allen.

Radiation Registry progress

Data on more than 90 per cent of the radiation workers who worked at UKAEA and BNFL establishments on or after 1st January 1976 are now included in the National Registry for Radiation Workers, established by the National Radiological Protection Board (NRPB).

NRPB has secured the backing of the TUC and the major employers in the nuclear industry for the Registry; in addition to the UKAEA and BNFL — for which data have already been received — the generating boards and the Nuclear Inspectorate of the Health and Safety Executive, have all decided to participate. The Ministry of Defence have the matter under consideration.

Arrangements have been made in anticipation of the inclusion in the Registry of data on workers who left the nuclear industry before 1st January 1976.

NRPB established the Registry with the objective of determining whether there are any differences in the cause of death, and the ages at death, of workers who had accumulated different doses during their working lives and to assess the probabilities involved should differences be found.

Attention is being given initially to workers in the nuclear energy industry because they are a large group and have well-documented dose records. In due course the register will include other groups of radiation workers and could be extended to include non-radiation workers. Names and certain other identifying details of radiation workers are recorded, together with their accumulated doses, and information regarding their subsequent exposure is being added year by year. Radiation work with different employers will be covered. Arrangements have been made with the Office of Population Censuses and Surveys, and with the General Register Office for Scotland, for the Registry to be notified of the dates and causes of death. By agreement with the individuals concerned, detailed information on the entrants will be strictly confidential and will be available only to the individuals concerned, their employers and the Board.

NRPB has established an Advisory Committee to provide guidance on all aspects of the Registry. Its membership, in addition to Board staff, is as follows:

Dr. K.P. Duncan, Health and Safety Executive,

Mr. H.J. Dunster, Health and Safety Executive,

Dr. J. Fox, Office of Population Censuses and Surveys,

Dr. M. Jacobsen, Institute of Occupational Medicine, Edinburgh,

Professor P.J. Lindop, Medical College of St. Bartholomew's Hospital,

Professor J.C. McDonald, London School of Hygiene and Tropical Medicine,

Sir Edward Pochin, Member, NRPB.

IN PARLIAMENT

QUESTION TIME

Uranium

21st June, 1978

Mr. Grimond asked the Secretary of State for Scotland in which areas of Scotland uranium exists in substantial quantities.

Mr. Millan: Deposits of uranium oxide are known to exist to the east of Stromness in Orkney and in the Ousedale area of Caithness. The extent of the deposits is not known.

Energy Commission

26th June, 1978

Mr. Macfarlane asked the Secretary of State for Energy if he is satisfied with the composition and the achievements of the Energy Commission.

Mr. Benn: The Energy Commission, whose composition was decided after extensive consultations both inside and outside Government, was set up to advise and assist me on the development of an energy strategy for the United Kingdom. I am encouraged by the progress which the Commission has made to date and have at present no plans to alter the membership.

Mr. Macfarlane: Is it not regrettable that the Secretary of State has chosen to reject the advice of the Select Committee on Science and Technology on this subject? Is it not equally regrettable that neither the United Kingdom Offshore Operators Association nor the Watt Committee on Engineering has been given a place on this very important body? Could it not be that people are right in suggesting that the Secretary of State might on this occasion be guilty of exercising power without responsibility?

Mr. Benn: I think that the hon. Gentleman is wrong. Two hundred organisations, many of which would like to have been directly represented — I am not saying that the Offshore Operators Association and the Watt Committee on Engineering do not have claims — that had claims of equal interest now receive the documentation of the Energy Commission. The transcripts of the discussions are published. My aim is to combine an effective body with the widest coverage of the discussions that take place. I am very happy that the representations of these committees should be before the Energy Commission, but if it were on the scale and of the size implied by the question there would be a national energy conference every three or four months, and I do not think that that would be effective.

Mr. Hooley: Is my right hon. Friend satisfied that the Energy Commission is so constituted that it pays sufficient attention to alternative sources of energy such as solar energy, wind and tidal power, as well as being concerned — quite properly — with the major sources such as oil, coal and gas?

Mr. Benn: That issue was discussed at the first meeting of the Commission and the point was made that my hon. Friend has made. I specially circulated to the Energy Commission the paper that he wrote on the subject because I wanted it to be aware of that line of argument. At the last meeting of the Energy Commission, the transcript of which will shortly be published, there was a long discussion about research and development, including alternative sources. I therefore hope that the Energy Commission, which necessarily reflects our existing energy pattern, will never be allowed to forget the need to develop alternative resources.

Mr. Gray: Does the Secretary of State accept that there is a danger of a certain amount of frustration occurring within the Energy Commission if it sees itself purely as a talking shop? How does he propose to react to the suggestions put to him by the Commission?

Mr. Benn: I understand that. The alternative to what is called a "talking shop" or parliament is, of course, a central body that would run all the energy industries in the country — a national fuel authority with a chairman, and power to determine policy. If that were done — it would be the only way to do it — we should eliminate or weaken the statutory responsibility to the House of Commons either of the Minister or of the chairman, so I have to strike a balance.

Research and development

26th June, 1978

Mr. Hooley asked the Secretary of State for Energy what estimate his Department has made of the aggregate number of scientists and engineers involved in research and development on wind, wave, solar and tidal power, as compared with the numbers involved in research and development on nuclear power.

Mr. Eadie: The Department's R & D programmes on wave, wind, solar, geothermal and tidal energies are in the main conducted by contracts placed with industrial companies, research associations, universities and polytechnics, and the Department has no data on the numbers of qualified staff employed by them or on the numbers employed on work financed and conducted by private industry. Some 24 qualified scientists and engineers are employed in my Department and in its energy technology support unit in the planning and management of its programmes. In the field of R & D on nuclear power, there are about 2,000 qualified scientists and engineers employed on such work in the UKAEA, about 400 in the electricity supply industry and an unknown but small number in the nuclear industry.

Test drilling

27th June, 1978

Mr. Sillars asked the Secretary of State for the Environment if he will list the sites for which the Atomic Energy Authority has now lodged planning applications for test-bore drilling in relation to the programme for underground nuclear waste disposal; if he will state the planning authority considering each application; and if he will state the progress made to date on each application.

Mr. Shore: The Atomic Energy Authority has submitted planning applications in respect of three areas for research into assessing the suitability of granite rock formations for underground disposal of appropriately treated radioactive waste.

Permission has been sought (a) from Kyle and Carrick District Council to drill test boreholes at a site in the Carrick Forest near Loch Doon; (b) from Northumberland County Council and Alnwick and Berwick District Council to drill at sites in the Chillingham and Usway forests in the Cheviot Hills; and (c) from the Highlands Regional Council to drill at a site on the Ulbster estate in Caithness. The Atomic Energy Authority is awaiting the decisions of the relevant planning authorities.

Nuclear power stations

28th June, 1978

Mr. Sillars asked the Secretary of State for Energy when he expects the first nuclear power stations to be decommissioned; and if any estimate is yet to hand of the probable capital cost of ensuring perpetual care of the installation.

Mr. Eadie: It is expected that the designed operating life of the Magnox stations, which should be the first to be decommissioned, will be exceeded, and the decommissioning dates are therefore uncertain. Studies are continuing on alternative methods of dealing with nuclear installations at the end of their useful lives and the extent to which perpetual care of sites or assets may be necessary has not been finally established. Power stations in Scotland are a matter for my right hon. Friend the Secretary of State for Scotland.

Mr. Sillars asked the Secretary of State for Energy what is the estimated working life of the Magnox and advanced gas-cooled reactor power stations; and what period of time has been calculated for repayment of capital borrowed for construction of each station.

Mr. Eadie: The Magnox stations were designed to have an operating life of 20 full power years; that is, years running continuously at designed power rating. However, it is expected that this life expectancy will be exceeded. AGR stations have been designed with an operational life of 25 full power years.

The CEGB does not identify its borrowings, or any part of them, with specific assets. The financial resources for its capital investment programme are primarily generated from internal sources. Borrowings, made on the board's behalf by the Electricity Council, are normally obtained from the National Loans Fund and are repayable over a period of 25 years.

Power stations in Scotland are a matter for my right hon. Friend the Secretary of State for Scotland.

Uranium

3rd July, 1978

Mr. Tom Ellis asked the Secretary of State for Energy

(1) if, in his recent successful negotiations with the Australian Government for the supply of uranium ore to the United Kingdom, he ensured that the Australian Government were aware of the relevant conditions imposed by the Euratom Treaty;

(2) whether the agreement recently concluded between him and the Australian Government for the supply of uranium ore to the United Kingdom is compatible with the terms of the Euratom Treaty;

(3) whether he has notified the European Commission of the terms of the agreement recently concluded between Her Majesty's Government and the Australian Government for the supply of uranium ore to the United Kingdom;

(4) whether the safeguards to be applied to the uranium ore which will be supplied to the United Kingdom by the Australian Government following the recent agreement between the two governments will be co-ordinated with the safeguard arrangements applied either by the International Atomic Energy Agency or by Euratom;

(5) whether the safeguards to be applied to the uranium ore to be supplied by the Australian Government contain provisions for the free movement of the ore or any of its derivatives amongst the nine member states signatory to the Euratom Treaty;

(6) if he will publish the terms of the agreement between the United Kingdom and Australian Governments for the supply of uranium ore in regard to the safeguards which the Australian Government are imposing on the use of the ore;

(7) when he concluded the recent agreement with the Australian Government for the supply of uranium ore to the United Kingdom;

Mr. Benn: A nuclear safeguards agreement between the United Kingdom and Australia has been initialled by officials. Discussions on the terms of an exchange of notes between the United Kingdom and Australia on uranium supply are taking place and I hope will soon be successfully concluded. Information on these exchanges would then be made public. Any uranium supplied following these exchanges would be subject to the safeguards agreement.

The Australian Government are aware of the conditions imposed by the Euratom Treaty on the supply of uranium to Community countries. The safeguards agreement that has been initialled contains specific provisions to meet the requirements of the Euratom Treaty. A copy of that agreement has been communicated to the Commission. Compliance with the agreement will be ensured by a system of safeguards applied by Euratom and the International Atomic Energy Agency in accordance with the Safeguards Agreement concluded on 6th September 1976 between the United Kingdom, Euratom and the Agency.

Agency safeguards do not apply to uranium ores but commence at the stage of the fuel cycle where the material is of a composition suitable for fuel fabrication or isotopic enrichment. Euratom safeguards cover the whole fuel cycle including uranium ores.

Electricity generation

11th July, 1978

Mr. Wigley asked the Secretary of State for Energy if he will publish a table indicating the volume of electricity generated by (a) coal-fired stations, (b) oil-fired stations, (c) nuclear stations, (d) hydro-electric stations and (e) other methods for each of the countries of the EEC, showing where appropriate what portion of hydro-electric generation is by pump-storage methods.

Mr. Eadie: The following table shows, in TWh hours, the quantities of electricity generated according to energy source in EEC countries in 1976. The figures relate to generation by the public supply and by industrial auto-producers.

	Germany	*France*	*Italy*	*Netherlands*	*Belgium*	*Luxembourg*	*United Kingdom*	*Ireland*	*Denmark*	*Total EEC*
Conventional thermal generation from:										
Hard coal and coke	93.6	46.9	3.6	2.6	8.1	0	179.4	0.1	9.4	343.7
Lignite, brown coal and derivatives	97.5	3.4	1.3	—	—	—	—	2.1*	—	104.3
Petroleum products (non-gaseous)	34.1	70.3	93.1	4.5	16.8	0.2	47.9	5.5	11.5	283.9
Natural gas	56.2	10.4	14.0	44.1	9.2	0.5	7.4	—	—	141.8
Derived gases	10.1	6.5	3.3	1.6	2.8	0.3	1.0	—	—	25.6
Other fuels	3.9	0.7	1.0	1.4	0.1	0	—	—	—	7.1
Nuclear electricity	24.2	15.8	3.8	3.9	10.0	—	36.2	—	—	93.9
Hydro electricity:										
From natural flow	12.7	49.0	39.2	—	0.1	0	3.7	0.6	0	105.3
From pumped storage	1.4	0.4	1.8	—	0.2	0.5	1.4	0.3	—	6.0
Geothermal electricity	—	—	2.5	—	—	—	—	—	—	2.5
Total generation	333.7	203.4	163.6	58.1	47.3	1.5	277.0	8.6	20.9	1,114.1

*From peat. 0 Represents less than 0.05 TWh. *Source:* Statistical Office of the European Communities: Electrical Energy Statistics 1977.

Hunterston B

11th July, 1978

Mr. Gordon Wilson asked the Secretary of State for Scotland what is the estimated cost so far of the breakdown of the Hunterston B reactor.

Mr. Gregor MacKenzie: Through the operation of the arrangements agreed between the Scottish electricity boards for the allocation of generating costs and the agreement for the supply of electricity to the Invergordon smelter, the costs of the Hunterston B outage will be shared between SSEB and NSHEB. I shall ask the chairman of the boards to write to the hon. Member.

Fast reactor inquiry

11th July, 1978

Mr. Gordon Wilson asked the Secretary of State for Energy when he proposes to commence the inquiry into the fast breeder reactor; when he considers the inquiry will report; and if he will make a statement.

Mr. Benn: Any proposal to build a commercial scale demonstration fast reactor will be subject to a public inquiry. The inquiry would not be limited to local planning issues but would allow wider relevant issues to be examined. The Government are considering what might be the most appropriate arrangements and timing for such an inquiry, in the event of a proposal being made.

In the Lords

Safeguards

10th July, 1978

Lord Brockway: My Lords, I beg leave to ask Her Majesty's Government whether they will raise at the appropriate international level the need to verify, by requiring accountability to the International Atomic Energy Authority, that States do not direct nuclear materials from power plants into weapons.

The Minister of State, Foreign and Commonwealth Office (Lord Goronwy-Roberts): My Lords, The International Atomic Energy Agency's existing safeguards system has as its aim the detection of any diversion of fissile material from peaceful nuclear programmes. We contribute substantially to the Agency's budget for this purpose, and we have taken an active part in international discussions about ways of improving the system.

Lord Brockway: Yes, my Lords, but is it not the case that the recent report of the Agency showed that the present system is inadequate to detect illicit production of nuclear bombs by the diversion of material from foreign power plants? Does it not say that of 41 States inspected, 12 had deficiences in accounting?

Lord Goronwy-Roberts: My Lords, the Agency report, to which my noble friend refers, indicates that it is satisfied that the safeguarding of the facilities with which it has so far been concerned — namely, research reactors and light-water power reactors — is adequate and has not resulted in the diversion of nuclear material. The Agency has recently undertaken the safeguarding of some fabrication and reprocessing plants on which the report admits that new techniques may be required, much as improved containment and surveillance measures should be developed further. In a letter to a newspaper the Agency has said that many of the inadequacies shown up in the 1977 report have been dealt with.

Lord Brockway: My Lords, may I ask the Minister whether there is a developing danger? Is it not the case that recently there has been detailed evidence of massive material sent to Israel — I am not implying doubts about the Israeli Government — by methods which were fraudulent and deceptive by the companies concerned? Are not the possibilities now of West German supplies to Brazil, and of American recycling of nuclear waste to South Africa, illustrations of this danger?

Lord Goronwy-Roberts: My Lords, at the time when this incident allegedly took place in 1968, the then Member States of Euratom had not ratified the non-proliferation treaty and no agreement existed whereby the Euratom States accepted IAEA safeguards. The current safeguards applied by both Euratom and IAEA to all Euratom countries would make a repetition of this alleged incident of 1968 impossible to keep quiet. It would be reported to the agencies and subsequently to the Secretary-General of the United Nations.

Advisory Council on Research and Development

Mr. Tony Benn, Secretary of State for Energy, has strengthened the membership of his Advisory Council on Research and Development through the appointment of four extra members. They are:

Professor Sir Hugh Ford, FRS., Professor of Mechanical Engineering at the Imperial College of Science and Technology, University of London;

Dr. Gordon Fryers, Director of Strategic Development, Reckitt and Colman Ltd;

Professor Sir James Lighthill, FRS., Lucasian Professor of Applied Mathematics, University of Cambridge;

Mr. A.M. Muir Wood, Partner, Sir William Halcrow and Partners Ltd;

Mr. Benn has also appointed to the Council:

Dr. J. Birks, CBE., Managing Director of British Petroleum to succeed Mr. M.M. Pennell, CBE., who has retired from the Council;

Dr. A.R.W. Baddeley, Executive Director of Esso Petroleum Co. Ltd; to succeed Dr. P.J. Agius, of Esso Petroleum, who has also retired from the Council.

These appointments bring the number of people serving on the Council to 17. Its chairman is Sir Hermann Bondi, the Department's Chief Scientist. The Council's task is to advise the Secretary of State on the general programme of research and development of the nationalised energy industries and such matters as he may refer to it.

North Sea — no panacea

North Sea oil will not cushion Britain from the long-term problems of energy supply, Mr. Alex Eadie, Parliamentary Under Secretary of State for Energy, told an inter-regional mining conference at Stirling in July.

Mr. Eadie said: "By comparison with most other industrial countries we are well-endowed with energy supplies for the next couple of decades. We can expect to be at least self-sufficient, and possibly net exporters of energy, for some years from 1980 onwards.

"North Sea oil production in May passed the one million barrels a day mark — a truly magnificent achievement, particularly since the very first trickle of North Sea oil came ashore only three years ago.

"But we should not allow our short-term abundance to lull us into a false sense of security. We must never forget that this will not cut us off from the long-term difficulties of energy supply which the world as a whole can expect to face around the end of the century.

"Even in the meantime, we will still be part of the international trading community and heavily dependent in our very open economy on growth and prosperity abroad to create the demand for our exports that we need for satisfactory levels of employment and income at home".

Mr. Eadie said that coal, nuclear power, energy conservation and possibly the renewable energy sources were likely to form the main planks of energy policy for the long-term.

First UK Wave Energy Conference

Results from the first phase of the UK Wave Energy Programme will be reported on and discussed in public for the first time at a Conference to be held on 22nd and 23rd November, 1978 at the Heathrow Hotel, London.

The Wave Energy programme was launched in 1976 by the Department of Energy with a budget of £1m. A year later the budget was increased to £2.5m and the first phase of the programme is due for completion in October 1978. A further £2.9m was made available in June this year for the Government's continuing Wave Energy Programme.

Papers will be presented covering the work on the four major devices being developed as part of the national programme:

Wave-operated 'ducks' — by Edinburgh University & Sea Energy Associates.

Wave-contouring Rafts — by Wavepower Limited.

Oscillating Water Column — by the National Engineering Laboratory.

Wave Rectifier — by the Hydraulics Research Station.

There will also be papers on other wave energy devices and on the wide-ranging problems underlying wave energy work.

The Conference will be residential to allow for maximum interaction between Industry at large and those engaged on the programme. There will be ample time for discussion during Conference sessions.

The Conference will be held in the York Videotheatre of the Heathrow Hotel (close to London-Heathrow Airport). The cost of attending the Conference, including two nights accommodation (21st and 22nd November) at the Heathrow Hotel and all meals, will be in the region of £150, payable in advance.

The Conference is sponsored by the Department of Energy and is being organised by the Energy Technology Support Unit, Harwell.

If you are interested in attending the Conference and/or being on the mailing list for an application form and further information, please send your name and address without delay to:

The Wave Energy Conference Co-ordinator, B10.28, Harwell, Oxfordshire OX11 ORA or telephone the Conference Office, on 0235-24141, extn. 2536 (or 2738) or telephone the Press Office, Harwell, on 0235-24141, extn. 2978 (or 2424) or telephone the Press Office, Department of Energy on (01)-211-3951 or 6953.

Cheshire seminar

On 29th June 1978 the Cheshire County Council organised a Seminar on nuclear power at Chester for Councillors and officials. Representatives from neighbouring County Councils were also present. In opening the meeting, Councillor Brian Harris, the Leader of the Council, said "Councillors often find themselves in national and regional forums, where they have an opportunity to influence events in the spheres of energy generation and conservation and of national economic growth which is so dependent upon future power supplies. To keep abreast of the latest thinking in the nuclear field is of vital importance to them".

After the welcome the first talk was given by Dr. N.L. Franklin, Chairman and Managing Director of the Nuclear Power Company, who outlined future energy requirements in the UK and stressed the difficulty of accurate forecasting for large capital investment programmes which would not come to fruition for approximately a decade after the taking of decisions. He outlined within these limitations the probable roles of coal, oil, natural gas and nuclear power in the future make-up of UK energy supplies. Dr. W.R.C. Crimmin of CEGB then outlined the theory and mode of operation of nuclear power stations in layman's language and illustrated his points by referring to the CEGB's stations at Trawsfynydd and Wylfa. Dr. Ian Blair of Harwell discussed environmental aspects of nuclear power and this talk was complemented by a presentation by Dr. S.M.B. Hill, the Authority's Chief Medical Officer, on the health and safety aspects of work within the industry. Mr. C. Allday, Managing Director of BNFL, described the structure of the UK nuclear industry with special reference to Capenhurst plant because of its local connection. Finally Mr. J.M. Hutcheon of UKAEA Risley gave a brief account of the Risley Nuclear Power Centre, the other main nuclear establishment in the area of concern to the audience.

Each presentation was followed by a discussion period and the speakers together formed a panel at the end of the Seminar to deal with general questions from the floor.

TRC appointment

Dr. D.H. Pringle PhD, FInstP, FRSE, Chairman of Nuclear Enterprises Limited, has been appointed a non-executive director of The Radiochemical Centre Limited with effect from 1st July, 1978.

One-day courses at NCT

As the final stage of their 1978 programme of one-day training courses for industry, the National Centre of Tribology have announced four further courses to be held at Risley before the end of the year.

Rolling Element Bearings — 17th October, 1978.
This type of bearing remains one of the most important in industrial applications and this course aims to give a comprehensive coverage of the most relevant aspects of the subject e.g. the main types of rolling element bearings, their applications and limitations and principles of their lubrication. The course, which is aimed at industrial engineers and designers, will also deal with bearing failures.

Bearing Materials in Hostile Environments — 31st October, 1978.
The design of industrial bearings can present great problems when hostile environments such as high or low temperatures are involved. Solutions to these problems depend very largely on correct choice of materials for bearing manufacture; this course, which is aimed at practising engineers and engineering designers, will deal in depth with factors to be considered in materials selection.

Maintenance and Fitting of Dynamic Seals — 28th November, 1978.
This course is designed to give those concerned in the maintenance and fitting of dynamic seals an appreciation of the factors which are important in ensuring long-life and trouble-free performance and to enable them to carry out the necessary operations correctly. The course, which is aimed at foremen and maintenance supervisors, will cover the different techniques required by the main types of seal.

Maintenance and Fitting of Rolling Element Bearings — 14th December, 1978.
This popular course, the third on this subject within a year, is designed to give foremen and maintenance supervisors concerned in the maintenance and fitting of rolling element bearings an insight into the various factors which are important in ensuring long-life and fault-free performance.

Application forms, programmes and details of the fees for all of these courses are available from:- The Course Organiser, National Centre of Tribology, UKAEA, Risley, Warrington WA3 6AT. Tel: Warrington (0925) Ext. 2640/3247.

AEA REPORTS

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

AERE-M 2900 *Granitic Depository for Radioactive Waste Size, Shape and Depth V. Temperatures.* By P.J. Bourke and D.P. Hodgkinson. March, 1977. 6pp. HMSO £1.00. ISBN 0 70 580416 6.

AERE-M 2914 *Measurement of the Supralinearity of* ^{7}*LiF Thermoluminescent Dosimeters.* By I.B. Hancock. April, 1978. 9pp. HMSO £1.00. ISBN 0 70 580219 1.

AERE-M 2930 *Experience of using the Magos Atomic Absorption Method for the Determination of Mercury in Biological Materials.* By T.R. Collier. February, 1978. 20pp. HMSO £1.00. ISBN 0 70 580039 3.

AERE-M 2946 *A Pollution Analyser using Harwell 6000 Series Electronics.* By P.R. Hooper. May, 1978. 6pp. HMSO £1.00. ISBN 0 70 580269 8.

AERE-PR/CSSD 2 *Computer Science and Systems Division Progress Report for the Period February, 1975 to January, 1976.* Edited by C.F. Coleman. February, 1978. 72pp. HMSO £2.00. ISBN 0 70 580029 6.

AERE-R 8790 *Heat Transfer Aspects of Underground Disposal of Radioactive Waste.* By P.J. Bourke. December, 1976. 15pp. HMSO £1.00. ISBN 0 70 580099 7.

AERE-R 9010 *The Role of Bulk Recombination in the Theory of Void Swelling.* By M.R. Hayns, January, 1978. 42pp. HMSO £1.50. ISBN 0 70 580089 X.

AERE-R 9012 *Mathematical Modelling of Chemical Transport in Soil Columns.* By K.L. Kipp. February, 1978. 113pp. HMSO £2.50. ISBN 0 70 580049 0.

AERE-R 9016 *Radioactive Fallout in Air and Rain. Results to the end of 1977.* By R.S. Cambray, E.M.R. Fisher, K. Playford and D.H. Peirson. May 1978. 60pp. HMSO £1.50. ISBN 0 70 580319 8.

AERE-R 9021 *High Resolution* γ *Spectra of 40-44 MeV* γ *Photon Activation Products. Part 2. The Elements Ruthenium to Uranium.* By D.R. Williams, April, 1978. 152pp. HMSO £3.50. ISBN 0 70 580209 4.

AERE-R 9051 *The Measurement of Attenuation Coefficients at Low Photon Energies using Fluorescent X-Radiation.* By L.H.J. Peaple and D.R. White. March, 1978, 13pp. HMSO £1.00. ISBN 0 70 580159 4.

AERE-R 9061 *The Effect of Variations in Damage Rate and Gas Deposition Rate During Simultaneous Damage and Gas Injection Experiments.* By M.R. Hayns and M.H. Wood. March, 1978. 17pp. HMSO £1.00. ISBN 0 70 580229 8.

AERE-R 9071 *Laser Raman Gas Diagnostic Techniques.* By D.R. Williams and I.A. Stenhouse. March, 1978. 12pp. HMSO £1.00. ISBN 0 70 580189 6.

AERE-R 9089 *A Comparison of Single Knock-on and Complete Bubble Destruction models of the Fission Induced Re-Solution of Gas Atoms from Bubbles.* By M.H. Wood. April, 1978. 16pp. HMSO £1.00. ISBN 0 70 580249 3.

AERE-R 9092 *The Effect of Recombination on Sink Strengths in the Rate Theory of Void Swelling.* By A.D. Brailsford, J.R. Matthews and R. Bullough. April, 1978. 32pp. HMSO £1.50. ISBN 0 70 580299 X.

CLM-R 173 *Reversed Field Pinch Reactor Study. 3. Preliminary Engineering Design.* By A.A. Hollis and J.T.D. Mitchell. December, 1977. 15pp. HMSO £1.00. SBN 85311 063 8.

CLM-R 175 *Atomic Collision Processes in Plasma Physics Experiments. Analytic Expressions for Selected Cross-Sections and Maxwellian Rate Coefficients 2.* By E.M. Jones. September, 1977. 31pp. HMSO £1.50. SBN 85311 056 5.

CLM-R 176 *Survey of Tokamak Experiments.* By R.J. Bickerton. 1977. 69pp. HMSO £2.00 SBN 85311 059 X.

ND-R 42(D) *A Tape-Controlled Remote Automatic Diameter Measurement Machine.* By W. Jennison and A.M. Salmon. January, 1978. 33pp. HMSO £1.50. ISBN 0 85 356101 X.

Courses at Harwell

The following courses are due to be held by the Education Centre, AERE, Harwell, Oxfordshire, Telephone Abingdon 24141 (STD 0235) ext. 2140 or 3116. Further information and enrolment forms can be obtained on application.

Commissioning, use and maintenance of reactor instrumentation

6th to 17th November 1978, at AEE Winfrith

This course is intended for practising engineers and technicians who are confronted with the problems of bringing into operation instrumentation and control systems associated with nuclear reactors and nuclear power stations and with their continued operation and maintenance. Participants should have some knowledge of the basic principles of nuclear reactions and reactors, electronics and the measurement of physical quantities.

Lectures are given by specialists from the UKAEA, CEGB and industry. There are opportunities during the course for participants to discuss with experts, new techniques and future trends. Fee: £420 + VAT.

Introduction to the use of small computers

14th to 17th November, 1978

A course of lectures intended for present and potential users of small computing systems, rather than computing science specialists. The emphasis is on using computing systems, rather than on the structure and operation of specific small computers; no attempt is made to train students to handle small computers or to programme specific computers. Fee: £168 + VAT.

A prerequisite for the course is a fundamental knowledge of computer terminology, structure and number systems. The opening lecture of the course will review these subjects briefly, but participants with little basic knowledge or experience of computers are advised to attend the separate introductory one-day course on

Digital computer fundamentals

13th November, 1978

An elementary one-day course covering the organisation and architecture of small computers. Topics include:- 1. Structure of a computer; 2. Number systems; 3. Hardware — input/output devices; 4. Software programming; 5. Simple logic and Boolean algebra; 6. An outline of microcomputers. Fee: £42 + VAT.