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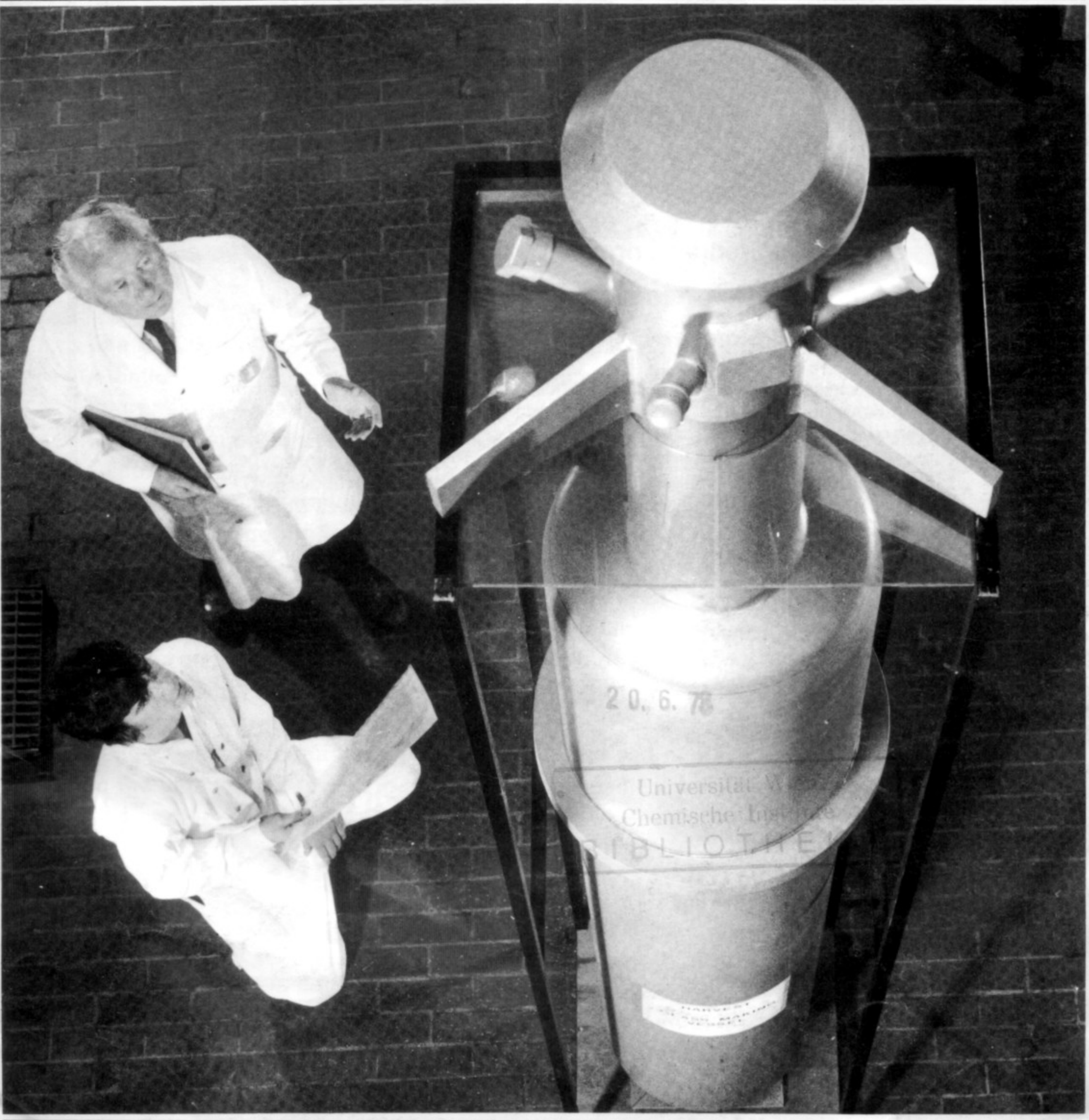
ATOM

NUCLEAR WASTE DISPOSAL

THE WINDSCALE INQUIRY

NUCLEAR POWER-THE MORAL QUESTION

THE FR FUEL CYCLE



MAY 1978 NUMBER 259

ATOM contents

THE MONTHLY INFORMATION BULLETIN OF
THE UNITED KINGDOM ATOMIC ENERGY AUTHORITY

ATOM, now in its 21st year of publication, appears this month in a new larger size and, it is hoped, a more interesting format.
ATOM was launched in 1956 as a monthly bulletin intended purely for internal use within the UKAEA, but its circulation rapidly grew far beyond this limit and it is now read by many people outside the nuclear industry in Britain and overseas. ATOM will retain its function as a publication of record of the work of the Authority and other organisations involved in the development of nuclear power; significant developments in the industry, and major speeches by its leading figures will also continue to be reported. Atom will in addition feature articles by outside contributors on different aspects of nuclear power.

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

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Front cover: A full-scale model of the vessel to be used for glassification storage and eventual disposal of highly-radioactive waste.

NUCLEAR WASTE DISPOSAL

Nuclear power will be the mainstay of the electrical industry in the future, but a sensible nuclear programme must include the fast reactor. Problems associated with the disposal of radioactive wastes can be solved and fast reactors can play a major role in the limitation and control of plutonium production. These are the principal ideas developed by Sir John Hill, Chairman of the Authority, in this lecture which was delivered at the Institution of Electrical Engineers on 16th February, 1978.

I have chosen to speak on nuclear waste disposal at this talk to the Institution of Electrical Engineers because nuclear power is vital to the electrical engineering industry. Public concern about nuclear waste is, however, an important factor in determining how rapidly we can expand our nuclear programme. It is therefore important that those who advocate expansion of our nuclear generating capacity should understand the real problems of nuclear waste; how it is handled now; how it will be disposed of in the future; and why it will not be the problem suggested by the anti-nuclear lobby.

I have, as you know, given many talks on nuclear power and in some of them I have been critical of those in the nuclear industry who have brought irrelevant complexity into the nuclear debate. The explanation of how a neutron causes fission, the discussion of critical size and the chain reaction has created the feeling that nuclear power can only be understood by the scientist. The association of the universal equation $E=mc^2$ with atomic energy has created an aura about nuclear power which is quite unjustified because this equation is no more and no less relevant to burning uranium than to burning coal or oil or anything else. I prefer to talk of uranium burning because it is a fuel which produces heat when it is consumed and most of the problems of nuclear power are engineering problems similar to those we encounter in conventional fossil fuelled generating plant. But nuclear waste disposal is different from ash disposal in a coal fired station, so perhaps tonight I might depart from my usual procedure and start by discussing the scientific properties of the materials that constitute nuclear waste. Unless we understand these properties it is not possible fully to understand the ways in which we handle and dispose of these wastes.

The burning of uranium gives out much more heat than the burning of coal – about three million times as much on a weight for weight basis so the quantity of nuclear waste to be dealt with is vastly less than for fossil fuels. If all the electricity used in Britain were produced from nuclear power stations we would produce only about 30 tons of fission products annually. On the other side of the coin the nuclear waste takes much longer to cool down and lose its activity and so we have to handle it while it is hot at least from a radioactive point of view. Moreover, because the burning of uranium gives out so much more energy than the burning of coal the radiation given out in the process is very much more energetic and penetrating. Shielding to contain the radiation has to be thick – over a foot of steel or three or four feet of concrete or 10 feet of water. The whole issue of nuclear waste is therefore connected with handling relatively small quantities of rather nasty material.

There are basically three types of activity that have to be dealt with in the nuclear power industry.

(i) The first and most difficult are the fission products themselves. These are what is left when uranium burns or undergoes fission. They are a group of elements in the middle of the periodic table distributed about a median corresponding to half the weight of the original uranium nucleus. They are the high activity wastes that cause most public concern about nuclear power.

(ii) The second group of radioactive materials are the nuclear fuels themselves like uranium, plutonium and americium. These are the unstable or quasi stable elements at the top of the periodic table which will undergo fission as a result of neutron capture or just decay away slowly as they have been doing in nature since the world began. In general they die away much more slowly than fission products and are therefore much less active. The radiation they emit is, to a great extent, easily absorbed and non-penetrating.

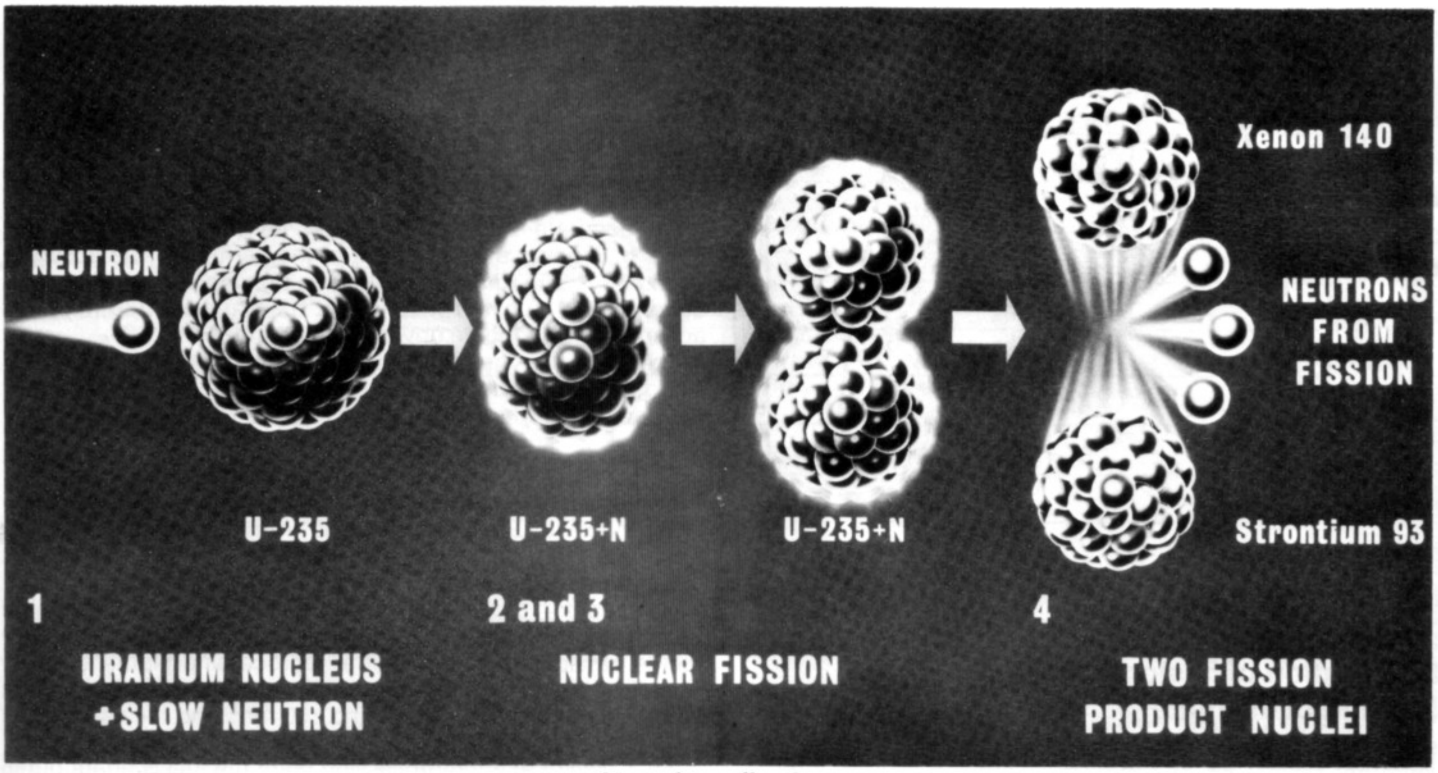
(iii) The third group of activities to be considered consists of structural materials which are used inside the reactor itself such as fuel element cladding material, control rods, support systems and even the pressure vessel itself. These components become activated by the neutrons produced in the fission process and remain active after removal from the reactor. The total activity is much less than in (i) and (ii) above but the bulk can be considerably greater.

Let us look then in more detail at these classes of radioactive material.

1. The fission products

Fig. 1 shows the fission process and fig. 2 the distribution of fission products from the burning of uranium. About 300 different nuclei have been detected and about 180 of them are radioactive. These nuclei are unstable because the fission process produces the wrong balance of protons and neutrons in the nucleus and as they correct this imbalance electrons and gamma rays are emitted. A large number of these fission products have a very short half-life and die away to stable elements in seconds, minutes or hours and as far as radioactive waste is concerned can be ignored, because they will all have disappeared before the fuel is even withdrawn from the reactor.

Other fission products have a half-life of days or weeks and these can all be allowed to die away in the cooling ponds before the fuel is processed. A particularly important fission product in this class is iodine 131 with a half-life of eight days. In some ways this can be regarded as a particularly difficult fission product because it is very active, it is volatile, it is readily



Uranium fission

absorbed in the body and gets into all the wrong places in the chemical plants and makes them very difficult to operate. On the other hand with an 8 day half-life it is easy to leave the fuel in the cooling ponds for six months before processing it by which time its activity will have decayed to less than one millionth of what it was.

As we go up the scale in lifetime we come to those fission products with a half-life in months or years and these are the most important from a reprocessing point of view. Cerium 144 with a half-life of 284 days contributes the most activity in fuel about a year old. Ruthenium 103 with a 40 day half-life and ruthenium 106 with a half-life of exactly a year are particularly troublesome. Ruthenium is an element with so many possible valencies that whatever you do to effect a separation some of it will pass in one stream and some in the other so that it always turns up in effluent streams you would like to throw away. It obeys Murphy's law so meticulously that it is even slightly volatile so that when you try to glassify it some of course goes into the off gas stream.

The most difficult fission products are, however, strontium 90 and caesium 137. These are both abundant with yields of about 5 per cent and have half-lives of about 30 years. This is short enough lifetime for them to be very active and yet it is too long to be able to wait for them to decay away. They constitute the principal activity in nuclear waste over the period 10 years old to 500 years old.

Finally, there are a very few fission products with half-lives of 10,000, 100,000 or even 1,000,000 years but these are present in such small quantities and have such a low specific activity that they are of little consequence and contribute less activity than was possessed by the uranium that was dug out of the ground in the first instance.

Fig 4 shows how the activity of fission products decays with time. The important things to note are first the very rapid fall in activity in the first months or years after removal from the reactor. Second the steady slow fall in activity dominated by the 30 year halving time of Cs-137 and Sr-90 and finally the very small residual activity of the weak longlived products.

2. Radioactive nuclear fuels

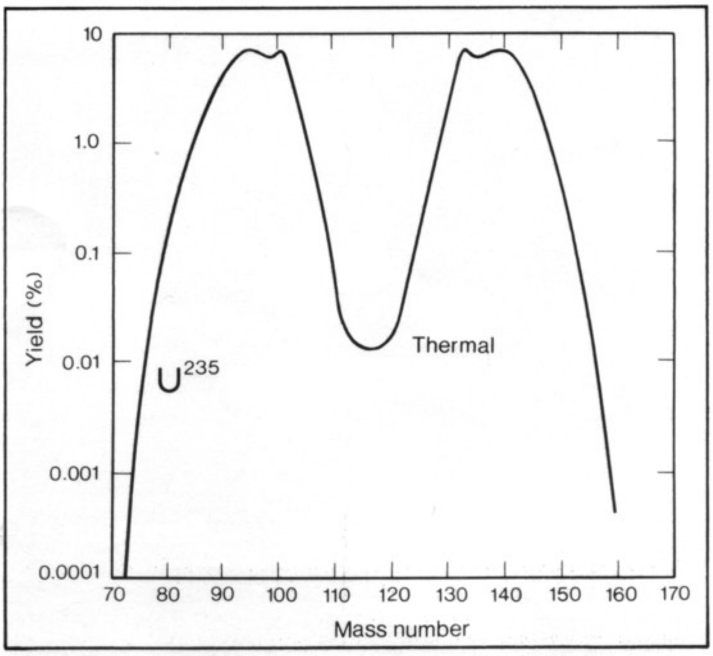
All nuclear fuels are radioactive to some extent. They are all very heavy quasi-stable elements at the top of the periodic table. They are unstable not because they have the wrong ratio of neutrons to protons as in fission products but because there are just too many of them in the nucleus for comfort. They decay by emitting helium particles which are energetic but can be stopped easily by a sheet of paper. It is generally true that the better nuclear fuels are more active than the poorer nuclear fuels.

Uranium 238 is the most abundant and is perhaps the one to consider first. It was present when the earth was first created and has a half-life almost exactly the age of the earth itself, 4,500 million years. It decays slowly by a series of processes and the emission of helium into ordinary lead which is inactive. The decay of U-238 and its daughter products is the most important source of radioactivity in and on the earth and provides the motive power for the building of mountains and the movement of continents without which all the land mass would have been eroded and lost beneath the surface of the sea. It is indeed fortunate for man that uranium has such a long half-life because without it is highly improbable that man could exist at all.

But uranium 238 is not a good nuclear fuel and most of the world's stock of good nuclear fuels (which are more active and less stable than U-238) have died away to nothing during the earth's history. All that is left to us are small traces of U-235 which has a half-life of 700 million years. Of natural uranium today the U-235 content that is left is only 0.7 per cent.

The nuclear industry of today is to a great extent wastefully burning up these last traces of naturally occurring nuclear fuel. But it does have some foresight and has recognised from very early on that it can create new nuclear fuel from abundant U-238 (or thorium 232) by irradiation in a reactor. All nuclear reactors used for commercial power production are in fact doing two quite separate things simultaneously. Firstly producing heat by burning nuclear fuels – uranium 235 or plutonium 239 – and at the same time converting U-238 into plutonium 239, i.e. breeding new nuclear fuel. The amount of new plutonium that is produced in this way can be anything from nothing to about 120 per cent of the amount of fuel burnt, depending on the reactor design.

Nuclear fuel when removed from a reactor therefore contains unburnt uranium, fission products (perhaps 3 per cent by weight) and artificially created nuclear fuels like plutonium and americium (collectively called actinides) to the extent of perhaps 1 per cent for current reactor designs. These man-made nuclear fuels have in general shorter lives than naturally occurring nuclear fuel but much longer lives than most fission products (from hundreds of years to tens of thousands of years). The radiation from them is soft – they can be handled with gloves. They are virtually no hazard outside the body but are damaging in immediate contact with living tissue, the lungs, liver, bone marrow etc.



Distribution of fission products from the burning of uranium.

The half-life is sufficiently long for us to treat it as infinite. These materials must therefore be burnt, which is the reason for making them, or stored or so dispersed as to be no hazard to mankind.

3. Radioactive structural materials

All materials irradiated in a reactor become radioactive to a certain extent, the activity depending upon the materials, the impurities in the materials and the intensity of the neutron flux. I draw particular attention to impurities because stainless steel is almost the universal structural material in the core of nuclear reactors and activities are critically dependent upon cobalt impurities. Cobalt 60 has a 5¼ year half-life and is a particularly powerful emitter of hard radiation. It is a much disliked element in the nuclear industry. The whole question of the ultimate dismantling and disposal of nuclear power stations is determined by the radioactivity induced in structural materials by the neutrons produced by the fission process.

I would like now to turn to the handling of nuclear wastes, but before doing so I think I should outline the rules under which the industry operates. The standards are based upon recommendations of the International Commission on Radiological Protection (ICRP) that any unnecessary exposure to radiation should be avoided and all radiation doses should be kept as low as is reasonably achievable, economic and social considerations being taken into account. ICRP have recommended numerical dose limits designed to ensure that the risk to the health of individuals and populations should not exceed an acceptable level.

These guiding principles were embodied in United Kingdom policy and defined in a Government White Paper Cmnd. 884 "The Control of Radioactive Wastes" as follows:

(i) to ensure, irrespective of cost, that no member of the public shall be exposed to a radiation dose exceeding the ICRP dose limit;

(ii) to ensure, irrespective of cost, that the whole population of the country shall not receive an average dose of more than 1 rem per person in thirty years; and

(iii) to do what is reasonably practicable having regard to cost, convenience and the national importance of the subject, to reduce doses far below these levels.

Radioactive waste disposals are controlled by authorisations issued on behalf of the Secretary of State responsible for environmental matters and the Minister of Agriculture, Fisheries and Food. The amounts authorised for dispersal are set on a case-by-case basis. They are always below the levels derived from the ICRP dose limits and frequently very substantially below these levels. The first step in determining permissible discharges involves studies of potential biological pathways back to man, for different radioactive isotopes and food chains. Some pathways turn out to be unimportant, others are more critical and it is upon these that control must be based. The authorised discharges are then set at a far lower limit determined by a judgement of what is the smallest fraction of the permissible level that can realistically be achieved by the best practicable means. When we read therefore of the activity of fish or milk being 10 per cent of the maximum permitted level we are not talking of 10 per cent of what would injure you. A more accurate comparison would be that a car going at 3 m.p.h. is going at 10 per cent of the permitted safe speed of 30 m.p.h. This in turn does not mean that there is absolutely no danger at 30 m.p.h. It means that the danger at 30 m.p.h. is acceptably low for both driver and for third parties.

This policy for the control of radioactive waste disposals has stood the test of time well, but it is always subject to review and will be studied on a routine basis by the Nuclear Waste Management Advisory Committee.

Waste management practices

When nuclear fuel is first removed from a reactor it is, as we have seen, very active and has a quite substantial heat output. It is by common consent accepted that this fuel is stored close to the reactor and usually under water until this initial high activity and heat output has died away. After about a year the fuel is transported to the central reprocessing plants in heavy shielded containers. These are made of steel or steel lined with lead. They weigh between 50 and 100 tons and they are finned to facilitate cooling.

After receipt at the reprocessing plant the fuel is again put in storage ponds to cool for another period of up to 10 years depending upon the value of the unburnt nuclear fuel. At this stage the fuel assemblies are fed to the reprocessing plant, the cladding is removed and the fuel itself is dissolved in nitric acid. A solvent extraction process first separates the fission products from the uranium and the plutonium and then subsequently the uranium and plutonium are separated.

The chemistry of this whole process is extremely simple. In practice the high levels of activity make it very much more difficult than the simple flowsheet would indicate and make the plants very expensive.

Let us start at the beginning as far as the operator of a reprocessing plant is concerned. The fuel elements as received from the nuclear station usually have a radioactive crud deposit or oxide scales on the outside of the cladding. This can flake off into transit flasks and, unless precautions are taken, storage ponds as well. The flasks must be sent back to the stations without measurable activity on the outside and not very much on the inside either. What do you do with the wash water that contains the crud or oxide scales?

The pond water will get some activity from defective fuel elements. How do you keep the ponds clean? What do you do with the water that comes from them?

The fuel cladding will, after removal, have traces of fuel and fission products adhering to it as well as its own induced activity. What do you do with this cladding?

The dissolution of the fuel will lead to fume and spray from the dissolver. Can this go to atmosphere? If not how to you clean it up? The plant will have to be washed out from time to time to get rid of sludges and solvent degradation products. What do you do with the washings?

I think I have indicated the measure of the real problem in designing and operating reprocessing plants. When the scale of the reprocessing operation was sufficiently small all sorts of things could be disposed of to sea or be buried. As the scale of the operation has increased, practices have had to be improved. It is not possible to permit operator exposure or discharges to the environment to increase *pro rata* with the throughput. If anything we will have to reduce operator exposure and discharges in spite of greatly increased throughput. This requires a steady upgrading of our plants and facilities. You will readily understand why in the reprocessing business so much attention is given to the elimination of side streams. They cost more to deal with than the main line operation itself.

Let us look then at the various streams containing radioactive wastes that arise in the reprocessing operations. They arise in gaseous, liquid and solid form and all have to be dealt with in the appropriate way. I will leave the highly-active fission

Isotope	Half-life	Activity after 1 year	10 years	100 years	1000 years
Barium^{143}	12 secs	–	–	–	–
Iodine^{131}	8 days	–	–	–	–
Ruthenium^{103}	40 days	20	–	–	–
Cerium^{144}	284 days	2.5×10^4	9	–	–
Ruthenium^{106}	1 year	1.9×10^3	2	–	–
Krypton^{85}	11 years	3×10^2	2×10^2	0.6	–
Strontium^{90}	29 years	3×10^3	2.5×10^3	2.9×10^2	–
Caesium^{137}	30 years	3.2×10^3	2.6×10^3	3.2×10^2	–
Samarium^{151}	90 years	4	4	2	0.002
Technitium^{99}	200,000 years	0.5	0.5	0.5	0.5
Iodine^{129}	17,000,000 years	0.001	0.001	0.001	0.001

Typical fission product activities in 1 Kg of total fission products.

product stream until last since this is the one that causes most concern.

(i) *Gaseous wastes* arise in small quantities from the discharge of cooling air from some designs of nuclear reactor. Other reactor types produce and discharge small quantities of tritium from lithium impurities in the graphite or from the heavy water moderator. These are all discharged to atmosphere and have no impact upon the environment. More significant gaseous wastes are produced when irradiated nuclear fuel is dissolved in tne first stage of reprocessing. Gaseous and volatile fission products are released of which krypton 85, iodine 129 and tritium are the most important. All are released to atmosphere at the present time but at some time in the future, when nuclear programmes expand world wide, it will be desirable, or perhaps even necessary, to remove the krypton 85 and iodine 129. The krypton with a 10 year half-life will be bottled for storage and decay and in the case of iodine 129 with a half-life of 1.6×10^7 years, permanently stored or transmuted in a reactor.

Gaseous effluents frequently contain spray and mists from active liquids and these have to be removed by filtration, electrostatic precipitation or adsorbtion methods and the resulting liquids treated subsequently as for liquid wastes.

(ii) *Liquid wastes.* The most important is the highly-active stream from the reprocessing plant which contains 99 per cent of all the fission products. I will consider this special stream separately. Many other liquid wastes arise in a reprocessing factory, low activity streams come from pond storage water, plant washings, and the distillates from the concentration of more active liquors. In the past these low active large volume liquid wastes have been discharged to sea after monitoring to check that the activity levels are within authorised limits.

Liquid wastes of intermediate activity arise from the scrubbing of gaseous effluents, the condensate from concentration of the highly-active fission product stream and solutions containing degradation products of the solvents and washings from the highly-active parts of the plant and the plutonium plants.

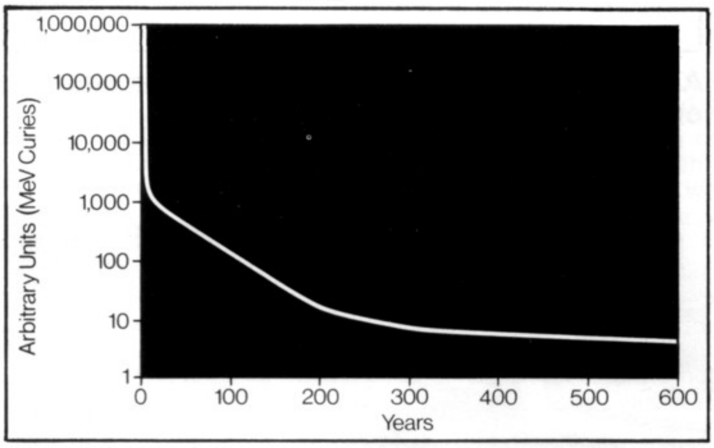
These wastes are dealt with in a variety of ways. Wherever possible they are concerntrated, conditioned and fed back into the early stages of the process so that the activity will finish up in the correct stream second time round. This is particularly important in the case of the long life plutonium bearing streams.

Other streams containing for example the troublesome ruthenium 106 (half-life one year) are concentrated and stored until its activity is of no consequence and then discharged. Ion exchange columns are used to remove strontium and caesium (30 year half-life) to acceptable levels.

Although it is never possible to get down to zero discharge it is clearly possible, by building more and more effluent plants, to asymptotically approach this ideal. The issue is simply how much money should be spent and how many lives consumed in building more and more plants to reach this ideal. The plants that were built 20 years ago to handle a relatively small throughput are clearly below the standards we would build today. We must, however, avoid the temptation to go too far the other way – as advocated by the more extreme environmentalists – and spend huge sums, of what is effectively public money, in achieving very little.

(iii) *Solid wastes.* There is from any large factory a big volume of waste paper, clothing and equipment. But because some of its originates in the active areas of our nuclear factories, this waste is liable to be lightly contaminated and has to be adequately disposed of. This waste is at present buried. In the future much of the combustible part of this waste will be incinerated.

Combustible waste contaminated with plutonium is now all incinerated and the ash and flue washings are leached with nitric acid and returned to the process. Non-combustible waste contaminated with *small* quantities of plutonium is drummed and dumped into the ocean deeps under international agreement and supervision. High active solid wastes such as fuel cladding is stored for decay and for future disposal.



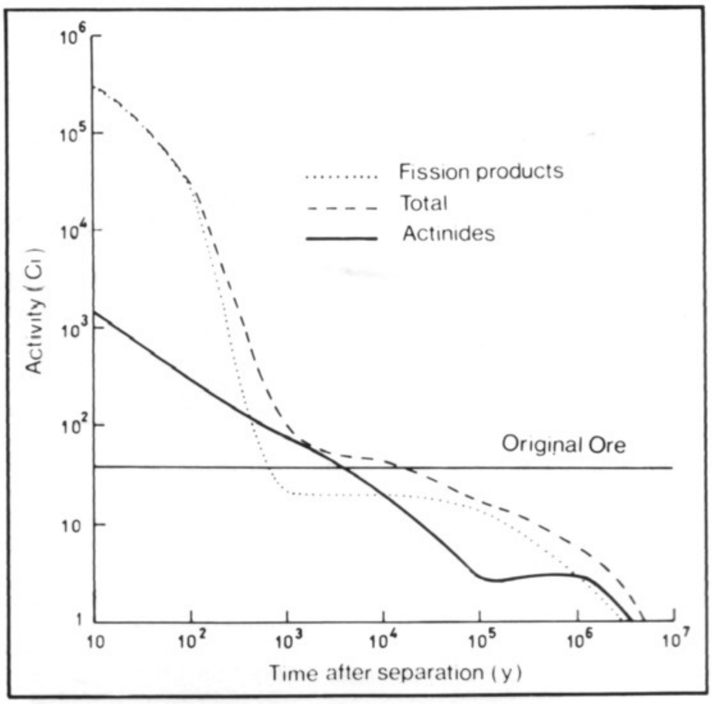
Decay in activity of waste constituents in spent 'Magnox' fuel.

(iv) *The fission product stream* I would now like to turn to the main cause of public concern, namely the main fission product stream issuing from the chemical separation plant. It is a solution of fission products in nitric acid and contains about 99 per cent of all the fission products. It is concentrated as far as is possible without causing crystallisation or precipitation and is stored in high integrity tanks within thick walled concrete vaults which are themselves clad in stainless steel. Internal cooling coils are provided to remove fission product heat and the tanks also have an external cooling jacket which effectively provides an additional cladding. Spare tanks are always available (this is a condition of the site licence) and means are available to transfer liquors from one tank to another if a lea kdeveloped.

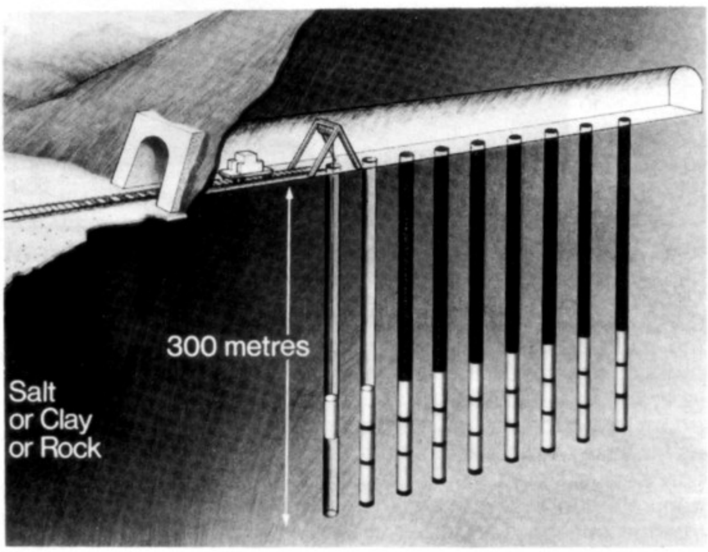
Some 770m³ of highly-active waste is contained in nine tanks at Windscale at the present time and represents the accumulation from virtually our entire nuclear programme, both defence and civil, over the last 25 years.

Although the storage of these highly-active wastes has been entirely satisfactory to date it is clear that we can do better than just leave them in an ever growing tank farm. Solidified waste is clearly much less likely to leak into the environment than a liquid and will required less supervision. It is therefore planned to glassify these wastes by mixing them with a slurry of the raw materials of glass and then raising the whole temperature to about 1000°C by which time all the volatiles will have boiled away and glassification will take place.

This process was developed at Harwell over ten years ago. The fundamental process is no different from that which has been used for the last 2000 years and the main problem is how to engineer a plant to do this simple operation reliably and remotely with such highly active materials. There can be no possible doubt that it can be done on a full production scale.



Activity of waste from 1t fuel and its originating ore body.



Underground burial of radioactive waste.

The only question is what is the best way from the point of view of cost, ease of operation and maintenance.

We can I think work on the assumption that in about eight years' time we shall have a first production plant in operation. (The French have a semi-production scale plant being commissioned at the present time.) These plants will produce glassified waste in stainless steel cylinders, each cylinder containing about one ton of glass which in turn will contain about 1/5 ton of fission products. With the production at that time of about four tons of fission products a year it will require the production of about 20 cylinders of waste a year. The heat output will depend upon the age of the waste, but will be of the order of 10 kW per cylinder. The cylinders will then be stored in deep ponds of water for another 20 or 30 years until the output is diminished sufficiently for the next stage of disposal.

These cylinders have got to be kept away from man for about 500 years until all the caesium 137 has decayed. We are planning to bury them sufficiently deep in rock that people will not accidentally dig them up again without knowing what it is they have unearthed.

I believe you could bury these glassified wastes pretty well anywhere but because of the long time they have to be kept away from man and the fact that we do not want to have to supervise them in the future, we have looked for geological formations which should be particularly suitable and require no long term supervision. The difference in cost between one place and another is not very much so we might as well choose the best. For the UK, granite structures would appear to be the most suitable because unfractured granite should be completely free from water and only percolating water could possibly transport activity back into the food chain and then back to humans.

There is not really any great hurry to find an ultimate disposal site. If we bury glassified young fission products we will have problems of heat because rock does not have a high thermal conductivity. We would prefer to wait until the heat output of the glass is down to a level which can easily be conducted away. If we do not we will have to have a ventilated store, or some other cooling arrangements, for an equivalent period of time. But there are pressures upon us to demonstrate the principle of ultimate storage and we would certainly like to get the research and proving work done without a rush and in good time.

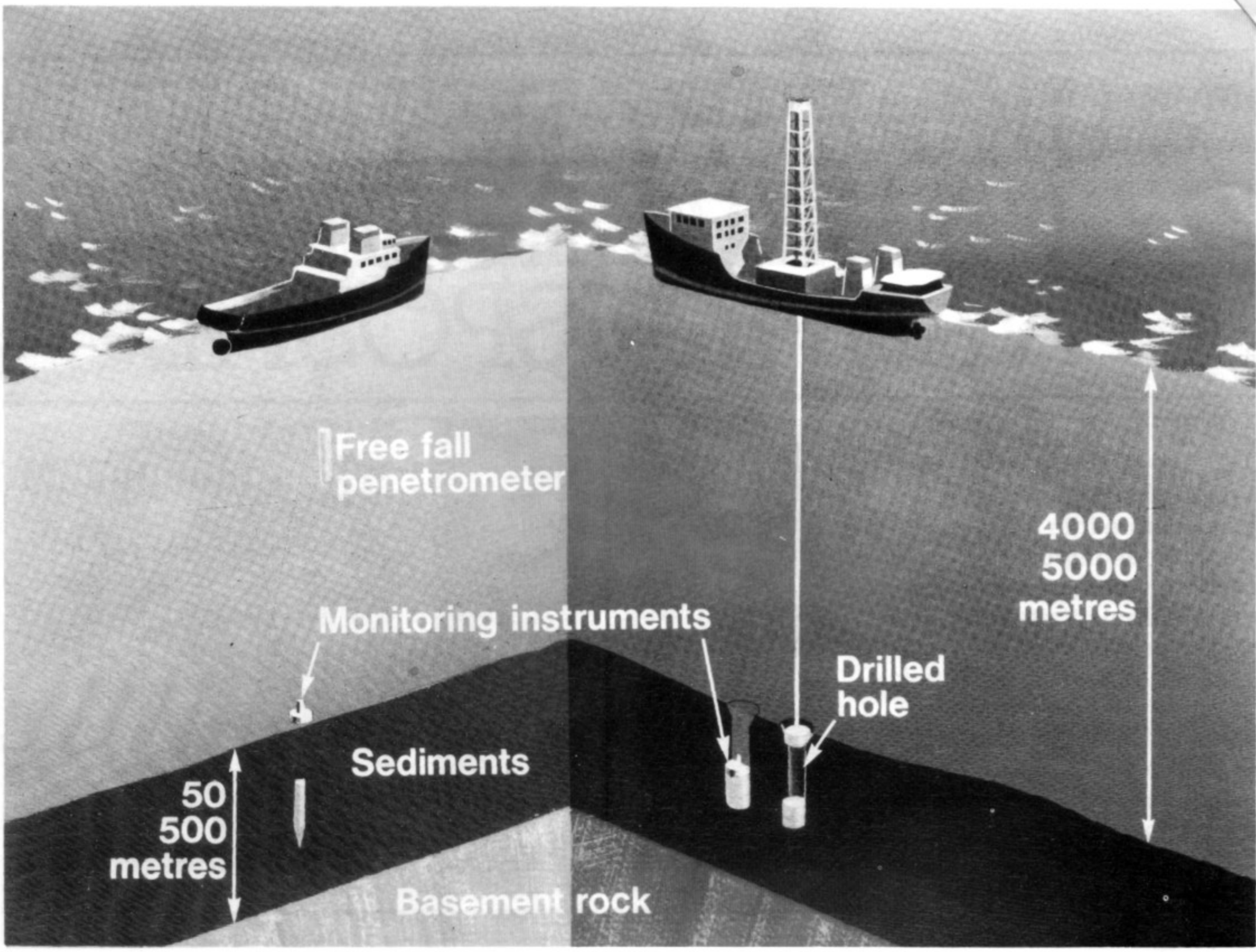
It may be that a better solution would be to dispose of the containers of glassified waste to the ocean depths or in places where sediment is being deposited at an appreciable rate or to bury them beneath the ocean floor. Preliminary studies suggest that these methods would be satisfactory. Not enough is known however about the conditions on the deep ocean floor to be able to assert with confidence that these methods are better than or even as good as the relatively straightforward method of burying the wastes in dry rock on land.

For all that is said about us to the contrary, the world nuclear industry is in fact very conservative and cautious. One thing we don't want to do is to put large quantities of highly-active material anywhere where it is irretrievable until we are absolutely sure it can do no harm. We are therefore being cautious to an extreme in relation to sea dumping. The wastes that are being dumped at the present time are very very low in activity compared with the main fission product output of the plant and need cause absolutely no concern. I personally think it will be a long time before the nuclear industry proposes sea bed dumping of the main glassified fission products, simply because the research programme to demonstrate that it is acceptable will inevitably, by its very nature, take a long time.

For my lifetime I believe that the majority of fission products will be kept in glassified form in deep water-filled ponds. Development and proving work on suitable deep burial grounds will be completed and the older wastes whose heat and energy is largely spent, will be progressively transferred to these burial places. There they will slowly lose their remaining activity causing no hurt to anyone in present or future generations.

Perhaps I might at the end of this lecture speak about the particular problems of plutonium because this is perhaps the other matter about nuclear power which gives rise to major public concern.

It has been said that plutonium was named after the devil.



Undersea burial of radioactive waste

This is not true. It was named after the planet Pluto, the outermost planet of the solar system. It has been said that plutonium is the most toxic material known to man: this is untrue. It is certainly a nasty material to handle and this gives rise to major problems in the design of plutonium plants. But it has nothing like the toxicity of some of the spiders and other insects, and is not significantly worse than the toxicity of many chemicals in widespread use. The particular hazard from plutonium is the inhalation of dust into the lung where less than a milligram can cause lung cancer. The issue is not whether plutonium can cause lung cancer. We know it can. The real issue is whether plutonium does cause cancer. Provided we process it in properly designed plants there is no reason why anybody should get cancer by working with plutonium.

There is concern that as breeder reactors produce more plutonium than they consume, the world will accumulate more and more of this nasty stuff until we are ankle deep in it and it will poison us all. Let me say a few words about why this is not so. The only reason for making plutonium is because it is a good fuel and we want to burn it. *All* reactors used in nuclear power stations produce plutonium. About half the plutonium they produce is burnt *in situ* and perhaps a quarter of all the energy produced in nuclear power stations comes from the burning of plutonium. But present designs of nuclear stations cannot burn all the plutonium that they produce because a significant proportion of it – plutonium 240 and plutonium 242 – does not burn easily and these isotopes can only be burnt in a fast reactor. We have, therefore, the paradox that the environmentalists who hate plutonium are opposing the fast reactor which is the only way that we can have a nuclear programme and at the same time control the amount of plutonium that we have in the world.

The fast reactor is the one and only nuclear incinerator and at the same time it will produce as much or as little new plutonium as we require. I can see no way that the world can have a sensible nuclear programme without introducing the fact reactor at some stage and I believe this will come in 10 to 15 years' time.

If we are to handle our fission product wastes responsibly I believe we must condition them properly before disposal. We are going for glassification and this requires reprocessing of the spent fuel. If we reprocess we will produce tons of plutonium, only a part of which is burnable in today's reactors. Either we keep it forever or we burn it in fast reactors, and, since its only desirable characteristic is that it is a superb fuel, I say burn it.

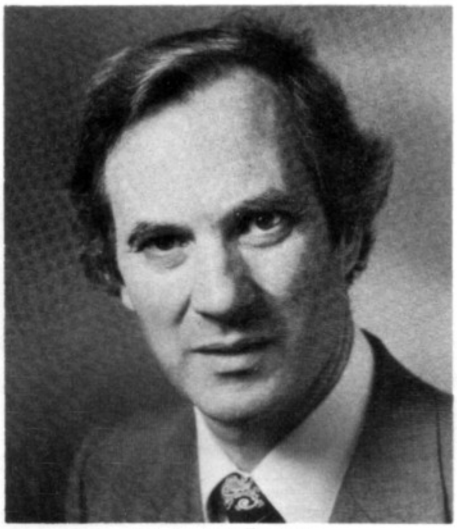
The logic of what the nuclear industry wants to do is clear. It is the industry which I believe has come just in time to save the world's industrial society from a devastating energy shortage. But just because these new fuels contain so much energy, the highest standards are required to ensure that they are not misused for weapons or the residual energy in the wastes is not allowed to damage our environment or our future health.

These difficulties have been recognised from the earliest days and, for all the mistakes that are made in any new industry, the safety record of the nuclear industry has been excellent. So also has been the record of the nuclear industry with regard to safeguarding the environment.

Our technology is improving all the time, largely as a result of the practical experience we are getting in operating our power stations and plants. I am certain that nuclear power is going to be the mainstay of the electrical industry in the future, leaving coal for the manufacture of substitute natural gas and the production of liquid fuels for transport. Moreover, the nuclear industry can do this with less hazard to the operators or the public and with less damage to the environment than any of the alternative ways of getting the energy we require.

UK RESEARCH ON UNDERGROUND WASTE DISPOSAL

The Authority's research programme into the geological disposal of nuclear waste has attracted a great deal of attention: in a recent article in *New Scientist*, London, Dr. Frank Feates * and Dr. Norman Keen of Harwell outlined the research programme. Their article is reprinted here with the permission of *New Scientist*



Dr. Frank Feates

Dr. Norman Keen

Irradiated nuclear fuel has been reprocessed at Windscale since the beginning of the United Kingdom's nuclear power programme 25 years ago. Reprocessing recovers the plutonium which has been created and the uranium which has not been consumed. The residue from the recovery process contains the products resulting from nuclear fission, and transuranic elements (the actinides) formed by transmutation of fissile products and other oxides. As extraction involves dissolution in nitric acid the waste starts off as a highly radioactive acid solution of uranium. This is concentrated to a small volume and is stored at the Windscale reprocessing plant.

The generation of 1 gigawatt-year of electricity produces 14·5 cubic metres of highly active liquid waste. Over 14 per cent of our electricity is now generated by nuclear power, and we have accumulated 700 cubic metres of such waste since the nuclear energy programme began. The waste is at present stored in carefully designed tanks—and none of these high level waste tanks has caused any problems. Various methods have been developed for converting the liquid into a solid. Incorporation of liquid waste in glasses appears the most suitable method of solidification—the final volume being about one-fifth of that of the concentrated liquid. Harwell manufactured the first such glasses containing radioactive waste about 15 years ago.

Glasses possess a number of important properties that make them particularly attractive for long-term storage: they can accommodate a very wide range of chemical elements; they are stable to very large radiation doses; they resist relatively high temperatures; they do not give rise to dust; and they are almost insoluble. Thus they provide a minimal risk of water or air pollution in the unlikely event of an accident.

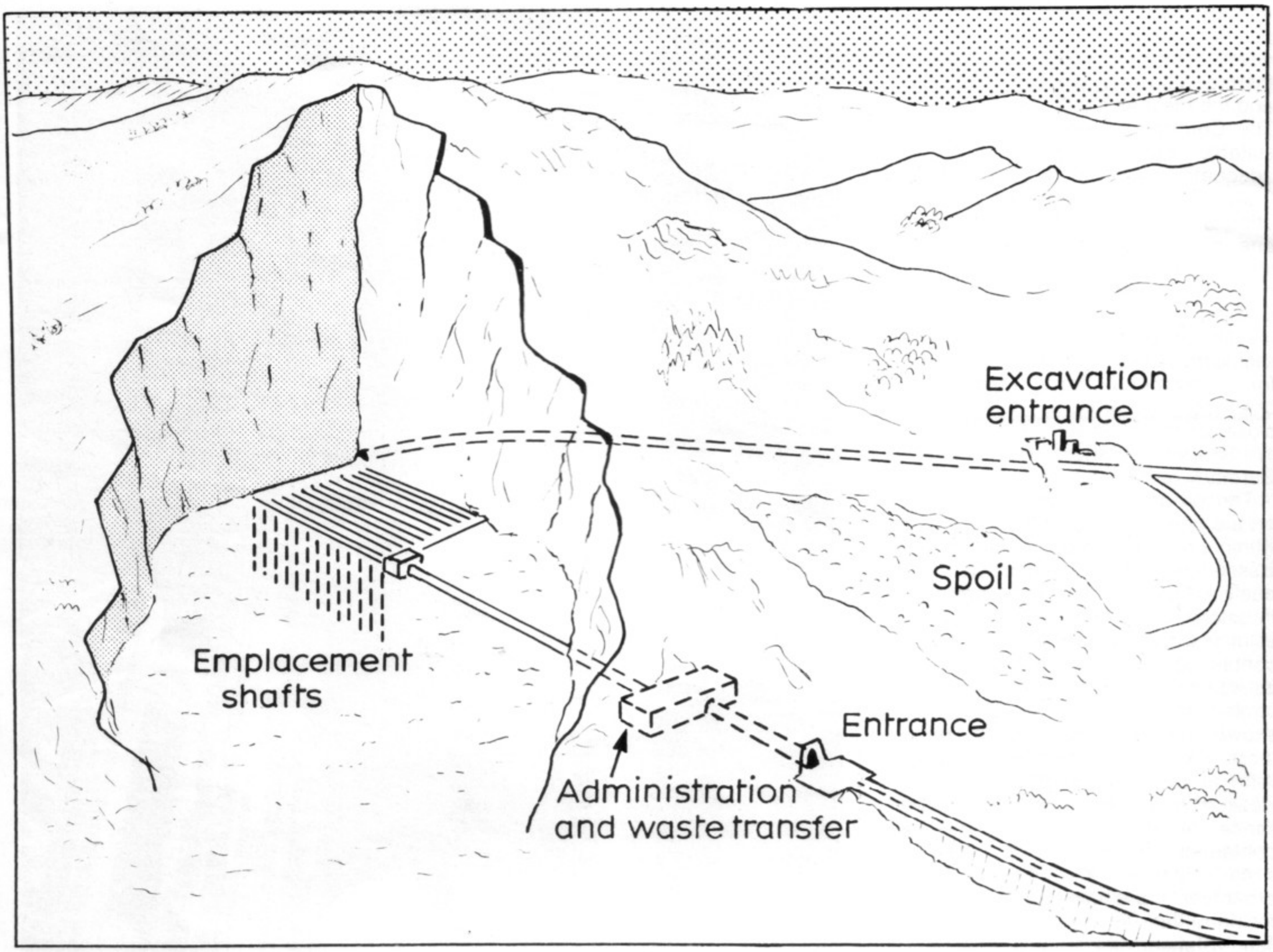
Present plans are to use the vitrification process developed at Harwell to convert the liquid waste into glass in steel cylinders about 60 cm in diameter and about 3 metres long containing about 1·4 tonnes of glass. Our present nuclear power programme will produce about 36 such cylinders a year. For ease of handling during disposal it may turn out to be better to produce smaller cylinders in correspondingly larger numbers.

The radioactive fission products produce heat as they decay over about a 300-year period. So it helps to keep the wastes liquid for a time so that the initial heat can be dissipated by water-cooled coils passing through storage tanks. After solidification the wastes will probably require cooling for several years before final disposal. The effects of the remaining heat on repository integrity require detailed consideration.

The present UKAEA research programme aims to assess the relative suitability of various natural geological structures as final repositories for the vitrified material. Our studies are concentrated on disposal into stable underground formations although we are increasingly considering emplacement on or under the ocean bed which appears to be a very safe method of disposal (*New Scientist*, vol 73, p 709).

Researchers have already carried out work in North America and in Europe on the use of salt formations for the isolation of nuclear waste. Clay and hard rock formations are also worth studying, and the European Economic Community is sponsoring an international collaborative research programme. Because of the high costs involved in drilling deep to study rock structures and assess their suitability, the present programme provides for each country to concentrate its studies on one type of rock. The United Kingdom, with France, will look at hard rocks such as granite; Germany, with Holland, will study salt; and Italy, with Belgium, clay. At this stage the programme requires a general study of the nature of rock structures deep below the surface to measure their water content, permeability and fracture structure so that we can assess any risk of water pollution. The study also calls for investigation of the effect of the heat output from the radioactive glassified waste on the rock structures. We must, too, undertake engineering studies to

*Dr. Feates has now taken up an appointment within the Department of the Environment



A conceptual design for a waste repository in hard rock

establish the most practicable designs for repositories in various types of rock formations.

The UKAEA commissioned the Institute of Geological Sciences (IGS) to specify the geological criteria that should be met by a rock structure if it was to be used for the construction of a repository. The principal criterion was that there should be negligible groundwater flow through the repository. Secondary criteria specified a minimum depth of 300 m (below the permafrost level in any future ice age); the absence of extensive seismic activity; and remoteness from massive engineering activities that might initiate rock movement. On a preliminary assessment several regions of the UK appear to satisfy the criteria. Detailed geological dossiers have been drawn up and geological field investigations are planned for at least three areas in the near future.

However, at this stage we are not seeking disposal sites. Our current research programme aims to obtain basic geological data about the structure of the rocks well below the surface. The rocks selected have no economic value and have never been studied in this way before. The programme will involve making small boreholes so that we can investigate the fracture structure using television and various physical techniques. We also plan to measure the rock permeability by diffusion and dispersion tests. When these studies have been completed the Institute of Geological Sciences will publish the results.

Twenty years for deliberation

The experimental programmes are expected to continue for at least three years. The results in all the European countries will then be considered so that the United Kingdom and other EEC countries can choose a preferred method for isolating their wastes. It is only at that stage that a firm commitment may be made to select a site for a potential repository, when a far more detailed scientific research study will be instituted. Ten years of research will be needed before we have enough information on any specific site to propose a pilot-scale trial of a disposal system. At that stage also, we may be able to decide whether deep-ocean disposal could safely be developed. Because of the time taken to allow the wastes' heat output to fall it is unlikely that there will be much glassified waste to dispose of before the end of this century. So there are 20 years in which to carry out necessary research, to develop and demonstrate a pilot disposal operation, and finally to construct a suitable repository. Whichever solution is eventually adopted it will require a complete assurance of safety and approval in detail from the appropriate government inspectorates and departments before operation. Current assessments, however, suggest that underground disposal can be safe with little effect on the local environment.

To reduce leaching, corrosion of canning materials, and the migration of radioactivity through the rock, the temperature rises of the bulk rock structures have to be minimised, Geological and chemical evidence suggest that they should not exceed 100°C, and theoretical studies have been conducted to establish the manner in which waste canisters would have to be distributed in a repository to meet this limit. These preliminary calculations indicate that the waste which will have accumulated by AD 2000 from existing nuclear power stations may need to be dispersed through a large volume of rock. To keep the volume to a minimum we are working to obtain more reliable data on heat transfer throughout and around repositories.

Because we do not have enough relevant data to enable us to test our models we have set up a field experiment in Cornwall where we can develop accurate ways of measuring thermal diffusivity, thermal conductivity, and the mechanical properties of rocks. The Cornish rock would not make a suitable waste repository but it is adequate for an initial research programme. We shall transfer instrumentation developed at the Cornish site to one of the geological research sites identified by the IGS. AERE workers have now built an electrical heater capable of simulating waste blocks which is being installed in a borehole on the research site surrounded by a number of holes for monitoring rock temperature changes. The work is continuing in close collaboration with related projects in Sweden, France, Belgium, and Germany.

The programme also includes work on the chemical effects that may occur within a repository. Factors affecting the dissolution and movement of radionuclides through the rock are being investigated in the laboratory using solutions obtained by leaching glasses containing plutonium and americium, as well as specially prepared solutions containing actinides. Experiments have shown that powdered granite retains these nuclides – studies are continuing with a range of concentrations, at elevated temperatures and in the presence of substances that may be contained in rock fluids, including silica, chloride, and fluoride. Other experiments are investigating the corrosion of various materials that may be used to sheath the vitrified waste in an underground repository.

Field experiments are also planned in association with the heating experiments in Cornwall. Specimens of metals will be suspended below the heating element to examine their corrosion in natural waters. In another borehole we shall monitor the corrosion of thin specimens of metal continuously over a range of temperatures. The materials we plan to test include the recommended canister cladding steel, lead, copper, gold and titanium. The experiment will permit sampling to detect changes in composition of the atmosphere above and around the specimens.

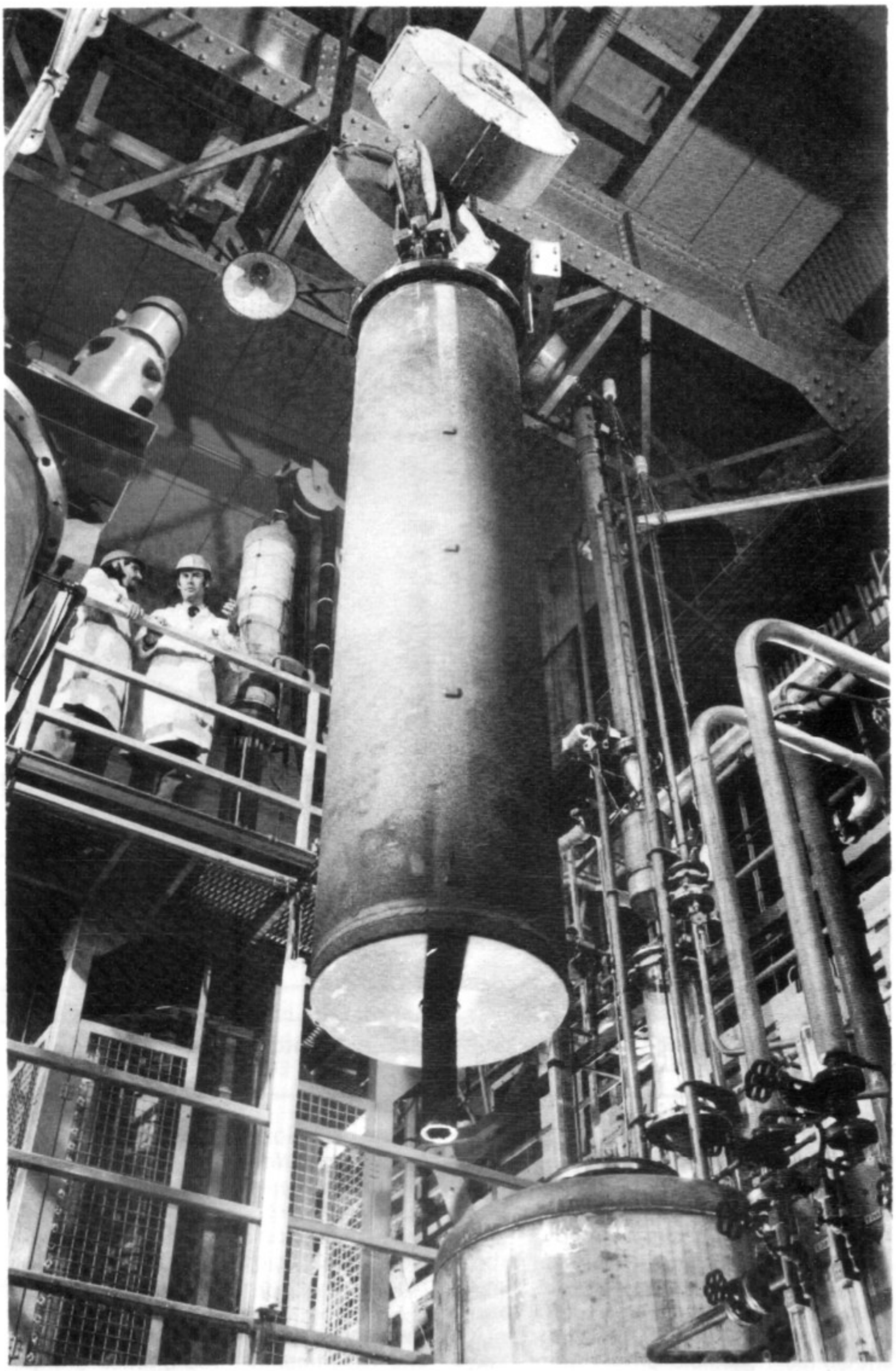
Finally, the AEA is preparing a conceptual design study for an underground repository. The study assumes that no one will want to retrieve disposal material and that the disposal region will be at least 300 metres below the surface.

A preliminary study of mining methods suggests that emplacement in the cubic array could be achieved at minimum cost by driving 5-metre-diameter horizontal galleries about 300 metres deep with vertical holes from the floor about 150 metres deep, each hole containing eight waste blocks (see Figure). Such an arrangement would minimise the length of horizontal galleries, which are likely to represent the major excavation costs. Vertical emplacement holes about 0·5 metres in diameter should be drilled rather than blasted to prevent undue stressing of the surround rock structures. Drilling equipment would, of course, need extensive modification for underground use in galleries with limited headroom.

We may also have to consider the possibility of surrounding individual canisters with a heat-transfer or insulating medium to control migration of heat or nuclides into surrounding structures. Access shafts for men, materials, and blocks could be constructed using existing mining techniques.

There may well be environmental advantages in using inclined or horizontal access shafts if the local topography is suitable. If repository development can continue while deposition and back-filling are taking place in parts constructed in earlier phases it will minimise the need to dispose of spoil on the surface and provide continuity of employment. Freshly excavated spoil can then be employed directly underground for back-filling, possibly incorporating medium or low-level waste with it to make maximum use of the excavation.

Present plans are to place as many of the service facilities as possible underground to minimise the environmental impact on the surface. The detailed design may eventually restrict visual intrusion to the access point and two or three ventilation shafts, all other facilities being subsurface.



A pilot plant at Harwell for the vitrification of radioactive wastes. The glass-making vessel (centre) is 45 cm diameter.

THE WINDSCALE REPORT-A REVIEW

Mr. Justice Parker's Report on the Windscale Inquiry, which was presented to the Secretary of State for the Environment on 26th January, is reviewed here by Simon Rippon, European Editor of the American publication *Nuclear News*.

It hardly seems necessary to tell readers of "Atom" that the report of the Hon. Mr. Justice Parker on the 100-day Windscale Inquiry was a complete vindication for the commercial reprocessing plans of British Nuclear Fuels Limited (BNFL) nor that the subsequent parliamentary debate on 22nd March resulted in an overwhelming endorsement of the findings in the report. There is now no possible reason to delay any further a start on the detailed design work and contract negotiations for the proposed Thermal Oxide Reprocessing Plant (THORP) at Windscale. But the final outcome of this historic inquiry has far wider implications both within the UK and internationally; and if the opponents of nuclear power should try to minimise these wider implications they should be reminded that it was they who first suggested them when they were campaigning for the inquiry.

In the first place the scope of the inquiry was very much broader than the basic planning issues associated with THORP. This again was largely due to the insistence of the opposition and even if they now criticise the Parker report for not dealing in detail with every argument presented to him they can certainly not claim that they did not have, and take advantage of, the chance at the inquiry to raise virtually every substantive issue put forward by the anti-nuclear movements around the world, with the exception of the fast reactor which will be the subject of a separate inquiry.

It is also worth recording that the effort mounted by the leading opposition groups at the Windscale inquiry was probably the largest ever made to oppose a nuclear project through legitimate democratic procedures. In spite of their complaints about lack of resources the opposition were very well represented at the inquiry and by virtue of the possibility for cross examination of all witnesses by all participants, every argument was examined in the most exhaustive detail. Under these circumstances the almost total rejection of the opposition arguments by Justice Parker and his two expert assessors, Sir Edward Pochin and Prof. Sir Frederick Warner, must be seen as a major defeat for the whole anti-nuclear ideology.

Needless to say the opponents have not been slow to attack the Parker findings. Some have gone as far as accusing him of bias and have suggested that his two assessors are part of the so called 'nuclear establishment' Anybody who attended the inquiry in Whitehaven or who has read some of the transcripts will know that these accusations are so blatantly untrue that they further discredit the people who are making them. The Report is not without its criticisms of BNFL and other bodies with responsibilities in the nuclear field. These are mostly contained in Section 17.8 ('Recommendations' – reproduced on Page 134 of this issue of 'Atom'). Criticism of BNFL centres on the local liaison and emergency procedures, which the Inspector felt could be considerably improved. There are further implicit criticisms of present practices in the Report's recommendations that the responsibility for vetting and reviewing Windscale's Security Precautions should be vested in some independent person or body and that the whole-body monitoring of local people should become a permanent feature of Windscale practice. The inspector also supported one objector's view of the statement in a note by the Department of the Environment, the Ministry of Agriculture, Fisheries and Food and the Department of Transport that radiation doses to the public "had generally been no more than a small fraction of the ICRP limits." Reports by the Fisheries Radiobiological Laboratory for 1975 and 1976 showed the maximum consumer of fish in the local fishing community as receiving 34 per cent of ICRP in 1975 and 44 per cent in 1976. Mr Justice Parker did not regard 34 per cent as being a small fraction.

Against the background of criticism from many of the objectors, it was gratifying to hear unreserved praise for Justice Parker from the great majority of speakers in the House of Commons debate and Peter Shore went as far as describing the two assessors as: "the most distinguished radiological and chemical engineering assessors we could find . . ."

Another feature of opposition response to the Parker report which has been apparent in letters to newspapers and in some of the speeches in the Commons debate, is a return to Flowers, Ford and Fox. Since the Parker report is so unequivocal it leaves very little scope for selection of quotations to support different viewpoints, but as has been all too apparent over the past couple of years, exactly the opposite is the case with the report of the Royal Commission on Environmental Pollution (the Flowers report) and to a lesser extent the US Ford-Mitre study and the Australian Ranger inquiry (Fox report). It should however be clearly recognised that the Windscale inquiry was set up largely as a response to the Flowers' call for wider public debate and many of the open questions were specifically addressed during the inquiry. The Flowers report, as well as the Ford-Mitre study and the Fox report were close at hand to Justice Parker and his two assessors throughout the Windscale inquiry and by the end most of the leading participants could almost quote from them by paragraph numbers alone.

The final, almost desperate, effort of opponents to get the decision on THORP delayed has been the suggestion that US non-proliferation policy could inhibit BNFL from concluding long term contracts with the Japanese and other overseas customers – even though France does not appear to have been inhibited in this way – and it is suggested that the decision on THORP should be delayed until the outcome of the International Fuel Cycle Evaluation (INFCE) is known. Contrary to the suggestion of various opponents this difficulty was considered during the Windscale inquiry and BNFL made their position very clear in the final summing up of their case. The position has, however, now been made abundantly clear by the Foreign Secretary, Dr. David Owen, during his winding up of the 22nd March debate. He said: "I want there to be no misunderstanding about the American view. They would prefer us to defer decision pending the results of INFCE and this has been conveyed to us by the Administration. However, construction of the reprocessing part of the plant will only start in late 1981–1982, though work on the ponds will need to start right away. I am advised that we need to lay the order now so as to be able to get ahead with the design, obtain planning permission and go out to

Mr. Justice Parker (centre) with his two Assessors, Sir Frederick Warner (left) and Sir Edward Pochin.

tender. Yet this timing will allow us to take full account of the results of INFCE as it proceeds, in how we design, safeguard, protect and manage the reprocessing plant and its products."

David Owen went on to say: "The Government fully shares President Carter's objective which is to limit as far as possible the danger of nuclear proliferation. We also share the aim of limiting the spread of reprocessing plants. Where we differ from President Carter is that we believe we can best achieve this by offering other non-nuclear weapon states the services of the new plant at Windscale."

Another important point made by David Owen was the fact that we cannot really expect, by the end of next year when INFCE is scheduled to be completed, that the 40 participating governments starting with quite different views will have agreed that reprocessing is, or is not, necessary or that fast reactors are or are not needed. "It is for this reason," he said, "that the governments taking part agreed, and many of them made this agreement a condition of taking part, that INFCE would not be used as an excuse for delay in reaching necessary decisions on nuclear policy."

In careful consideration of the Non-Proliferation Treaty (NPT) Justice Parker established the view that it is a "straight-forward bargain" in which the non-weapon states have agreed to refrain from making or acquiring nuclear weapons and to submit to safeguards in return for assurances on the part of weapon states that they will afford every assistance to non-weapon states in development of nuclear energy for peaceful purposes. He has also gone to some trouble to establish that at the time of entering into the NPT the course of peaceful nuclear development, that everybody, with the possible exception of the Canadians, was envisaging, included the development of reprocessing, the separation of plutonium and the use of fast reactors. And therefore he concludes: "to deny reprocessing facilities would be against the spirit – and, as I see it, the letter – of our obligations under the main existing bulwark against proliferation".

But do we really need it? This is the favourite question of opponents to nuclear power in general and to reprocessing in particular. At a preliminary hearing before the start of the Windscale inquiry Justice Parker made it clear that he would be prepared to consider arguments on the broader energy issues that go far beyond the scope of a normal planning inquiry and at an early stage in the actual proceedings he warned objectors that if they wished to advance the view that alternative sources of energy would remove the need for Windscale, then he would expect them to produce evidence about likely cost, environmental impact and reliability of these alternatives and to consider the risks associated with placing too much dependence on optimistic projections of what might be achieved with alternative sources of energy in the future.

In the event the inquiry did hear a considerable amount of evidence from both sides on energy demand projections, resources availability, energy conservation and alternative energy, and even though these arguments are not discussed in any detail in the final report, considerable weight can be attached to Justice Parker's conclusion that: ". . . none of the suggested measures or sources appeared to me sufficiently likely, either alone or in combination, to produce such savings in energy or contributions to energy supply as would justify or render reasonable any course other than a steady development of nuclear power."

Rather more consideration has been given in the final report to the specific need for oxide fuel reprocessing to deal with the arisings of spent fuel from the currently rather modest, domestic programme of AGR nuclear power plants. Quite apart from the question of resource recovery, the 'throw away' fuel cycle is rejected largely on the grounds that it would present a larger problem for ultimate disposal of high level waste due both to the greater volume of spent fuel assemblies and to the greater surface area for leaching presented by the fuel material. The 'stow away' approach in which it is envisaged that spent fuel would be retained in retrievable storage so that the option of recovery of the unused uranium and plutonium resources could be adopted at a later date, is discounted largely because of uncertainties about extended pond storage, but also because it is considered that there would still be a need to make provision for reprocessing any spent fuel elements that failed during storage.

Although it has in the past been assumed that extended pond storage of oxide fuel would not present any particular problems, it transpired during the inquiry that there is a scarcity of solid information on this question. There are also some real doubts in the case of highly-irradiated stainless-steel-clad fuel from AGRs. The conclusion of Justice Parker is: "On the evidence before me it is clear that, if there is going to be a delay in the commencement of reprocessing of AGR fuel, an urgent research programme is necessary to determine whether the cladding can be so designed or pond storage methods so adjusted and improved, as to make increased pond storage life prudent. That it is not prudent with existing design methods I have no doubt." At the same time Justice Parker has discounted any suggestion that the nuclear industry has been negligent in not giving earlier consideration to the question of extended storage of spent fuel by noting that until recently it was the common assumption that reprocessing would take place after a relatively short period of pond storage.

Having established a need for oxide reprocessing of domestic fuel arisings, the next question is whether to double the size of the plant and reduce unit costs by taking on foreign business. Apart from the non-proliferation issues the main source of argument in this case was economic. This is a subject which always provides plenty of scope for discussion of rival sets of costings and the Windscale inquiry was no exception. But BNFL were able to point out an error in the most substantial set of rival figures produced by Dr. Peter Chapman, which when corrected brought his final costs roughly in line with the values that had been given in evidence earlier by BNFL. While acknowledging that there are still uncertainties which could adversely affect the economics of THORP as the project progresses, Justice Parker has accepted the basic cost estimates of BNFL. He also records a comment of Raymond Kidwell, the Counsel for the Friends of the Earth, after viewing the contract which BNFL are hoping to conclude with the Japanese – he observed that it appeared to be very profitable for BNFL.

Mr Justice Parker deals also with the moral and ethical issues surrounding the Inquiry and the wider nuclear power debate. In a chapter on 'Public Hostility' he says (13.6) that much of the opposition appeared to be based on sincerely held moral grounds, and that amongst those who advanced opposition on such grounds there was a tendency to suggest that supporters were acting in an immoral way. This attitude is plainly unsustainable for it is clearly possible to hold an equally sincere belief that reprocessing is necessary on moral grounds. If by reprocessing we can lessen the amount of plutonium to the escape of which future generations may be exposed; if we can avoid the possibly greater harm to both present and future generations which would result from deriving energy from the mining and burning of coal instead of from nuclear power; if we can, by using nuclear power, save society in 20 years' time from the troubles that would follow upon a reduction in living standards; if at the same time even a modest number of the unemployed can obtain employment, and if this can be achieved at the cost of an insignificant exposure of ourselves to radiation, it may be that support is the moral answer. It is not for me to attempt to reach a conclusion on the morality of the situation. It can however be stated that, the question is not as easy as some believe or would wish to believe. It was, moreover, abundantly clear on the evidence that some who pursued the moral line had done so without investigating the consequences of pursuing alternatives

One of the most valuable features of the Parker report is the way in which it has been written. It reduces 100 days of hearings, over four million words of transcript and a huge pile of supporting documentation to a very readable 86 page report which still manages to deal with all the issues.

In reducing the vast mass of evidence presented at the inquiry to a readable report of manageable proportions, Justice Parker has inevitably upset some of the opponents by the brevity of his discussion of their particular contributions. It is, however, quite wrong to suggest that any scrap of evidence has been ignored. Time and time again during the inquiry Justice Parker demonstrated that he had read and fully digested virtually every document presented to him. He showed great patience with those objectors who were motivated by irrational fears and was suitably severe with those who tried to adopt scare tactics. He also demonstrated an impressive grasp of the complex technical arguments and was not fooled by figures. By way of example it is worth recording his comment on the evidence of Dr. Alice Stewart and George Kneale when it transpired that moving one person in a sample from one age group to another destroyed the statistical significance of one of their results. Parker's comment is: "It may be that in reaching such a conclusion I am flying in the face of statistical theory but my own conclusion is that if the significance or otherwise of an apparent result can depend on the chance that a single man died just before rather than just after a particular birthday, the result shown is not convincing."

Such a clear report on such complex issues deserves an unqualified endorsement by government and it was therefore gratifying to hear the Secretary of State for the Environment, Mr. Peter Shore, in opening the Parliamentary debate, accepting point-by-point virtually all the conclusions reached by Justice Parker. He took note of the short list of recommendations in the report, none of which present any particular problems to the proposed plans for Windscale, and summed up by saying: "the Government believes that Mr. Justice Parker's report, based upon all the mass of evidence submitted and assisted as he was by the great expertise of the most distinguished radiological and chemical engineering assessors we could find, has shown that this reprocessing can be carried out without any significant increase in radiological risk; that environmentally it offers a better option than the alternative of storing our spent fuel for disposal in a form which includes the plutonium and unused uranium; that the security risks can be contained in ways compatible with our democratic way of life; and that the reprocessing of foreign fuel does not run counter to our policy to prevent the proliferation of nuclear weapons and may in fact re-inforce that policy."

Extracts from the Windscale Inquiry Report

Mr Justice Parker's summary of the principal conclusions and recommendations is printed below.

17.1 It is convenient to summarise my conclusions by way of giving my answers to the three questions set out in paragraph 1.7 and the principal reasons which have led me to arrive at such answers. This will necessarily involve some repetition of what has appeared before but this is unavoidable.

Question 1. Should oxide fuel from UK reactors be reprocessed in this country at all?

17.2 Although reprocessing of oxide fuel is not necessary to preserve the option either to build CFRI or to launch an FBR programme, and although it is possible that it will be decided not to proceed further with FBRs at any rate for a period, I conclude that a new plant for reprocessing oxide spent fuel from UK reactors is desirable and that a start upon such a project should be made without delay. My principal reasons for this conclusion are as follows:—

1. Stocks of spent fuel from AGRS presently existing and under construction will, unless reprocessed, continue to build up and will have to be stored until finally disposed of in some manner.

2. It is necessary to keep the nuclear industry alive and able to expand should expansion be required. Such expansion might be required, either to meet additional energy demands, or to preserve a 'mix' and to avoid over-dependence on a particular energy source, or to reduce the number of fossil fuelled stations as a result of confirmation from further research of the views expressed in the Ford Foundation Report (and elsewhere) that such stations are more harmful than nuclear stations.

3. Keeping the industry alive will involve further reactors being constructed and further quantities of spent fuel arising. Such further quantities will, if not reprocessed, also have to be stored until finally disposed of in some manner.

4. All the spent fuel stored will contain fission products and the long-lived actinides including plutonium. The inventory of plutonium will therefore continue to increase for so long as reprocessing is delayed.

5. The prolonged storage of ever-increasing spent fuel containing an ever-increasing quantity of plutonium would involve the development of new storage methods. This would be both both a costly and a lengthy process.

6. To store such increasing quantities

of spent fuel would only be sensible if it was likely that it would ultimately be decided to dispose of the spent fuel (with its entire content of plutonium and other radioactive substances) without reprocessing.

7. Such a decision appears to be unlikely and not to be in the best interests of ourselves or future generations. This is because:—

i. It involves throwing away large indigenous energy resources and, for so long as there is a nuclear programme of any kind, making us wholly dependent on foreign supplies. The undesirable consequence of energy dependence of this nature has been only too well demonstrated in recent years in the case of oil.

ii. It involves committing future generations to the risk of the escape of more plutonium than is necessary. If the plutonium is extracted by reprocessing the total inventory can be greatly reduced.

iii. It involves committing future generations to a greater risk of escape of the remaining content of the spent fuel since the spent fuel is likely to be more vulnerable to leaching by water than solidified highly active waste.

8. If reprocessing is going to take place at some time it is preferable to start without delay since the techniques can then be developed at a reasonable rate, and greater experience can be gained, both of the process itself and of the behaviour and effects of the emissions involved, whilst spent fuel stocks and arisings are comparatively small. This is to the benefit of workers, public and future generations alike.

9. The risks from the emissions involved in reprocessing are, on current estimates, likely to be very small and, if reprocessing is to take place at some time, will in any event occur at some time. Evidence that current estimates are seriously wrong did not appear to me to be convincing but, should it be proved correct, this is likely to have occurred well before THORP begins to operate. THORP would then have to operate to the new limits or not at all.

10. The risks of accident will, if reprocessing is to take place at some time, also have to be incurred, at some time. At the present time they are likely to be containable within tolerable levels. If reprocessing were to begin suddenly on a large scale after a lapse of time the risks would probably also be containable but would be likely to be greater.

11. The risks from terrorism are not significant. The plutonium separated from UK fuel would be stored at Windscale and would not be subjected to movement from Windscale save in the form of fuel, which is not an attractive target.

12. The risks arising from transport would be no greater than at present. Spent fuel will have to be carried to Windscale in any event. Fresh fuel sent out from Windscale would not present any significant risk.

Question 2. Should reprocessing be at Windscale?

17.3 I have no doubt that the answer to this question should be in the affirmative. The existence of the facilities already at Windscale and the store of knowledge concerning the behaviour of radionuclides discharged from Windscale, coupled with the facts that any alternative would be likely to involve additional transport of plutonium or prohibitive expense, make it clear that, if the operation is to be carried on at all, Windscale is the obvious location. It will involve additional exposure to local inhabitants but the risks involved appear to me to be so small that this fact cannot outweight the advantages mentioned.

Question 3. Should the plant be double the size required for UK spent fuel and used to reprocess foreign fuel?

17.4 The financial advantages of having a plant to reprocess foreign fuel on the basis intended by BNFL are plain. There is the additional advantage that planning permission, a start on THORP and the receipt of foreign fuel for reprocessing would do something to relieve the pressure on non-nuclear-weapon states to develop their own facilities. It would also demonstrate that this country intends to honour at least the spirit, and as I think the letter, of its obligations under the NPT. This could well be an advantage in negotiations, over the period when THORP is building, to strengthen the NPT. Furthermore, the existence of substantial reprocessing facilities in one or more nuclear-weapon states is a necessity to deal with fuel which fails in reactors or deteriorates in storage.

17.5 The disadvantages of accepting and reprocessing foreign fuel are also clear. It will involve additional routine emissions, additional storage of spent fuel pending reprocessing, additional highly active waste to dispose of and, which was chiefly relied on, additional movements of plutonium in some form, and the putting of non-nuclear-weapon states nearer to the bomb.

17.6 These disadvantages appear to me to be clearly outweighed by the advantages. The risks from the additional routine emissions are very small; the additional storage presents no significant risk and certainly no greater risk than would be involved in the storage for prolonged periods of UK spent fuel; the total highly active waste from reprocessing of UK and foreign fuel combined will contain only a fraction of the plutonium which would be contained in UK fuel alone if such fuel were disposed of without reprocessing; the risks from the movement of plutonium can be largely dealt with by technical fixes. The one substantial objection which appeared to me to arise is that the separation of plutonium and its supply to non-nuclear-weapon states will put them nearer to the bomb. Since, however, this matter can be alleviated to some extent by technical fixes; since it will not in any event happen for 10 years; and since a refusal to accept foreign fuel would be in breach of the spirit if not the letter of the NPT and would put pressure on non-nuclear-weapon states which could lead them to produce their own plutonium long before they could receive any from THORP, I cannot regard this as an overriding objection.

17.7 It is also important to remember that the unless foreign business on the required scale can be obtained BNFL would not proceed with the plant as presently proposed. To meet UK needs only would require a smaller plant and the whole concept would have to be the subject of reconsideration and re-design. This would be likely to involve an undesirable delay in starting on reprocessing of UK fuel. It would also mean that when further capacity was required we should, instead of having it available at the cost of foreign cutomers, have to finance it outselves.

In the light of the above I would answer the third question in the affirmative.

17.8 My principal recommendations are the following:—

1. Consideration should be given to charging some independent person or body with the task of (a) vetting security precautions both at Windscale and during transit of plutonium from Windscale and (b) reviewing the adequacy of such precautions from time to time (para 7.18).

2. BNFL should devote effort to the development of plant for the safe removal and retention of krypton 85 and, if development proves successful, should incorporate it in the proposed plant (para 10.52).

3. More permanent arrangements for whole body monitoring of local people should be instituted. Subject to certain general principles, the details should be agreed by those directly concerned They would not be approprite to planning conditions (paras 10.93, 10.94 and 10.126).

4. The authorising departments should however consider whether provision of such facilities should be made a condition of authorisations to discharge (para 10.95).

5. Consideration should be given to the inclusion of some wholly independent person or body with environmental interests in the system for advising central government on the fixing of radiological protection standards. That person or body should probably be changed from time to time (para 10.111).

6. A single Inspectorate, as recommended by the Royal Commission, should be responsible for determining and controlling all radioactive discharges (para 10.113).

7. There should be specific discharge limits for each significant radionuclide The onus should be placed clearly on

the operator to show that a discharge cannot practicably be avoided before the limits are fixed (paras 10.115–10.116).

8. The provisions of the Radioactive Substances Act 1960 relating to the powers to hold inquiries into proposed authorisations to discharge should be re-examined (para 10.122).

9. The relevant authorities should carry out more monitoring of atmospheric discharges (para 10.126).

10. FRL should publish their annual reports more rapidly in future. There should, as recommended by the Royal Commission, be one comprehensive annual survey published of all discharges and at intervals, reports by NRPB on radiation exposure (para 10.126).

11. BNFL should do more, in future, to ensure that safety precautions and operating procedures at Windscale are sufficient for all eventualties, are strictly observed and are continually rehearsed. (para 11.11).

12. The current review of NII should examine whether they are sufficiently equipped with scientific expertise to check the designs for the proposed plant (para 11.24).

13. It is essential that those who would be required to take action under the Windscale emergency plan are fully aware of the responsibilities the plan places on them (para 11.30).

14. The local liaison committee should be re-organised and its functions re-defined. (para 11.34).

15. Fuel flasks should, as far as possible, continue to be delivered to Windscale by rail, but this is not a matter appropriate to planning conditions (paras 14.28 and 14.45).

16. Outline planning permission for THORP should be granted without delay, subject to conditions (paras 14.39–14.41, 14.45 and 16.1).

Plutonium

2.34 Certain facts about plutonium are given here because it was apparent to me that there exits much misunderstanding about it.

1. It is not true that plutonium never existed until man made it. It was stated on behalf of one party at an early stage in the case that God never made plutonium. Later, that party's own expert witness accepted that the existence of a natural nuclear reacotr, which had made plutonium in the long distant past in Gabon had been established. To talk of the creation of plutonium as 'man's bargain with the Devil' or 'Faustian bargain' is therefore no more than emotive nonsense.

2. It is not true that plutonium is highly radioactive. Its principal isotope plutonium 239 is relatively stable and as a consequence its half-life is very long and its radioactivity (per unit mass) is very low.

3. It is not true that plutonium has only two uses, making bombs and making electricity commercially. Plutonium 238 is used within the body as the power source for heart pacemakers.

4. It is not true that in all circumstances very small amounts of plutonium are lethal. Insoluble particles when inhaled certainly are hazardous in small quantities. Considerably larger amounts could be eaten without appreciable harm.

5. It is not true that plutonium is only safe when protected by massive shielding. As regards shielding from its radiation, it could be sat on safely by a person with no greater protection than, as Professor Fremlin put it, 'a stout pair of jeans'.

6. It is not true that plutonium is the most toxic substance known to man. Numerous radionuclides are more toxic than plutonium 239 if present in food or water, and particularly the isotopes of radium, two of which are over 100 times as toxic when the comparison is made between soluble forms. Similarly, several of the isotopes of thorium are rather more toxic than plutonium 239 if inhaled if one compares insoluble forms.

7. It is not true that an escape of plutonium would be a unique disaster. The damage done, for example, by the breaking open of a tanker of chlorine of the size which regularly travels by road and rail would be a great deal more damaging than the breaking open of a container of spent fuel with its plutonium content.

On the other hand it is true

1. That plutonium is a bomb-making material.

2. That if plutonium reaches a critical mass there will be a chain reaction and thereby the creation of highly active fission products.

3. That in certain circumstances plutonium is very dangerous to man.

4. That plutonium, if released into the environment, persists for a very long time.

5. That, as a result, stringent precautions are necessary to prevent plutonium falling into the wrong hands, from reaching critical masses and from returning to man over the long period of its life.

6. That, as was readily accepted by Friends of the Earth Ltd (FOE), it is in everyone's interest to find as safe as possible a resting place for atomic waste, whether in the form of spent fuel containing plutonium or in the form of glass blocks containing only about 1,000th of the amount of plutonium that would be contained in the spent fuel. There was, rightly much stress laid upon our obligations to future generations. These obligations include the obligation to find a safe resting place for our waste if we can, rather than leave it for them to do so. Resistance to such attempts is neither in their interests nor in our own. In whatever form the waste is to be, it is likely to be safer in deep holes in stable geological formations than preserved in above ground storage.

Energy forecasts to the year 2000 and beyond

Britain could need to import nearly 100 million tons of coal equivalent by the year 2000 according to a paper prepared for the Energy Commission by the Department of Energy, and published on 27th January as Energy Commission Paper No. 5.

The paper presents a more detailed picture of the forecasts in Energy Commission Paper No. 1 "The Working Document on Energy Policy", and extends their range beyond the year 2000 to 2025.

For simplicity it describes in detail one single reference case, based on a set of six assumptions about economic growth and levels of energy production. Four variant assumptions are also examined.

Among the paper's conclusions are:

- there could be a net energy import requirement approaching 100 mtce by the year 2000, and growing thereafter;
- of this, at least 50 mtce are for uses that could be met by coal and nuclear power if they were available;
- if higher natural gas reserves became available this would extend supplies for the premium market and postpone the need for synthetic natural gas production (SNG);
- coal may be most economically used in the manufacture of SNG and directly in industry, rather than in power station fuelling;
- it seems unlikely that renewable energy supplies will make a significant and economically viable contribution to supplies before the end of this century.

Guide to analytical services

A guide to the extensive analytical services at Harwell has just been published and is now available.

The leaflet describes in detail a wide range of elemental, trace, surface and organic analytical techniques, including many special techniques of general applicability which have been developed for the nuclear programme.

These facilities are already widely used by customers in all sectors of industry in problem solving. Typical examples are: quality control, on-line analysis, component or product failure and environmental surveys.

Harwell can tackle complete problems facing firms in these fields using the range of techniques described in the booklet. In addition, specific measurements can be made on advanced equipment as an extension to the customer's own research facilities. All these services are backed up with interpretation by highly qualified and experienced staff.

Copies of the guide are available free of charge from: Mr T. Carter, Harwell Analytical Services, Building 551, Harwell, Oxfordshire, OX11 0RA. Telephone: Abingdon (0235) 24141 Extension 4151.

NUCLEAR POWER-THE MORAL QUESTION

Nuclear power, has raised moral and ethical as well as technological issues and the British Council of Churches, recognising this, has participated in the nuclear power debate. In this short article, Mr. Philip Searby, Secretary of the Authority, considers some of the views adopted by the Council.

Mr. Searby is active in Church of England affairs: he has been a Reader in the St. Albans diocese since 1950 and a member of the St. Albans diocesan synod since 1976. This article first appeared in the April, 1978 edition of the Church of England's publication 'Crucible' and is reproduced here by permission.

1. The October to December issue of Crucible reproduced the evidence from the British Council of Churches to the Windscale Planning Inquiry into the proposal by BNFL to expand their nuclear fuel processing activities at Windscale.

2. Though the BCC witnesses in evidence said that they were not "against nuclear power itself" – and the BCC General Secretary himself wrote to the Church Times to stress that their objection to the new reprocessing plant at Windscale "does not in any way imply an anti-nuclear stance" – it is regrettably true that the BCC submission of evidence has given many people the impression that the BCC and the churches generally are opposed to the development of nuclear power. In their oral evidence, the authors of the BCC submission do not rule out a contribution from both thermal and fast reactors to meet the energy needs of the future, but for those to whom only the evidence reproduced in Crucible is available this view would perhaps not be apparent since many of the arguments presented there appear to have little validity when presented as objections to the new reprocessing plant unless objection is being taken to the development of nuclear power itself.

3. Crucible comments that "the evidence . . . urges the need to take full account of ethical and social factors in assessing the case for developments in nuclear energy". This is indeed highly desirable and until there has been full debate on this, it is perhaps difficult for representative bodies to put forward views which could be seen by the public generally as meant to summarise those of the individuals and organisations they represent. Such a debate raises many important points; this article can only deal briefly with some of them.

4. Much of the BCC case seems to rest on the contention that there is "significant disagreement among experts relating to relevant technical considerations". But the fact that views are expressed on both sides and that there is disagreement between different people does not imply that the weight of evidence supporting the various views is the same. The BCC approach could be used to suppress all new ideas and developments – and historically has undoubtedly been so used. The evidence quotes the Royal Commission on Environmental Pollution and its report certainly helped to discredit some of the wilder flights of fancy of the opponents of nuclear power. But the particular individuals who reported on nuclear power and the environment cannot be regarded as the ultimate authority – nor indeed would they so claim – and much has been written since which paints a more favourable picture of scientific and practical attitudes to nuclear power. One specific document with a rather different emphasis is, for example, the report prepared by the Royal Society commenting on the needs for development in the field of energy published in February 1977.

5. In this connection, therefore, it is relevant to record that in their final submission to the Windscale Inquiry the BCC say "We do not suggest that no decision should be taken in the absence of such (substantial technical) agreement; indeed the likelihood is that in general the more significant the issue the less we shall look for or demand substantial agreement. In those circumstances, the requirement of technical agreement may well be replaced by a judgement of the risks or costs of not proceeding".

6. The BCC submission also argues against "the foreclosing of alternative and less dangerous options by a decision to expand a part of the nuclear energy process which gives prominence to the use of plutonium." Many would argue that the evidence to support this conclusion is lacking; the credible options are not being foreclosed (even where their economic and environmental implications may make them doubtful options) and much information has been presented to counter the argument that nuclear power and the use of plutonium as an energy source is less safe than other forms of energy.

7. But the main ethical and social issues in the development of nuclear power (as opposed to an examination of whether a particular nuclear plant should be built now, later or not at all) lie much deeper. Both in the oral evidence at the Windscale Inquiry and in the paper published by the Board of Social Responsibility "Nuclear Choice" reference is made to the importance of avoiding energy shortage and the possibilities for energy conservation. But neither really faces up to the basic issue:

(a) the continuity of energy supplies at reasonable cost is placed at greater risk if nuclear development is curtailed;

(b) incurring this risk means greater

(b) ... jeopardy than otherwise to the prospects of meeting the legitimate desires of the members of the developed world like ourselves at least to maintain their present standards and of the growing population of the undeveloped world to achieve standards closer to ours;

(c) the consequences of failing to meet these desires could be serious for all concerned.

In these circumstances is the curtailing of nuclear development a reasonable and just thing to do?

8. Arguments have been put forward on the moral and other benefits of a simpler life style but three points need to be made on this:

(a) How feasible would a return to a simpler life style be? Is it, for example, consistent with the current density of population in many of the economically advanced areas of the world? Is the current life style in many of the developing countries acceptable and even if it is can it remain so with the vast increase in population bound to occur over the next 50 years or so.

(b) Moreover, is it necessarily right to assume that a life style which would inevitably deprive many people of the material, intellectual and perhaps spiritual benefits of modern living is in any sense "better"?

(c) Even if it were, what right have we to dictate to others on the life style they should prefer or to deny them the opportunities to enjoy such economic and material advance?

9. It is not, surely, suggested that there are any overriding moral objections to safeguarding the standards of living of our descendants provided due account is taken of our responsibility for our environment. One reads, for example, of the "legacy" this generation is leaving to its descendants in radioactive waste but this can surely be balanced by the legacy of new technologies and the opportunities they provide to enable later generations to manage successfully without access to the resources which we and our ancestors have already consumed. Of course we must avoid closing off other options. Supporters of nuclear development have never argued that work should not be done on alternative energy sources. What has been argued is that due account needs to be taken of the feasibility, cost and environmental consequences of such alternative developments in exercising the overall political judgement on the balance of expenditure between various objectives, nuclear and non-nuclear energy, energy and social welfare in other respects, e.g. health, and so on.

10. It is of course legitimate for any individual Christian or non-Christian to take a personal view on the basis of the facts as known to him on the morality or otherwise of a particular course of action, whether taken by himself individually or by the community in which he lives, or by a Government on behalf of that community. Nuclear energy derived by human ingenuity from the material resources available to us (both the ingenuity and the resources being God-given, a Christian would say) is like all other such resources capable of exploitation for good or evil ends. Christian stewardship of our resources requires us to judge between alternative courses of action; to many people the facts when fully known suggest clearly that the wise and responsible development of nuclear energy is, when seen against the risks that its rejection would entail, a key part of a true Christian stewardship of the gifts entrusted to us by God.

The Management of Highly-Radioactive Reprocessing Waste in Sweden

In December 1977, the Swedish nuclear power utilities published a report entitled "Handling of Spent Nuclear Fuel and Final Storage of Vitrified High Level Reprocessing Waste". This report was the work of the Nuclear Fuel Safety Project (KBS) organised by the Swedish utilities in response to a Government Bill which became law in April 1977, stipulating that new nuclear power units must not be put into operation in Sweden unless the owner is able to show that the waste problem has been solved in a completely safe way.

The KBS report comprises five volumes: I General, II Geology, III Facilities, IV Safety Analysis, V Foreign activities. Volume I (General which includes a summary of the more detailed information in Volumes II, III and IV can be read independently. KBS carried out numerous investigations and surveys as a basis for their report. The results of these studies are published in KBS Technical Reports.

A report on the management and disposal of spent unprocessed fuel is planned for publication in the first half of 1978.

It is envisaged that the spent fuel from Swedish nuclear power stations after storage in a central facility will be sent overseas for reprocessing and that the resulting highly-active vitrified waste in stainless steel cylinders will not be returned to Sweden for disposal until 1990 at the earliest. If all the fuel from 13 reactors which had been operating for 30 years were reprocessed, there would be 9000 cylinders of 40 cm diameter and 1.5 m height. The cylinders would be stored for at least 30 years, during which period the heat output would be reduced by half. Before transfer to a disposal facility, the cylinders would be encapsulated in a titanium and lead canister to provide good resistance to corrosion from ground water. The canisters would finally be placed in an underground disposal facility in holes drilled in rock and surrounded by a buffer material of low permeability, such as quartz sand and bentonite, as a further protection against ground water corrosion. The disposal facility would eventually be sealed and no further surveillance would be necessary.

Field investigations have been carried out at five sites in Sweden to determine the suitability of bed-rock for a disposal facility and three sites have been selected for more detailed studies. A depth of 500 metres is considered adequate and the research work carried out has shown that the three sites selected offer satisfactory conditions. Since the bed-rock at these sites consists of Sweden's most common types of rocks – granite, gneiss and gneissified granodiorite, it is reasonable to expect that many other sites in Sweden would provide equally suitable conditions.

Although the Swedish law requires a demonstration of waste disposal in a completely safe way, it has been accepted that no human activity can be regarded as completely safe. The interpretation of the law is, therefore, that the chosen method should meet the requirements of radiological protection standards which are laid down in the Swedish Radiation Protection Act.

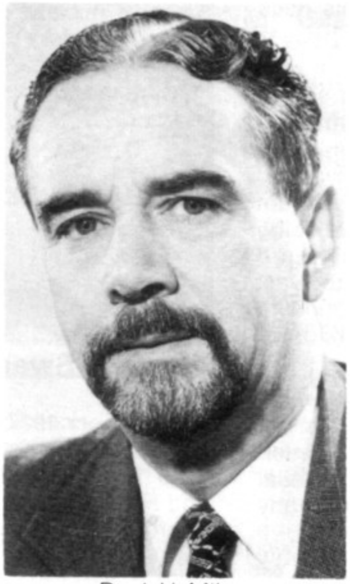
The critical group identified by the KBS in their extensive safety analysis, comprises people drinking water from a deep well drilled in the vicinity of the disposal facility. Under unfavourable conditions such people could be exposed to a maximum individual radiation dose of 13 millirems per year from this source compared with the 500 millirems maximum permissible individual dose for members of the public, from sources other than natural background radiation or medical procedures, recommended by the International Commission on Radiological Protection (ICRP). But the 13 millirems per year level could only be reached after 200,000 years. Doses received from radium in some drinking-water wells in Sweden substantially exceeds this level. The assumptions and data used in the safety analysis were selected with safety margins and it is considered probable that the actual individual dose received by a member of the critical group would be about 1/100 of the maximum calculated dose of 13 millirems per year. The safety analysis also showed that any release of radioactive substances during an accident or during normal operations involving the vitrified waste prior to its disposal would be insignificant.

K.B.S. conclude that the proposed management and disposal system for waste from the reprocessing of spent fuel would meet the requirements of the new law.

LONG-TERM OPTIONS FOR THE FR FUEL CYCLE

Dr. R. H. Flowers

Mr. K. D. B. Johnson



Dr. J. H. Miles

Dr. R. K. Webster

This paper by Dr. R. H. Flowers, Mr. K. D. B. Johnson, Dr. J. H. Miles and Dr. R. K. Webster of Harwell, was presented at the Fifth Energy Technology Conference held in Washington in February this year. The paper is designed to complement and amplify the general philosophy developed by Dr. Walter Marshall in his Graham Young Memorial Lecture "Nuclear Power and the Proliferation Issue"

Introduction

Most present discussions of plutonium concentrate on ways in which this element can be recovered from thermal reactor fuel. The objective is either to recycle the plutonium to thermal reactors, or preferably, in view of the strong resource arguments, to provide the initial fuel inventories for a developing fast reactor programme.

In this paper we do not consider reprocessing of thermal reactor fuel. Instead, we will discuss the position at a much more advanced point in time – possibly around 2050 – taking the Liquid Metal Fast Breeder Reactor as our typical reactor. To allow the discussion we will assume that by then fast reactors will have completely displaced thermal reactors from the power system. We will consider some of the changes that we can expect to occur in the out-of-reactor fuel cycle which will also simplify the safeguarding of plutonium. We will also discuss specific measures that could be introduced to increase safeguards even further, if judged to be worth the economic penalties at the time.

Reasons for reprocessing in a fast reactor fuel cycle

We first ask why reprocessing is needed at all in a fuel cycle such as that associated with the Liquid Metal Fast Breeder (LMFBR), and then isolate the important demands which a fast reactor power system will make on reprocessing.

In an LMFBR, fuel is made up of two main types: core elements and blanket elements. Core elements consist of a $PuO_2/^{238}UO_2$ mixture at a ratio of around 1:3. Blanket fuel consists of uranium 238 oxide only. Fission of the core fuel in the central regions of the reactor provides almost all of the reactor power. Plutonium is created from uranium 238 but the quantity is not sufficient to balance the plutonium consumed by fission, and at the end of the reactor cycle the quantities of both uranium and plutonium in the core fuel have been reduced. The blanket elements are located in the outer regions of the reactor and absorb neutrons escaping from the core, thereby creating plutonium from uranium 238. Taken together, the blanket and core fuel elements can, if required, be managed to create a small excess of plutonium over the original inventory – in the course of time this excess can be accumulated to fuel a new fast power reactor.

The basic objectives of reprocessing are therefore very simple: to make up the uranium and plutonium deficiencies in the core fuel, to make up the uranium deficiency in the blanket and to transfer the plutonium from the blanket to the core fuel. Figure 1 shows the schematic flow diagram for an LMFBR operated to be just self-sufficient in plutonium. Its net function is to generate energy from a continuous feed of U-238.

In an idealised system we would introduce the feed of U-238 as new blanket elements and move them to become core elements as their plutonium content rose, finally removing them for disposal when all their uranium and plutonium had been consumed. In the absence of this hypothetical system, our reasons for fast reactor reprocessing are:

(i) to replace core constructional materials before unacceptable corrosion or neutron damage occurs
(ii) to redistribute the plutonium as outlined above
(iii) to remove fission products to reduce parasitic neutron capture.

We have already noted that when fully optimised an LMFBR can be managed to yield a small excess of plutonium. To put this in perspective, the net excess which could be produced per GW(e) – year in an LMFBR is little more than half the quantity produced in a Pressurised Water Thermal Reactor. This leads to an important conclusion on reprocessing for LMFBR cycles. A growing fast reactor power system is likely to face a plutonium shortage, so there will be a strong incentive to reduce the plutonium inventory of the complete fuel cycle, a considerable fraction of which comprises the discharged spent fuel; there will also be an incentive to develop fast reactors which can produce a greater plutonium yield. It follows that, unlike the case of thermal reactor fuel reprocessing, there is a very strong pressure for rapid reprocessing and refabrication of fast reactor fuel.

Fuel processing procedures in a fully evolved LMFBR cycle

Processing requirements set by the fast reactor system

We can identify two trends which will influence plant design in the long term: this need for a rapid turn-round of fuel and the inevitable higher level of radioactivity associated with such fuel.

The former will require a plant design which minimises plutonium hold-up at any stage. The product from the reprocessing plant should be made suitable for direct input to the fabrication plant, and there should be very close coupling between these two parts of the fuel cycle.

As a result of the much shorter cooling time and higher burn-up of fast reactor, compared to thermal reactor, fuel the fission product activity per kg of fuel will be at a significantly higher level. Table 1 shows the trends in γ-activity. This trend taken with the higher flow rates of plutonium and the need to restrict the radiation dose to operators to the lowest reasonable level, could lead to the concept of a reprocessing and fabrication plant allowing remote operation, and if technologically feasible, remote maintenance.

Possible developments in LMFBR fuel processing

We now consider how these trends might be met by developments in the LMFBR cycle, and discuss in turn the prospects for developing reprocessing plants to yield a product suitable for immediate use in the fabrication plant, for a fabrication technology to suit remote operation, and for coupling the reprocessing and fabrication stages.

(a) *Co-processing of uranium with plutonium*

There are several ways in which spent core and blanket fuel might be scheduled through a reprocessing plant, but conceptually most can be reduced to the following basic needs: the removal of just sufficient uranium to leave a mixed uranium-plutonium stream which is suitable for the fabrication of core fuel, and the generation of a depleted uranium stream suitable for the fabrication of new blanket fuel. In both cases fission products must be reduced to the levels specified for new fuel. In making new core fuel this approach involves "co-processing" of uranium and plutonium, after removal of about half of the uranium present in the mixture obtained by dissolution of core and blanket fuel.

Co-processing is not yet an established technique, but we have made an assessment of one scheme, illustrated in Figure 2, simply to investigate its potential feasibility. In practice, we need to research alternative procedures, particularly to avoid corrosion and disposal problems that might be associated with the use of sulphuric acid. In Figure 2, a dissolver solution prepared from LMFBR fuel passes into the first column of the first cycle of a reprocessing plant. Uranium and plutonium are extracted together into tributyl phosphate/odourless kerosene solvent, and fission products are almost totally removed by a nitric acid scrub stream. In the second column the plutonium is backwashed into the aqueous phase by complex formation with sulphuric acid, and the required ratio of uranium is retained with the plutonium by suitable adjustment of the nitric acid strength, and the volume ratio between the solvent and aqueous phases.

Table 1: γ-radiation levels from spent fuel

	γ MeV/sec. tonne
PWR (5-year cooled)	4.4×10^{15}
LMFBR (150-day cooled)	2.1×10^{17}

In the third column the remaining uranium is backwashed from the solvent, essentially free from plutonium, with very dilute nitric acid. From experience

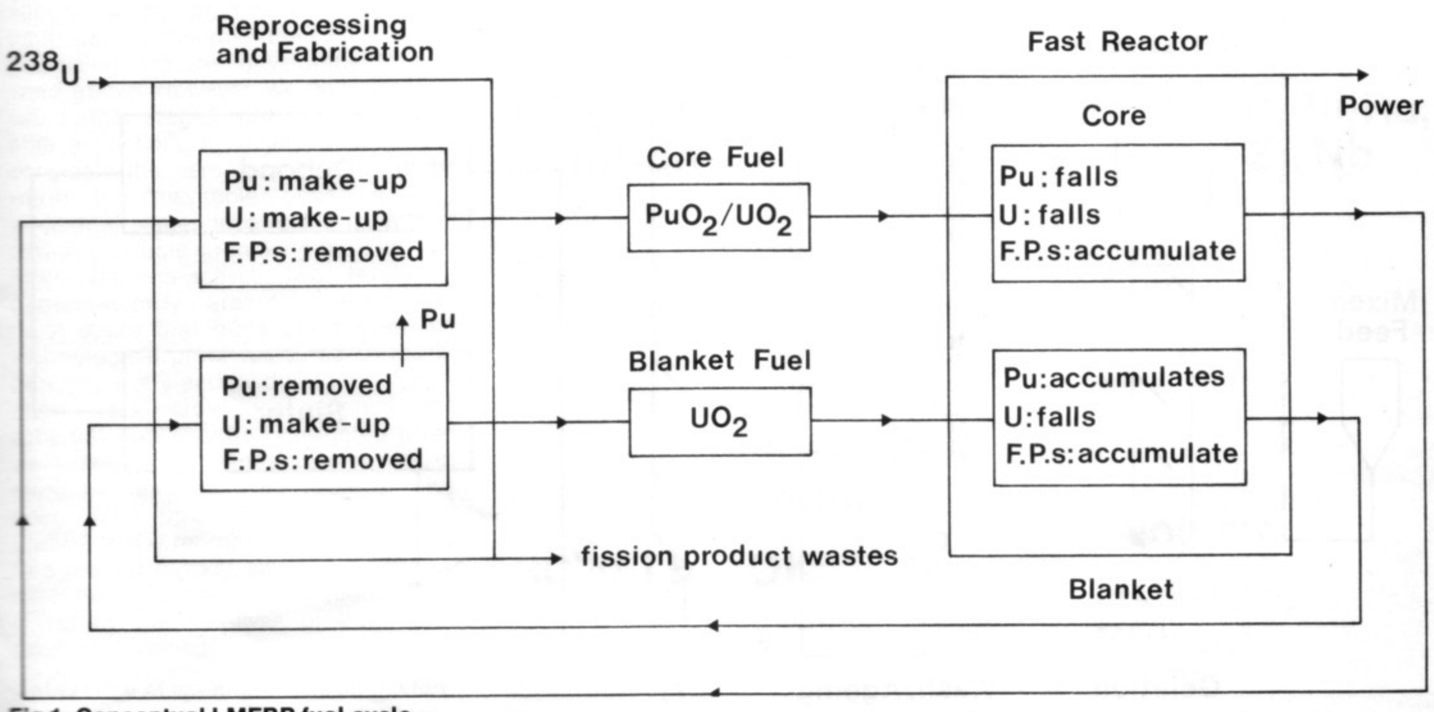


Fig 1. Conceptual LMFBR fuel cycle

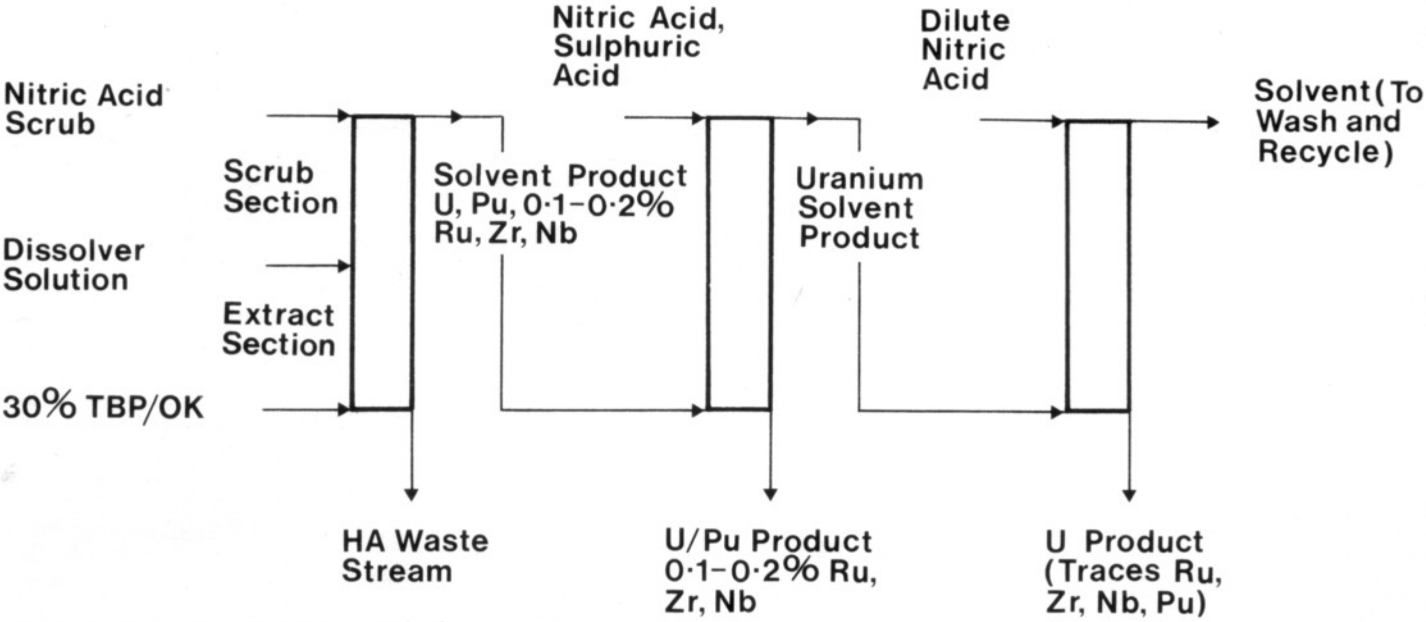


Fig 2. Co-processing of fast reactor fuel

with plant trials we can expect the presence of about 0.1–0.2 per cent of Ru/Zr/Nb fission product activity in the uranium-plutonium stream, and rather less in the uranium product. The uranium and uranium-plutonium product streams would then pass through further decontamination stages to reduce fission products to the levels specified for fabrication.

(b) *Fuel fabrication by the gel process*

One of the aims we identified above was to move towards more remote fabrication techniques. Conventional fabrication plants involve many dry operations, often including the pressing, sintering and grinding of pellets before assembly by operators into fuel rods. While there may be some prospect for automating those stages to allow more remote operation, a better approach may be to develop a completely new technology based on gel precipitation. In this process the uranium/plutonium product stream from the reprocessing plant after conditioning and the addition of organic material, is fed through vibrating jets to give droplets of controlled size (Figure 3). These fall through ammonia gas, are decelerated through foam and then enter an aqueous ammonia solution to form discrete spheres containing precipitated uranium, plutonium and fission products. After washing and drying, the now hard discrete spheres pass through fluidised systems to furnaces to yield high density oxide spheres. By using two or three chosen sphere sizes, high density material can be made up in fuel pins by vibro-packing.

This process could replace may of the mechanical stages of the current pelleting plants by fairly simple fluid handling procedures. It seems particularly promising for remote operation.

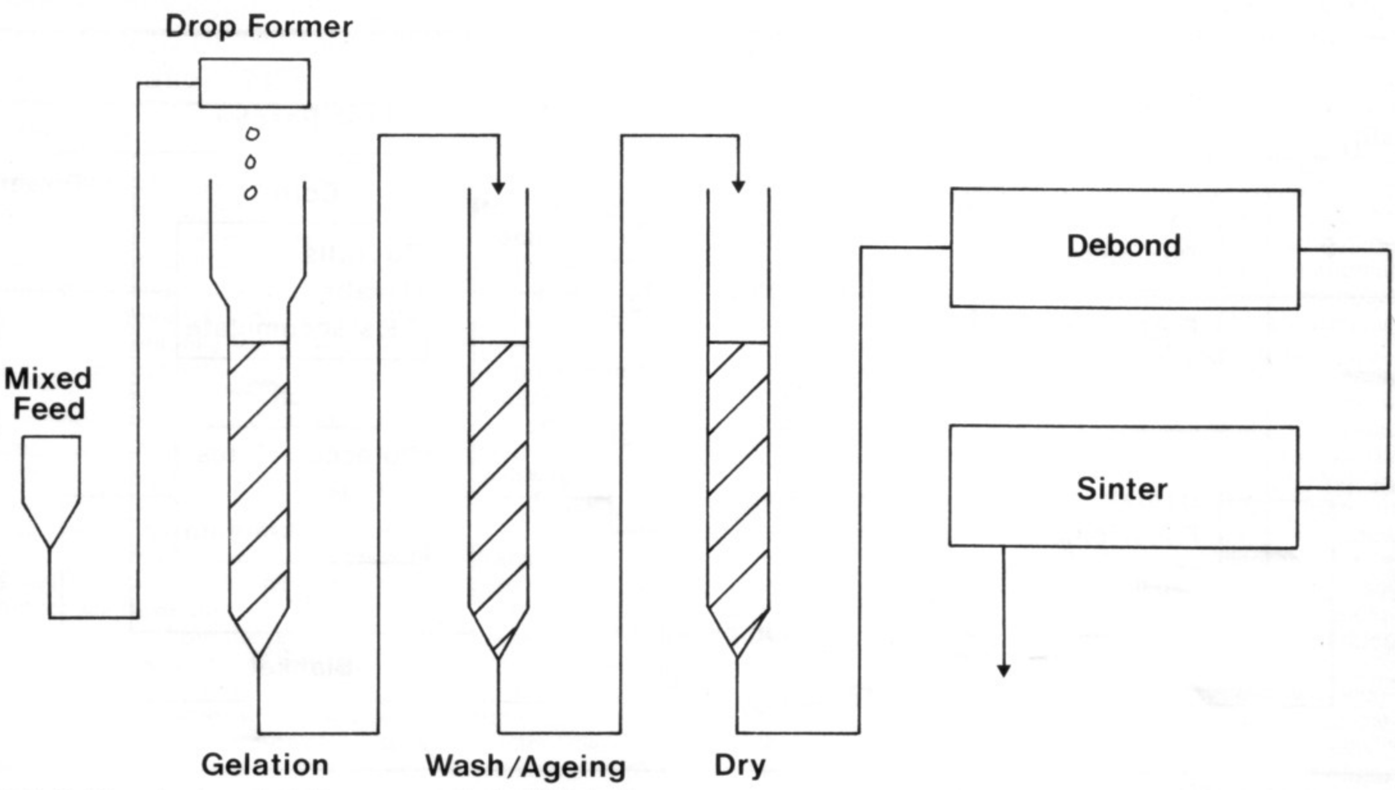


Fig 3. Outline of gel precipitation process for fuel fabrication

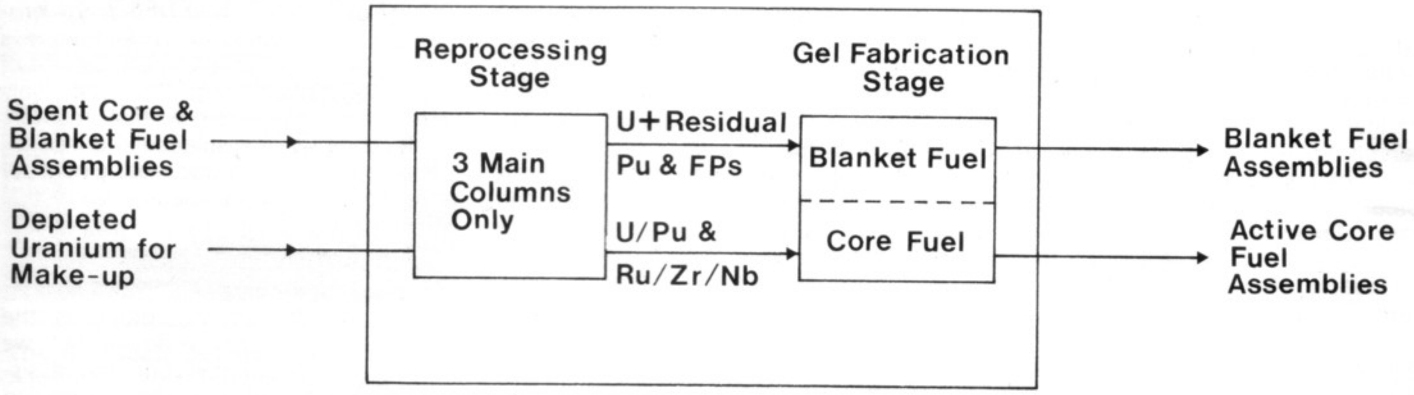


Fig 4. Conceptual integrated plant for fast reactor fuel

(c) Integrated fuel plants
The development of integrated fuel plants, by which we mean the containment of reprocessing and gel fabrication stages as a single plant, allows the close coupling which we noted as a step supporting the fast turn-round of LMFBR fuel. This procedure also makes the cycle highly resistant to the diversion of plutonium for mis-use. Provided remote fuel welding, assembly and inspection procedures are available, this development would lead to a single plant in which the input consists of spent LMFBR fuel assemblies the product would be completed new fuel assemblies, and plutonium would be mixed with excess uranium at all stages within the plant.

Potential further developments for reducing plutonium accessibility

We believe that the further development of international 'Safeguards' procedures will prove to be an effective way of limiting the accessibility of plutonium in an established LMFBR power system. If, in addition, it is judged necessary to support such procedures by strictly technical measures then the most promising are the developments outlined above. However, we now describe two further stages that could be available as options if society at that time considers the perceived benefits to be worth the inevitable penalties. The additional stages involve the recycle of fission products so making the new fuel more gamma-active; two levels of gamma-activity are considered. We must stress that guite apart from the technological problems to be solved in handling the γ-activity during the fabrication and subsequent stages the schemes can only be considered when we reach an era in which stocks of plutonium and spent thermal fuel have been used up and in which spent LMFBR fuel is reprocessed and returned to a reactor quickly, say within 250–300 days from discharge. This requirement is set by the half-lives of the fission products involved.

Relaxation of specifications on fission product levels in new fast reactor fuel

At present there are very stringent specifications on the level of fission products permitted in uranium and plutonium to be used in fuel. This is particularly so in the reprocessing of thermal fuel where the uranium product must meet the decontamination limits needed to allow recycle to isotopic enrichment plants if required. For LMFBR fuel the limits set for uranium need not be quite so stringent, as the requirement is for the production of further blanket fuel only. We have already noted the need to minimise operator exposure levels. If higher activities are to be considered, not only must the fabrication plant allow remote operation and maintenance but remote procedures would also be required for fuel inspection during production and before loading into the power reactor. If these developments prove to be feasible, then 0.1–0.2 per cent of the Ru, Zr and Nb activity could be passed through to the new fuel by restricting the reprocessing plant to a single cycle. It would consist of three separation columns only, as in Figure 2, and the subsequent purification stages would be omitted. Figure 4 gives a schematic diagram for the complete integrated plant.

Enhanced recycle of fission products

Provided that reservations on remote handling at all stages can be met, deliberate recycling of fission products on a short time scale could produce new LMFBR fuel with a gamma-activity level comparable for example with that of 5-year old spent PWR fuel. This is the stage referred to by Walter Marshall[1] when he pointed out that in the long term, if society considered the procedure to be worthwhile, new LMFBR fuel could be given a high level of protection by the use of radioactivity.

Fission product recycle would involve operating a reprocessing plant in such a way that plutonium is never totally separated from fission products; the

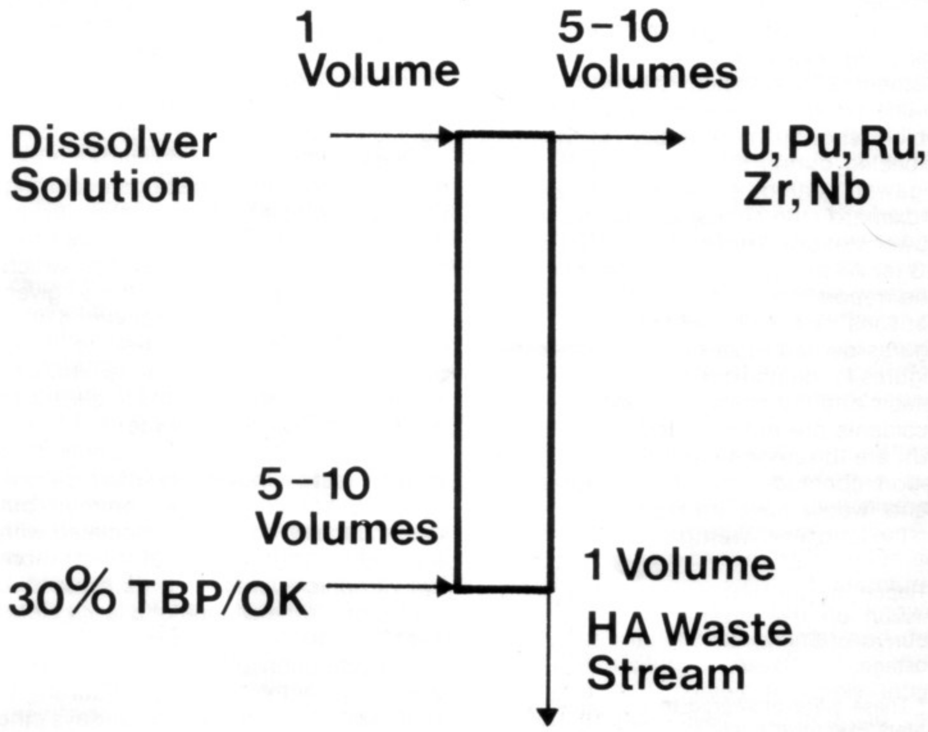


Fig 5. Modification of the first separation column for fission product recycle

flowsheet is adjusted to allow some fission product activity to pass through the plant with the uranium-plutonium mixture. This might be achieved for fast reactor fuel by modifying the first separation column of Figure 2 to the arrangement shown in Figure 5. The main changes are the elimination of the scrub section of the column and an increase in the volume of organic phase passing through the column compared with the volume of the aqueous phase. This should also allow the number of stages in the extract section of the column to be reduced towards 3–5. Calculation suggests that at a phase volume ratio of 5, about 20 per cent of Ru, Zr/Nb and 1–2 per cent of the rare earth activity would be extracted; at a ratio of 10 there would be larger amounts of Ru, Zr/Nb with perhaps 10–20 per cent of rare earth activity.

These estimates are provisional, particularly in view of the complex chemistry of ruthenium, and would require confirmation by an experimental programme. It would also be necessary to investigate the behaviour of ruthenium through the fabrication process to ensure that volatility problems can be controlled. Nevertheless this assessment shows that a substantial level of activity could in principle be recycled with the uranium-plutonium fuel, provided that this is undertaken within the limitations set by the half-life of ruthenium 106 (1.01 years).

Conclusions

The concepts we have described in this paper will take time to develop, and could be introduced only in the course of a planned evolution of reprocessing plants. With that in mind we have reviewed some of the features which might influence LMFBR fuel processing around 2050. At that point we can expect fast reactors to have displaced thermal reactors, and that the pressure on plutonium fuel will demand a fast turn-round of the spent fast reactor fuel. We can expect a trend towards integrated reprocessing and fabrication plants and these would necessarily provide a substantial level of intrinsic safeguards for the fuel. Plutonium would be contained within a single plant, except when present in spent or new fuel, and at no stage within the plant would it be fully separated from uranium. If considered desirable at the time a further level of protection could be achieved by fission product recycle, but at considerable cost in the development of remote fuel handling procedures. Application of this technique is limited by the relatively short half-life of the key fission products and only becomes feasible when fast reactors have completely displaced thermal reactors, and any associated stocks of long-cooled thermal reactor spent fuel have been used up.

Acknowledgements

The discussion in this paper is the responsibility of the authors, but we would like to acknowledge the assistance and stimulus we have received from colleagues in the UKAEA and BNFL, and also at EPRI and ORNL, during meetings at which we have jointly considered the technical possibilities for making the U-Pu fast reactor cycle more resistant to unauthorised diversion of fissile material.

Reference

1. W Marshall, UKAEA, 'Nuclear Power and the Proliferation Issue' The Graham Young Memorial Lecture, February 1978.

Hazards of conventional energy sources

Figures contained in a report,* on the hazards of conventional sources of energy published by the Health and Safety Commission on 17th March shows that the cost in terms of workers' lives is greater for electricity generated from coal than oil and gas or nuclear power.

The report forms the Health and Safety Commission's reply to questions from the staff side and trade union sides at the Dounreay experimental research establishment which were originally sent to the Secretary of State for Energy following questions he submitted in October 1976 on nuclear reactor safety.**

The comparison is made in a table which shows the number of deaths expected during the production of one gigawatt year of electrical energy (approximately the annual output of a large power station). These are – 1.8 for coal, 0.3 for oil and gas and 0.25 for nuclear. The report points out that the comparisons are only tentative and the figures quoted must be used with care. Figures for deaths due to possible health effects and the effects of severe but rare accidents are not included in the table, but are discussed in the report. The report concludes that these rare accidents would have no significant effect on the long term averages in the table.

* Report by the Health and Safety Commission on the Hazards of Conventional Sources of Energy, HMSO, price £1.00 plus postage.

** These were answered in the Health and Safety Executive publication "Some aspects of the Safety of Nuclear Installations in Great Britain." HMSO, £1.00 plus postage.

In addition, further tables give information on numbers of accidents and diseases recorded for a wide variety of occupations and activities. Again, because of the extremely varied nature of the source of statistics the figures quoted, says the report, must be used with care.

The compilation of the report was a complex exercise and the report itself makes clear that it does not attempt to reach any decisions, but is intended only to provide one of the strands of information which will be taken into account in discussions by the relevant authorities on future energy policy.

The report considers all the currently significant sources of energy including coal, gas, oil and water power but it has not taken account of hazards occurring after the point at which energy leaves the premises of the producers. Use has been made of energy statistics which indicate the proportion of a given source which is finally converted into electrical energy. By referring to these an attempt has been made to attribute a specific number of deaths to electricity production from each source.

The report looks at accidents that might affect the public and divides these into two categories; the common but unspectacular accident associated with transport and the rare but much more catastrophic events such as a massive explosion or the escape of a large cloud of toxic gas.

Consideration of possible explosions inevitably centres on liquid natural gas and liquid petroleum gas, says the report. Although a massive escape of gas followed by an explosion cannot be excluded, there is no record of such an event involving these substances occurring in the UK. Details are given of a number of incidents which happened outside the UK which indicate that deaths are likely to be numbered in tens though theoretical calculations show that casualties could be much higher, even as many as a thousand or more, including members of the public.

The report points out that for three of the sources considered, coal, oil and gas, the pattern of exploitation is similar; the fuel is extracted from the ground, processed in some way, transported by road, rail sea or pipeline to its point of use and burned. At each stage there may be storage and subsequently the products of combustion are discharged to the environment. The potential hazards arising from each of these stages are considered for the three sources.

Hazards associated with hydroelectric power are also looked at. Some of the other hazards included are associated with flooding, tip slides, emergency plans, routine releases to the environment, heavy metals and other pollutants and failure of control measures.

Bearing design course

A one-day tribology course on bearing design will be held on 1st June, 1978 at the National Centre of Tribology, Risley.

The course fee, inclusive of notes, refreshments and VAT is £51.84. Application forms and programmes are available from the Course Organiser, National Centre of Tribology, UKAEA, Risley, Warrington WA3 6AT. Telephone: Warrington (0925) 31244, ext 2640/3247.

IN PARLIAMENT

The Windscale Debate

A report by a Parliamentary Correspondent

The Government had a comfortable win at the end of the Commons debate on 22nd March on the Windscale inquiry report when they carried a procedural motion by 186 votes to 56, a majority of 130. The vote cut across party lines with the Liberals and some Labour and Conservative MPs against the Government.

Opening the debate, Mr Peter Shore, Secretary of State for the Environment, said that the House of Commons was facing the essence of the dilemma which the use of nuclear energy posed.

Major environmental, national and international issues were involved in the decision to build a plant for reprocessing spent oxide nuclear fuel. One issue was the contribution to Britain's total energy supply that nuclear power stations would make over the next 25 years and more. The second was the best and safest way of disposing of the nuclear waste and emissions that nuclear energy inevitably created. Thirdly, there was the question of how to secure nuclear installations and nuclear fuels against attack and theft without unacceptable damage to the civil liberties that people cherished. Last and by no means least was how the legitimate demands of non-nuclear weapon states for secure supply of nuclear materials for power generation could be met with the least danger of misuse or diversion as source material for nuclear weapons.

From the very beginning of the nuclear era, from the first explosion in the New Mexico Desert, and the destruction of Hiroshima and Nagasaki in 1945, the world had known of the terrible potential for destruction that splitting the atom had brought – both its immense explosive power and the even more fearsome and continuing consequences of nuclear radiation and at the same time its tremendous potential as a source of power for peaceful purposes.

The key question was how could the peaceful development of nuclear power be promoted without radiation and harm to the present and succeeding generations. Without at the same time opening up the threat of the ever wider spread of nuclear weapons.

In the past 25 years 19 countries had constructed nuclear power reactors and for some time Britain had been in the lead.

Mr Shore continued: "No one can be certain about future energy supplies and the demands that will be made upon them. Forecasts of the extent of the so-called energy gap and its effect on different countries are inevitably subject to wide margins of error.

"But even with the most energetic pursuit of new sources of energy supply, substantial further development of nuclear power in the main industrial countries and in the newly industrializing countries too seems now unavoidable."

Britain's reliance on nuclear power, Mr Shore said, was likely to be more modest by comparison with some other highly industrialized countries mainly because of her coal, oil and gas. Even so it was clear she had to have a nuclear component if she were to maintain her industrial base and an acceptable standard of living.

Existing magnox reactors, with the advanced gas-cooled reactors already operating or under construction, would provide some 10 gigawatts of capacity and should contribute about 20 per cent of the country's electricity in the 1980s. By the year 2000 thermal reactor capacity was likely to be substantially greater.

Mr Shore denied that the proposal to reprocess oxide fuel was inseparably linked to a major nuclear programme involving fast breeder reactors. This was not so for two different reasons. First, because the plutonium and uranium retrieved by reprocessing could be used again in existing thermal reactors, although less efficiently.Second,because Britain already had sufficient plutonium from existing magnox reprocessing plants – and would have more in the years ahead – to enable her to fuel not only the CFR 1 but seven more fast breeder reactors taking her well into the 21st century.

Mr Shore continued: "If I considered that reprocessing involved any significant radiological danger to the general public, to workers, or to the environment there would be no question of my giving outline planning permission for the proposals which British Nuclear Fuels Ltd have put forward."

He agreed with the report of the inspector, Mr Justice Parker, that the risks were small. But if new evidence caused the Government to revise their view of the risks, they had the obligation and the means to enforce higher safety standards.

Magnox fuel could not be kept for more than a year or so before it had to be reprocessed.

AGR spent fuel could not be kept indefinitely in ponds. There was a risk that it would deteriorate and present a serious hazard. If they decided not to reprocess they would have to design and develop new facilities for long-term storage. This would be expensive and take time.

He shared the inspector's view that they would be unlikely to decide to dispose permanently of spent fuel without reprocessing, partly for reasons of safety and partly for reasons of fuel economy.

"Reprocessing and the vitrification of highly-active waste seems the more promising approach, in our circumstances, to nuclear waste disposal," Mr Shore said.

He went on: "My conclusion, therefore, is that for environmental reasons we should pursue the reprocessing and vitrification route to long-term disposal, where are research and development is much further advanced, rather than adopt a new and less promising approach."

There was, additionally, the resource argument that plutonium and uranium contained in the spent fuel represented too important an indigenous energy resource to be wasted.

There was the fear of a terrorist attack on Windscale. "I recognize and respect this fear and I certainly cannot give any absolute guarantee against terrorist attack on this or any other major installation," Mr Shore said. "Nevertheless the Government have long recognized these potential hazards. We have considerable experience in maintaining the security of existing stocks derived from the reprocessing of magnox fuel.

"Strict security precautions are taken both at the Windscale site and for the transit of plutonium to and from Windscale."

The Government had decided in 1976 that BNFL should be allowed to take on further contracts from overseas customers for the reprocessing of irradiated fuel. The proposals for the new plant included capacity for foreign reprocessing including that under a contract already on offer from the Japanese. The foreign business, and in particular the Japanese business, offered considerable financial and economic advantages.

The value of the Japanese contract could be as much as £200m or more; European contracts might be worth as much again and in addition there would be the further contract to transport fuel to Windscale and the French plant at Cap de La Hague. This could be worth another £200 to £250 million.

One of the key questions was whether non-proliferation of nuclear weapons was likely to be helped by the supplying of processed fuels to non-weapon countries or whether the effects of denying reprocessed fuels was more likely to encourage them, if not drive them, to develop their own reprocessing plants.

He went on: "It has been argued that it makes little difference whether our customers reprocess their own plutonium or we return plutonium to them. I disagree. When plutonium is returned under the proposed contractural arrangements it will be in known quantities under safeguards and for known peaceful purposes."

Britain had agreed to apply internationally approved controls to all nuclear supplies. These would extend to the plutonium received for reprocessing and returned to customers. "To prevent nuclear proliferation is a major national objective," he declared. "If we thought that the Windscale proposals would encourage it, we would most certainly not allow them."

Mr Tom King, Opposition spokesman on energy (Con, Bridgwater), said that Mr Justice Parker had played a valuable part in the process but he was not the final arbiter and Parliament had an important role. He hoped that they would avoid the scaremongering and exaggerated claims which had marked the debate in the country and in the newspapers.

"This is not a battle between nuclear enthusiasts and environmentalists. There are plenty of sincere people who believe that the nuclear solution is the best environmental solution. It is through an environmental approach that they have come to support a nuclear case," Mr King said.

He agreed with Mr Justice Parker's refusal to adopt any specific energy forecast. All who studied the problem knew that the only certainty about energy forecasts was that they would be wrong. The Conservatives took the same view as was expressed in the Flowers Report and had no interest in nuclear power for its own sake, nor any desire to see it extended beyond its needs.

There was enormous scope, and much greater scope than had been shown, for a reduction in the growth of energy demand and even for a net reduction.

Mr King went on: "I accept that commercial arguments have a place, but I am not prepared to accept any commercial arguments, and they have no relevance, unless one accepts that this project is basically safe."

He accepted that safety was a relative matter, but the Secretary of State had referred to the "menace and benefit" of nuclear power. That phrase could be applied to many other energy resources. The current record of the nuclear industry was remarkably good.

Mr Tom Litterick (Lab, Birmingham, Selly Oak) said there was a considerable difference between being maimed or even killed in a coal mine and the possibility of a genetic mutation of a quite different order and the risk for the entire race.

Mr King said that that was the sort of thing he was referring to earlier when he had spoken of misleading fears.

Referring to the international issue, Mr King said that it was preferable that reprocessing should be done in the existing nuclear weapon states under proper control otherwise it would be a positive incitement for third countries to try it themselves. Third countries feared that developed countries would get out of nuclear fuels and compete with the poorer countries for fossil fuels while preventing the poorer countries getting nuclear energy. That was a recipe for international conflict.

The next speaker was one of the leading opponents of the Windscale development proposal, Mr Leo Abse (Lab, Pontypool). He questioned why it was necessary to take such a hurried decision. The proposition seemed to be that if Britain did not become the nuclear dustbin she would lose hundreds of millions of pounds. But, he said, what a terrible price would have to be paid. "It means we shall be entering an export business with appalling malignant side effects," he added.

Mr Abse said that the argument "if we do not do it others will" had been used in relation to the slave trade. It was an argument being used now to justify the export of plutonium.

However, the contention was false anyway. If it took a country as sophisticated in nuclear technology as Britain a decade to develop a reprocessing plant, how long would it take a novice country.

He went on: "If without waiting for the international evaluation we go ahead we confirm to the world our role as nuclear hawks and destroy our credibility as a nation genuinely concerned to make the attempt to arrest nuclear proliferation.

"We dissociate ourselves, if we go ahead at this moment, from the nuclear doves, from the United States, Holland and Canada and we shall be contributing, with a Germany hell bent to make money out of the Brazilian atomic contract and a France wishing to make money out of her Pakistan deal, to ensuring that the world would be awash with plutonium.

"I believe that some of the atomic salesmen are like pimps peddling a diseased harlot eager for profits and ready to put into the world circulation cancer and death."

Death came to all, but for the first time man had to contemplate the possibility of the destruction of the human species. Britain alone could not prevent that, but could make a contribution towards its prevention.

Mr Patrick McNair-Wilson (Con, New Forest) said if they were to have a sensible energy policy, nuclear power was essential. It had served the nation well for the past 25 years. No form of power was without hazards.

Mr Arthur Palmer (Lab, Bristol, North-East) said little had been said about reprocessing until recently. Much of the opposition started when the "Daily Mirror" newspaper talked about Britain becoming a nuclear dustbin.

Mr Palmer said that the United Kingdom had a moral obligation to take on the work as a contribution to non-proliferation. If Britain did not do the work, non-nuclear states would have every reason to do their own reprocessing and instead of plutonium being concentrated and controllable it would be widespread and uncontrollable.

Mr Richard Page (Con, Workington) said that in his short time in the House he had developed a healthy scepticism to official and Government forecasts. He wondered if the plant would operate profitably and the process as effectively as had been predicted.

The inquiry had certainly chased away natural local worries about the environment and the effect on health, but there must be effective and continual monitoring of all discharges, preferably by an independent body able to ensure complete fairness and impartiality. Nobody in Cumbria should be put at risk by any long-term health or genetic problem.

Mr Robin Cook (Lab, Edinburgh Central) said the discharges for which the plant had been designed were much higher than the proposed controls discussed in America and Germany.

For the Liberals, Mr David Penhaligon (Truro) said that there were large gaps in the technology of waste disposal and the Government were committing themselves to spending money at the wrong end. Nobody had yet succeeded in putting waste material into glass blocks.

He would be more enthusiastic if the Government proposed to spend more on that sort of research and development because if that technique of disposal, or similar techniques using granite, did not work, the whole thing collapsed.

Mr Penhaligon said that on the question of security and civil liberty, the political opinions of those working in a processing plant would be of extreme importance, and so would those of their parents and children and contacts. It would be a major erosion of civil liberties. People responsible for that sort of material would have to accept that sort of reduction of civil liberty.

The Liberals would be indicating their dissatisfaction. They could not see the need for rush nor why President Carter's initiative could not be allowed to run its course.

Mr Michael Jopling (Con, Westmorland) said he felt happier about the project now than he had before the inquiry took place, and his feelings were widespread in Cumbria.

Ms Maureen Colquhoun (Lab. Northampton, North) said the report did not take into account human and ecology needs. The inquiry findings were a disaster for Britain. The Government should be ashamed to support the folly of Windscale.

Dr David Owen, Secretary of State for Foreign and Commonwealth Affairs, winding up the seven hour debate, said it had been argued that they should defer the decision on Windscale until the International Fuel Cycle Evaluation was completed. That was intended as a clearing house for ideas and evaluation of alternatives but underlying it were political judgments. It would be optimistic to believe that in a year or two 40 governments starting with different views would agree that reprocessing or fast breeders were or were not necessary.

Dr Owen said that INFCE would not be used as an excuse for delaying decisions on British nuclear policy. He went on: "The Americans would prefer us to defer decisions pending the results of INFCE and that has been conveyed to us by the United States Administration. We should take a decision in full knowledge of that view."

However, construction of the reprocessing part of Windscale would only start in 1981 or 1982, but work on the storage ponds needed to begin right away.

The form in which plutonium was returned to its customers would be determined in consultation with them. While in store it would be safe. It was in transit that plutonium would be vulnerable.

The protection accorded while nuclear material was in transit varied according to type. In some cases armed guards were necessary and in others massive containers offered protection. By selecting the most appropriate chemical form it was possible to ensure that the material being shipped would prove of little or no value if it were stolen. He did not wish to hide the gravity of the problem, but did not for obvious reasons wish to give too many details.

Power costs

8th March 1978

Mr Emery asked the Secretary of State for Energy whether he will list the fixed costs per kilowatt generated by nuclear power stations and the fuel cost, including reprocessing costs, for the last 10 years and compare these figures with the fixed costs and the fuel costs for electricity generated by coal and with oil.

Mr Eadie: I am advised by the CEGB that the detailed breakdown of figures in the form requested by the hon. Member could not be obtained without disproportionate cost. However, I give below CEGB generation cost figures by fuel type for each financial year since 1971-2. These are figures for power stations commissioned in the previous 12 years. The costs include (*a*) capital charges based on historic cost depreciation with interest at the average rate payable by the board applied to the written down capital expenditure; (*b*) fuel including nuclear reprocessing costs, and (*c*) other operating costs. These figures are not, of course, a guide to future investment decisions.

A breakdown of the figures for the past three years is being prepared by the CEGB, and I shall pass on this information to the hon. Member as soon as it is available.

CEGB Generation Costs 1971–72 to 1976–77

p/kwh

	Nuclear (Magnox)	*Coal fired*	*Oil fired*
1971–72	0·43	0·43	0·39
1972–73	0·48	0·49	0·40
1973–74	0·52	0·53	0·55
1974–75	0·48	0·74	0·88
1975–76	0·67	0·97	1·09
1976–77	0·69	1·07	1·27

Radiation accidents in the nuclear power industry

8th March, 1978

Mr Emery asked the Secretary of State for Employment whether he will list for 1965, 1970, 1973 and the latest available date, within the nuclear power industry, the figure of accidents for fatal, serious and non-serious accidents caused by radiation as a percentage of the number of individuals employed and the comparison of the accident rates with workers in the coal industry and agricultural workers.

Mr John Grant: I am advised by the Chairman of the Health and Safety Commission that the relevant information in the form available and in terms of numbers of persons involved is as follows:

	Nuclear Power Industry			*Coal Mining*			*Agriculture*	
	Fatal	*Serious*	*Non-serious*	*Fatal*	*Serious reportable*	*Non-reportable*	*Fatal*	*Other*
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1965	Nil	Nil	0·10	0·05	0·24	42·3	*	*
1970	Nil	Nil	0·06	0·03	0·21	29·5	*	*
1973	Nil	Nil	0·12	0·03	0·21	24·3	0·01	1·96
1976	Nil	Nil	0·06	0·02	0·21	19·6	0·01	1·80

* Not available.

Fatal or serious accidents caused by radiation in the nuclear power industry would be those resulting from occurrences reportable to the Health and Safety Executive under the Nuclear Installations (Dangerous Occurrences) Regulations 1965, earlier legislation and, in the case of the UKAEA, equivalent arrangements. Non-serious accidents are other accidental radiation exposures in the nuclear power industry exceeding prescribed limits. The data cover relevant employees of the UKAEA, the Central Electricity Generating Board, the South of Scotland Electricity Board and British Nuclear Fuels Ltd.

Fatal and serious accidents in coal mining are reportable under the Mines and Quarries Act. Non-reportable accidents are taken from information suplied to the executive by the National Coal Board, and they involve absences from work of more than three days.

Fatal accidents in agriculture are reportable under the Agriculture (Safety, Health and Welfare Provisions) Act. "Other" accidents are notified to the executive by the Department of Health and Social Security and are based on notifications of absences of more than three days under the National Insurance (Industrial Injuries) Act.

JET

14th March, 1978

Mr Patrick McNair-Wilson asked the Secretary of State for Energy if he will estimate the total value in £ sterling likely to accrue from the future work at the Culham Centre on the Joint European Torus project over the following periods (*a*) from the present to the end of 1980, (*b*) from 1980 to 1985, and (*c*) from 1980 to 1990.

Mr Eadie: These figures are not available. The construction cost of the Joint European Torus is estimated at 7,500 million Belgian francs – about £120 million – over the five-year period 1978-9 to 1982, and the operating cost is likely to be £25 million a year from 1983 to 1990. The award of contracts will reflect the Community character of the project, and I would expect United Kingdom firms to obtain a reasonable share.

Alternative fuel cycles

17th March, 1978

Mr Forman asked the Secretary of State for Energy what investigations are being made by his Department or by bodies responsible to his Department into the possibilities of alternative nuclear fuel cycles, such as that based on thorium and uranium.

Mr Eadie: Alternative fuel cycles are the subject of continuous consideration by most of the major nuclear power organisations in the world. In the United Kingdom most of these investigations are carried out by the Atomic Energy Authority which has studied uranium/plutonium and thorium/uranium fuel cycles and mixtures of the two in relation to various types of nuclear reactor. Its efforts in this field are currently concentrated on participation in the International Nuclear Fuel Cycle Evaluation.

The fuel cycle in use throughout the world now is a uranium/plutonium cycle. In order to introduce thorium cycles it is necessary first to recycle plutonium with thorium in a reactor or to make greater use of highly enriched uranium 235. All of these have been studied in the past by the United Kingdom Atomic Energy Authority and are currently being re-examined in the context of nuclear weapon proliferation risks.

Nuclear electricity costs

Mr Arthur Lewis asked the Secretary of State for Energy whether he will issue a directive to the generating boards to disclose in their annual reports and accounts the total cumulative sum spent by them on exploitating nuclear energy, and the total cumulative amount of nuclear-generated electricity fed into the grid.

Mr Eadie: No. The CEGB already

publishes figures relating to nuclear expenditure and supply in its annual reports and associated Statistical Yearbook. The Scottish generating boards are the responsibility of my right hon. Friend the Secretary of State for Scotland.

National Nuclear Corporation

20th March, 1978

Mr Palmer asked the Secretary of State for Energy if he will make a statement on the proposed change in the shareholding and the management of the National Nuclear Corporation.

The Secretary of State for Energy (Mr Anthony Wedgwood Benn): Following my statement on thermal nuclear policy on 25th January, I shall want to be sure that the nuclear industry has the organisation and management which it needs to implement the Government's decisions. I have no proposals to announce yet.

Mr Palmer: Is my right hon. Friend aware that between 1972 and 1973 the Select Committee on Science and Technology was very critical of the arrangement under which the General Electric Company was given an artificially dominant position in the National Nuclear Corporation? Is he further aware that the Select Committee also predicted the difficulties that would arise if the General Electric Company decided to withdraw? Has that situation not arrived? In view of the considerable amount of public capital involved, should not a statement be made fairly soon?

Mr Benn: I appreciate the points that my hon. Friend makes. Following the announcement of policy that I made in January, certain industrial and management implications will follow. The GEC has indicated to me that it wishes to withdraw from the supervisory management position.

Mr Tom King: Does the Secretary of State agree that, as it seems clear now that the policy has been announced and there are to be changes in the structure, it is a matter of some urgency that the new structure should be arrived at as soon as possible so that the policy can be implemented without delay? Will he contribute to that effort?

Mr Benn: That is a most helpful supplementary question. The organisation must fit in with the decision made. Therefore, there is urgency in the matter. On the other hand, in these, as in other matters, I am trying to proceed by consent.

Uranium exports

20th March, 1978

Mr Abse asked the Secretary of State for Energy whether it is his intention to exercise his veto under the Anglo-German-Dutch treaty to prevent the export to Brazil of enriched uranium from Almelo and Capenhurst: whether he will make a statement on the future of Urenco relating to the supply of enriched uranium to countries who have refused to sign the non-proliferation nuclear treaty.

Mr Benn: There is no need for a veto. We are satisfied that the safeguards and other non-proliferation conditions which have been negotiated between the three parties and Brazil are adequate.

All Urenco contracts contain safeguards clauses. The policy of the partnership is that suitable and effective safeguards and non-proliferation conditions should be applied when enrichment services are supplied. Even if a customer country is not a party to the NPT, IAEA safeguards can be and are applied.

Nuclear industry accidents

20th March, 1978

Mr Emery asked the Secretary of State for Energy what steps he has taken to publicise the number of fatal and serious accidents in the nuclear power industry caused by radiation.

Mr Eadie: I have undertaken, in consultation with the Secretary of State for Scotland, to bring serious occurrences in the nuclear industry to the immediate notice of the House. We have also arranged for the quarterly publication by the Health and Safety Executive of information on certain occurrences at nuclear sites, including the exposure of individuals to radiation. Information on accidents has also been published from time to time in response to questions in the House; and I published last July comparative figures on fatal accidents in various fuel industries for the period 1957-1976. These statistics underlined the outstanding safety record of the nuclear industry.

Toxic waste

22nd March, 1978

Mr Edge asked the Secretary of State for the Environment what research his Department has conducted in the field of toxic waste disposal.

Mr Marks: A large-scale research programme was initiated by the Department in 1973 into the disposal of waste as landfill with special reference to toxic wastes. The report on this research, which was undertaken jointly by the United Kingdom Atomic Energy Authority, Atomic Energy Research Establishment, Harwell, the Water Research Centre and the Natural Environment Research Council's Institute of Geological Sciences, will be published soon.

New programme on battery research

Work has just started at Harwell on a new collaborative research project to investigate new materials for use in advanced batteries. Seven different research institutes are co-operating in the venture, four in the UK and three in Denmark.

The project, which will cost about £275,000 will run initially for 18 months and is expected to be 50 per cent funded by the EEC as part of its Energy Research Programme. The remainder of the cost is being met by the UK and Danish Governments.

Harwell is internationally known as a materials research centre and has been involved with industry in advanced battery development for a number of years. The laboratory also plays a central role, through the Energy Technology Support Unit, in energy research and planning.

The object of the new project is to develop materials for the next generation of advanced batteries in a co-ordinated programme drawing on the wide range of expertise of the contributing laboratories. Major teams of scientists in at least five industrialised countried are working on new battery systems but there are still formidable problems of corrosion and safety with most of these systems. The new research programme looks further ahead and aims to develop novel electrochemical materials and concepts such as an all solid-state battery.

Improved methods of storing electricity by means of advanced designs of rechargeable battery are important for the following reasons:

> The requirements to smooth out the day-time peaks and night-time troughs in electricity demand.
>
> To provide eventually a storage means for electricity which could be generated in future years from alternative energy sources of irregular intensity (wave power, wind power, solar energy).
>
> To facilitate the introduction of electric vehicles; this is important to reduce dependence on oil supplies and to improve urban air quality.

The UK scientific co-ordinator is Dr Bruce Tofield. The Danish scientific co-ordinator is Dr Johs Jensen from Odense University who is a key figure in energy research in Denmark and a regular visitor to Harwell, where he has spent several periods of study leave.

The UK Project Manager is Dr R. M. Dell of Harwell who has been responsible for the previous Harwell work on advanced batteries. He commented: "When, early in 1976, the Danish Government decided to set up its own national energy research programme, with battery research playing a prominent role, it seemed an excellent opportunity for the UK to collaborate with a European partner under the auspices of the EEC's Energy Conservation R & D Programme. The other institutes were invited to join in making a research proposal to the EEC in June 1977 and the commission's intention to award a contract became known shortly before Christmas. Work on the project is now beginning in all seven institutes".

The UK groups collaborating with Harwell in this venture are led by Professor John Goodenough of the Inorganic Chemistry Laboratory, Oxford, Dr Brian Steele of the Department of Metallurgy and Materials Science at Imperial College, London, and Professor Richard Brook of the Department of Ceramics at Leeds University. The Danish participants are Odense University, Risø National Laboratory and the Technical University at Copenhagen.

BOOK REVIEWS

World Energy Resources 1985-2020

'World Energy Resources 1985–2020' (Executive Summaries of reports on resources, conservation and demand to the Conservation Commission of the World Energy Conference).
Published in February 1978 for the World Energy Conference by IPC Science and Technology Press, IPC House, 32, High St., Guildford, UK, GU1 3EW.
Price (paperback) £9.50 (Hardback) £16.00
This compilation of Executive Summaries was published by IPC Press for the World Energy Conference (WEC) in February 1978. It represents a major step in the assessment of global energy resources and an important guide to the valuable work of the Conservation Commission of the World Energy Conference.

The full reports and their summaries were the work of independent groups of experts. After critical appraisal by National Committees of WEC they were submitted to the Istanbul Conference for discussion in September 1977. As a result of this discussion the Conservation Commission will in September publish its own appraisal of world energy resources. It had been intended that the eight reports would also be published in September. However the foreword to the book states that the publication date was brought forward due to the urgency of the problems and the excellence of the work. Certainly after reading the book one is left in little doubt about the former.

It was WEC policy that the study groups in each of the eight fields should work independently. Whilst this allows for greater expression of views it limits the value of the book as a single work on World Energy Resources. Growth estimates for population, GNP etc., vary from report to report as do the techniques used to derive information. If used correctly this selection of techniques should prove benefical. However in this instance it would have been better had all reports used the returns of the WEC National Committees submitted in late 1976. Although slightly outdated these at least give comprehensive world coverage of information. The survey methods used in some of the reports are inadequate. The 'Worldwide Petroleum Supply Limits' reports uses the Delphi Questionnaire technique to give an illusion of accuracy to geographically limited data.

The overall tone of the book is summarised in the foreword. Without making extravagant claims it clearly indicates that the potential of the 'conventional energy' sources is high. The authors are at pains to stress that in order to achieve the potential, urgent and direct policy decisions must be taken to secure long term objectives. 'Conventional energy' resource estimates show a very high degree of conformity with other highly reputable reviews notably: The Workshop on Alternative Energy Strategies report, "Energy: Global Prospects 1985–2000" although in view of the common source of contributions anything else would perhaps be surprising.

Prominent among the contributors to WEC and WAES are Dr Richard Eden and the Energy Research Group at Cambridge University. They are primarily responsible for the 'World Energy Demand' section at the very end of the book. Implicit in this arrangement with the supply section followed by those on conservation and then demand is recognition that demand will be greatly affected by potential supply considerations. Thus in the report two constrained energy supply scenarios are developed, one using constrained total energy supply and the other constrained oil supply. It may be further commended in that unlike many reports this one does not attempt sweeping world generalization. On the contrary regional energy balances are produced to reflect differing economic conditions and the result is a commendable attempt to analyse a complex subject.

By far the largest part of this book is taken up by the study of energy supply. The 'Nuclear Resources' report was produced by Atomic Energy of Canada Ltd. with the advice of other bodies such as the UKAEA. This excellent report derives electricity demand growth from the World Energy Demand chapter and uses an 'S' curve of penetration to suggest the growing proportion of electricity supplied by nuclear electricity. On the basis of this method a world nuclear capacity of 1543 GW by 2000 is forecast. This is a reasonable projection and one which lies near the median point of other recent projections. When combined with the authoritative and well analysed uranium resource forecast the projection illustrates the massive uranium supply problem that would result before the turn of the century without the introduction of advanced fuel cycles such as the fast reactor. The 'Unconventional Resources' chapter in its discussion of fusion does however recommend the somewhat controversial hybrid fusion/fission system as one such cycle. However some authorities believe that the two systems can develop more quickly and make a greater contribution as separate elements.

It is unfortunate to have to end on a critical note but there is one major weakness of the report. The economics are inadequately considered. This is particularly the case as regards conservation where the costs and benefits of adopting the various measures envisaged are not stated. This omits a very important element in the equation. Furthermore all reports avoid where possible the analysis of energy prices. Yet in the long term this is really what the problem is all about. We will not suddenly find that there is no oil or gas but rather that the price is such that we can no longer afford it. The petroleum report does recognise this and indicates that it was not attempting to predict the future merely to indicate technical maximum production rates. Maybe then the reports are doing nothing new. Certainly they are comprehensive and authoritative but what is really needed is study of the world energy price future and its effect upon economic development. However one should not be too harsh about the book. Indeed it sets the standard for future studies in this field, and so long as it is used as a reference book for each individual topic rather than a comprehensive world energy resources survey it can in itself be a valuable source document. As a guide to the work of the eight full reports it is excellent.

EEC book on energy R & D

The Commission of the European Communities has published a status report on contracts concluded in the first phase of its four-year energy research and development programme, which began on 1st July, 1975.

The Commission says in the book*: "The Energy R&D Programme of the European Communities, a four-year indirect action programme coping with 'new energies', energy conservation and energy systems modelling, is now well underway. All projects to be carried out in the frame of the first phase of this programme are in progress and the Commission's services, together with the different advisory bodies, are already strongly involved in the implementation of the second phase of the programme.

"It seemed to us at this point that the publication of a comprehensive overview of all contracts concluded in the first programme phase would be the best way of keeping informed those individuals or institutions naturally interested in our work. The present report should be considered as the first attempt to fulfil this task."

* Energy R&D Programmes: First Status Report 1975-76"; available direct from Martinus Nijhoff, PO Box 269, Lange Voorhout 9-11, The Hague, Netherlands: price 45 Fl plus 6 Fl postage.

Erratum

On page 69, Atom 257, March, 1978, the figure given for gas pressure of the CO_2 flow should read 340–4,500 kN/m^2 and not kN/m^3 as shown.

NRPB approve ICRP recommendations

The National Radiological Protection Board has advised the Government that the system of dose limitation recommended by the International Commission on Radiological Protection provides a satisfactory basis for controlling the exposure of people to ionising radiation in work places and in the general environment.

NRPB also considers that the detailed recommendations and supporting argument and data call for interpretation of many specific points, particularly as they relate to various practical applications. It therefore intends to publish comments and views on these from time to time. These will be sent to appropriate government departments and statutory bodies and will be put on sale through HMSO.

To provide its advice in a distinct and formal way NRPB has established a new series of documents, "Advice on Standards for Protection."

In advising the Government NRPB was complying with the Direction of the Health Ministers of August 1977; the wording of this is reprinted in this first statement, ASP1, "Recommendations of the International Commission on Radiological Protection (ICRP Publication 26): Statement by the National Radiological Protection Board on their acceptability for application in the UK (HMSO, 5p)". In directing NRPB in this way the Health Ministers were implementing a recommendation of the Royal Commission on Environmental Pollution in its report "Nuclear Power and The Environment". The Royal Commission also stated that "There is no better way of deriving basic standards than on ICRP recommendations, given that the scientific standing and independence of its members is maintained".

Further information is available from the Information Officer, NRPB, Harwell, Didcot, Oxon OX11 0RQ. Telephone Rowstock (023 583) 600, extension 410.

ASTM zirconium conference

The ASTM Fourth International Conference on Zirconium in the Nuclear Industry will be held from 26th–29th June, 1978 at the Stratford-upon-Avon Hilton in England. The symposium is sponsored by Committee B-10 on Reactive and Refractory Metals of the American Society for Testing and Materials (ASTM). Cooperating societies include the American Nuclear Society, the British Nuclear Energy Society, and The Metal Society (UK).

Thirty-nine papers will be presented by authorities from six countries. The programme will emphasize the role of zirconium alloys as fuel cladding in power producing reactors and will be of special interest to designers, fabricators and users of nuclear fuel, as well as the regulatory agencies and suppliers in the nuclear fuel cycle.

For complete programme information contact: H. M. Cobb, ASTM, 1916 Race St., Philadelphia, Pa. 19103.

New catalyst unit

Harwell is to set up a new Unit designed to help British industry keep in the forefront of advanced catalyst development.

The unit's programme is aimed at developing Harwell's materials technology and special equipment is close collaboration with industry. Support for the underlying research has already been given by the Chemical and Minerals Requirements Board of the Department of Industry (CMRB) to the extent of £330,000 over the next three years.

The objective of the Harwell Catalyst Unit will be to focus the general requirements of industry into a programme designed to develop techniques and existing facilities for catalytic research. The techniques developed in the unit would be readily available to industry to solve specific commercial problems on a confidential and fully re-chargeable basis.

Dr R. S. Nelson, who is head of the Harwell Metals and Chemical Technology Centre, will have overall responsibility for the new venture. He said: "Harwell is particularly well suited for this new programme, because, as a consequence of our nuclear power programme, we have developed special materials technology and in particular are fortunate in having perhaps the most comprehensive range of surface characterisation techniques in any UK laboratory.

"We see the work of the unit as forging new partnerships with industry, particularly the petrochemical manufacturers. In broad terms, the end result of this should be the production of better chemicals, together with better and more economical use of valuable chemical feedstock".

The technical and commercial strategy for the unit's programmes will be decided with the help of an advisory committee comprising representatives from the unit, industry and the universities. The first meeting of this panel took place at Harwell on 2nd February, 1978. Industrial representatives were from ICI, Johnson Matthey, BP and the British Gas Corporation.

Practical gear lubrication and design course

A one-day tribology course on practical gear lubrication and design will be held on 20th June, 1978 at the National Centre of Tribology, Risley.

Gears tend to be a specialist subject but some understanding of design practice, lubrication considerations and the likely reasons for failure are essential for practising engineers and designers. The course lecturers are experts in these fields. Notes will be issued and ample time will be allowed for questions.

The course fee inclusive of notes, refreshments and VAT is £51.84. Application forms and programmes are available from the Course Organiser, National Centre of Tribology, UKAEA, Risley, Warrington WA3 6AT. Telephone Warrington (0925) 31244 Ext 2640/3247.

AEA REPORTS

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

AERE-R 8904 *The UK Chemical Nuclear Data Committee Files. A Summary of the Primary Data Available in ENDF/B Format.* By A. L. Nichols. September, 1977. 44pp. HMSO £1·50. ISBN 0 70 580378 3

AERE-R 8959 *Reliability and Architecture of Plant Safety Systems.* By M. J. Cooper and M. Cheeseman. May, 1977. 48pp. HMSO £1·50. ISBN 0 70 580428 3

AERE-Bib 196 *List of Unclassified Documents by the staff of Metallurgy Division, AERE, Harwell, from January, 1972 to July, 1977.* Compiled by V. Wallis. November, 1977. 41pp. HMSO £1·50. ISBN 0 70 580398 8

AERE-R 8775 *Facsimile. A Computer Program for Flow and Chemistry Simulation, and General Initial Value Problems.* By E. M. Chance, A. R. Curtis, I. P. Jones and C. R. Kirby. December, 1977. 148pp. HMSO £3·50 ISBN 0 70 580458 5

AERE-R 8853 *Two-Dimensional Model Studies of Some Trace Gases and Free Radicals in the Troposphere.* By R. G. Derwent and A. R. Curtis. August, 1977. 45pp. HMSO £1·50. ISBN 0 70 580088 1

AERE-R 8862 *Capacitance-Voltage Profiling Techniques.* By B. J. Smith. October, 1977. 33pp. HMSO £1·50. ISBN 0 70 580338 4

AERE-R 8891 *Characteristic Gamma-Ray Spectra from Light Elements in ^{241}Am (a, n) Sources and their Use in Detecting Source Impurities.* By E. W. Lees and D. Lindley. December, 1977. 20pp. HMSO £1·00. ISBN 0 70 580438 0

AERE-R 8919 *A Multi-Access Real Time Data Acquisition System for Laboratory Instruments.* By B. L. Taylor. November, 1977. 11pp. HMSO £1·00. ISBN 0 70 580368 6

AERE-R 8979 *Facsimile. Introduction to a Computer Program for Initial Value Problems.* By A. R. Curtis. December, 1977. 23pp. HMSO £1·00. ISBN 0 70 580448 8

CLM-R 169 *Applications of Laboratory and Theoretical MHD Duct Flow Studies in Fusion Reactor Technology.* By J. C. R. Hunt and R. J. Holroyd. May, 1977. 47pp. HMSO £1·50. SBN 85311 053 0

AERE-R 8981 *Determination of Boron in Borosilicate Glasses by Neutron Transmission.* By P. F. Peck. December, 1977. 10pp. HMSO £1·00. ISBN 0 70 580468 2