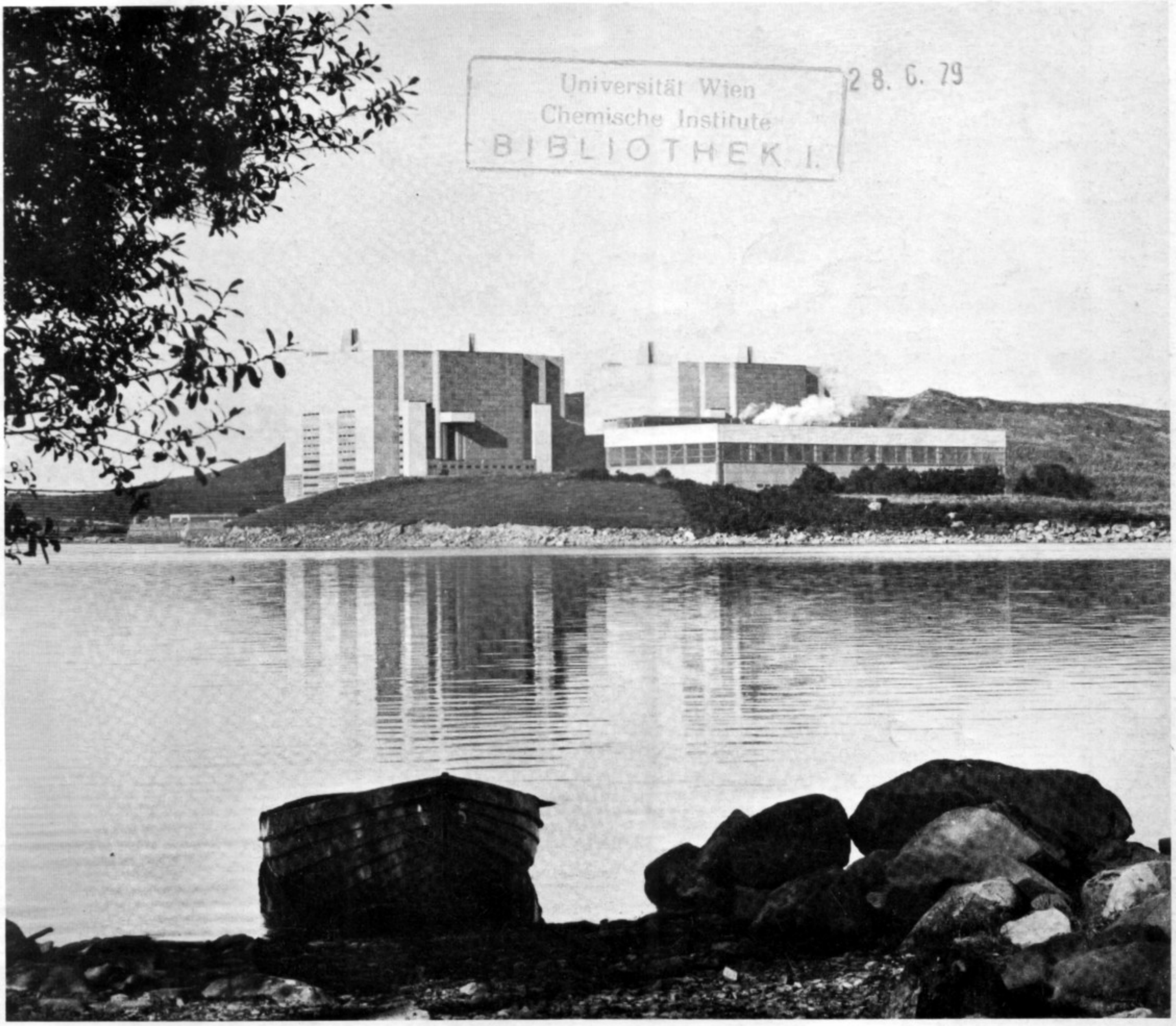
JUNE 1978 NUMBER 260

ATOM

STATUS REPORT ON FUSION
NUCLEAR POWER AND THE ENVIRONMENT
WOMEN'S ENERGY CONFERENCE
ENVIRONMENTAL PROTECTION FROM RADIATION
NUCLEAR SAFEGUARDS DEBATE
ELECTRICITY INDUSTRY REORGANISATION



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Front cover: Trawsfynydd nuclear power station in Gwynedd, Wales

STATUS REPORT ON FUSION

This report by the International Fusion Research Council (IFRC) is reprinted here with the permission of 'Nuclear Fusion' the International Atomic Energy Agency's monthly journal of Plasma Physics and Thermonuclear Fusion.

Introductory Note

The International Fusion Research Council (IFRC) has, as requested by the International Atomic Energy Agency, updated the 1970 Status Report on Fusion (Nuclear Fusion 10 (1970)413).

At a meeting held in April 1977 at the International Centre for Theoretical Physics, Trieste, the international fusion programmes, advances and potentials were assessed. The present Status Report is a result of the collective efforts of the IFRC members: C.M. Braams (Netherlands), M.H. Brennan (Australia), B. Brunelli (Italy), G. von Gierke (FRG), K. Husimi (Japan), E.E. Kintner (USA), B. Lehnert (Sweden), D. Palumbo (CEC Brussels), R.S. Pease (UK), M. Trocheris (France) and B. Kadomtsev (USSR) who were assisted by the Agency representatives J.A. Phillips, A.N. Belozerov (Scientific Secretary), and H. Seligman. The Chairman of the IFRC, Dr. R.S. Pease, chaired the sessions and accepted the responsibilities on the final status report.

The Council's unanimous views were conveyed to me in an executive summary and later as a final status report. This report stresses the advantages of fusion power, summarizes the present status of controlled fusion research, comments on trends and prospects for development, identifies important technological problems, estimates possible costs and timescales, and makes recommendations on international co-operation in this field.

In the belief that the findings of this authoritative body of experts merit broad consideration, the report is published in its entirety in Nuclear Fusion, to whose readership it should be of particular interest.

The efforts of the IFRC and its Chairman are greatly appreciated.

Sigvard Eklund

1. Introduction

The central role of energy consumption in modern society is well known. The world is now also keenly aware of the potential shortages arising from the pending exhaustion of fossil fuel resources, and of the social stresses that result from the sharply rising fuel prices and the localized nature of the reserves.

Nuclear fusion is the process in which light nuclei collide, fuse together to form heavier ones and release energy. It takes place in high-temperature matter, as in the sun. Controlled nuclear fusion offers the prospect of a major new source of energy from the light elements on earth, one that is essentially limitless and which, if it is successfully developed, could be used for the large-scale central generation of electricity. Thus, controlled nuclear fusion is potentially a final solution to the energy problem, a feature which it has in common with both nuclear energy from fission breeder reactors and solar energy (both direct and indirect forms such as wind, waves and thermal gradients).

Nuclear fusion, like fission, offers the prospect of continuous central electricity generation. Environmentally it appears to have potential advantages over fission because the fuel used is more abundant, no fission products are produced, fusion does not of itself involve any fissile and transuranic elements, and the amount of fuel in the reaction zone (about 1 g) is safe. Nonetheless, fusion does have some environmental impact, including radioactivation of structural materials. The quantitative aspects of this matter are discussed later in this report.

Solar energy is abundant and environmentally attractive. It is diffuse and variable in time and place, and seems on this account more difficult than nuclear energy for central electricity generation but more favourable for localized use, especially in developing countries. One may therefore envisage that in the next century three long-term sources of energy could be available to replace the dwindling or exhaused fossil fuels: fusion, fission and solar energy, each one claiming its place when, depending on local conditions of supply and demand, its characteristics give it a competitive lead.

Fusion is still in the research stage. Very good progress has been made since the IFRC last reviewed the work in 1970. As a result, it seems that the scientific basis for building controlled nuclear fusion devices with a net energy output from the deuterium-tritium reaction is no longer seriously in doubt. But this result needs to be proved, and the research has to be combined with engineering developments to establish whether or not technologically and economically practical fusion energy systems can be developed.

The purpose of this report is to present the current status and prospects for fusion and to recommend to the IAEA international initiatives to help establish the fusion option.

2. Physics Research Progress

Two basic conditions have to be satisfied in order to realize fusion reactors: firstly, the fuel has to be heated to a temperature T in the range from 50 to 500 million degrees; secondly, the so-called Lawson criterion has to be fulfilled, i.e. the product $n\tau$ of plasma number density n and energy confinement time τ has to exceed about 10^{14} cm^{-3} s. The most accessible reaction is that between the hydrogen isotopes, tritium and deuterium, which can ignite at 100 M°C with $n\tau = 10^{14}$ cm^{-3} s; other reactions, such as D-D, D-^{3}He or D-^{6}Li, require higher values both of temperature and of $n\tau$. The required values of $n\tau$ can be lowered by about an order of magnitude in the so-called two-component approach, but at the penalty of high circulating power in the envisaged power station.

The required conditions can, in principle, be fulfilled in two ways, namely by magnetic and by inertial confinement. In both methods, substantial progress has been made during the past years. Common to both is an improved understanding of physical phenomena in high-temperature plasmas, arising from improved methods of experimental, theoretical and computational exploration and a wider range of experimental devices.

In magnetic confinement, the most impressive progress towards the plasma conditions needed in a reactor has been achieved with the so-called tokamak system. Over the years, a dozen or so devices of increasing size and power have contributed to the understanding of tokamak behaviour. Substantial progress has been achieved also with other systems of magnetic confinement, although on a more limited scale and with less overall world efforts.

The most important progress with inertial confinement has been in the theory and in the successful demonstration of laser-driven pellet compression. Target compression and heating has recently also been achieved by relativistic electron beams.

2.1 Magnetic confinement

2.1.1 TOKAMAK SYSTEM

In this system the plasma is heated and confined by an electric current passed through the plasma in a toroidal chamber, with a strong external field to stabilize the current flow. Following the encouraging results obtained in the late 1960s, there was a considerable world-wide development of the tokamak programme. This effort and the favourable properties of tokamaks have led to a remarkable progress since 1970.

Quantitatively, the ion temperature has been raised from 700 eV to about the value of the electron temperature, viz. 2000 eV, by introducing secondary heating techniques. The confinement times have been improved to about 50 ms. Higher densities and cleaner plasmas have been achieved and it was observed that the confinement time increased linearly with density; as a result, the value of the thermal insulation, measured by the $n\tau$ product, has been improved forty-fold to $10^{13}cm^{-3}$ s, so that there is now an overlap of what is achieved and what is needed for substantial energy production.

Most recent results of experiments on larger apparatus have shown that increasing the linear dimension of tokamaks by a factor of two has not led to difficulties in generating the discharge, and it has produced the expected trend in the improvement of the energy confinement time.

The increase in ion temperature was possible through successful development of heating by neutral particle injection. The progress made in this field can be measured by the intensity of the neutral beams, which was brought from some tens of kilowatts in 1970 to nearly 1 MW now.

In addition to the increase in plasma temperature and confinement time, substantial progress has been made in understanding the relevant physical phenomena. A much better analysis of plasma stability has been made both experimentally and theoretically. By the use of powerful computers it is possible to simulate fairly accurately the evolution of tokamak discharges. These results make it possible to predict the performance of tokamaks within the range of present parameters, and to extrapolate beyond these to reactor conditions.

However, progress is still required in the understanding of many aspects of the physical behaviour of tokamaks. In particular, a deeper understanding of transport phenomena, including so-called disruptive instabilities, is needed, especially for increased values of electron and ion temperature and plasma size. Further effort should be devoted to increasing the plasma pressure as compared with magnetic field pressure; in present tokamaks the ratio of these two quantities (β) is up to about 1%, whereas 5—10% is required to enable a more efficient use of magnetic fields necessary for an economical thermonuclear reactor. Another important problem is the control of impurities in plasma, where specialized techniques such as divertors, gas blankets and improved methods of cleaning the vacuum wall already offer good prospects of keeping impurities to a low level.

An increase of the ion temperature from the present value of 20M K to thermonuclear values of 50—500M K by existing methods seems entirely feasible, but it will require an increase in secondary heating powers by about ten times. For example, in neutral injection, powers of several tens of megawatts with energies of more than 100 keV will be needed for the next generation of tokamak machines. Other methods of heating the plasma have been demonstrated, such as adiabatic compression and radio-frequency heating, and these can also be applied.

The next generation of powerful tokamak machines (both in size and magnetic field) now under construction or awaiting approval is expected to bring direct information on the physics of plasmas with thermonuclear reactor parameters. In particular, the experiments will include the study of deuterium-tritium plasmas under conditions approaching ignition, that is when the energy released by the nuclear reactions and absorbed in the plasma can overcome the energy lost from the plasma by conduction and radiation.

2.1.2. OTHER MAGNETIC SYSTEMS

In the stellarator and related systems, containment of the plasma can be achieved without requiring a net current in the closed plasma ring. To ensure equilbrium of the plasma, a magnetic field of complex geometry is produced by external coils; in the stellarator, the torsatron and the helical heliotron, this is a twisted field possessing the property of a 'rotational transform'. As compared with the tokamak devices, these systems offer the favourable potential of running continuously.

The recent experiments on new installations with helical winding systems giving poloidal fields equivalent to those in small tokamak experiments have shown the possibility of reaching, with Ohmic heating, the same plasma parameters as in tokamaks. The temperatures reached are in the range 5—10M°C, and values of $n\tau$ are 5×10^{11} cm^{-3} s. The experiments demonstrate that, as expected theoretically, under these conditions the helical windings are as effective in confining plasma as the discharge current of a tokamak. Furthermore, the idea that stellarators inevitably suffer from so-called Bohm diffusion is now decisively refuted, both experimentally and theoretically. The main reason for this great improvement is the use of more powerful helical windings, together, perhaps, with the elimination of imperfections in the magnetic fields. It is now a task of the immediate future to apply the new heating methods to stellarators in order to achieve improved plasma conditions in the absence of the currents used in Ohmic heating.

There is a wide variety of stellarator and related geometries still to be studied. In particular, some stellarator configurations were approached from the high-beta side. The theory suggests the possibility of confinement of such high-beta configurations, and experiments were made using the technique of theta pinches. Among these possibilities, an optimum field configuration may be found which has the necessary properties to provide a steady-state confinement system for a thermonuclear reactor.

2.1.3. THE DIFFUSE PINCH

Investigations have been carried out in a number of laboratories on the confinement of plasma in toroidal discharges stabilized by longitudinal fields which are only of the same magnitude as the fields due to the discharge current. The fluid stability of these systems has been demonstrated in detail and their self-stabilizing properties theoretically explained. In particular, reverse field pinches and screw pinches have shown stable confinement of plasma at the high values of beta (> 10%) needed for economic toroidal reactor systems, in agreement with theory.

Up to now, these experiments were done on installations of small size where plasma/wall interactions restricted both the achievable electron temperatures and the duration of the stable configuration. It is desirable to proceed to larger-scale experiments in order to evaluate their reactor potential. Table 1 shows the evolution of plasma parameters in toroidal pinches during the last two decades.

2.1.4. OPEN SYSTEMS

Open systems have the advantage of topological simplicity. They have a definite disadvantage, namely the rapid loss of plasma and energy through the ends. They have practical advantages for a reactor, in particular: high values of beta, simple refuelling and exhaust of reaction products, smaller unit size, and relative simplicity of construction and maintenance. Therefore, large efforts are justified to find ways to reduce end losses and improve the energy balance. The most promising line according to recent results is the magnetic mirror concept, which is already a serious candidate for a reactor; others, like linear theta pinches, solenoidal systems and plasma focus, are at an earlier stage.

Progress towards stable confinement of hot ion plasmas in magnetic mirror fields has been substantial during the past years. Plasma stabilization by filling the trap with a warm plasma stream led to the production of plasma with high ion temperatures (10—20 keV) and densities (up to 10^{14} cm^{-3}). Even in a completely stable mirror-confined plasma, however, the loss of particles and energy along the magnetic field lines caused by classical Coulomb scattering (end loss) may still be too high for a fusion reactor. Calculations indicate that this problem may be overcome by the introduction of new features, such as (a) recirculation of the lost energy, or (b) reduction of end losses by a more complicated geometry of the magnetic field, such as tandem mirrors and linked mirrors. These techniques are now being actively investigated.

During the past several years, there was increasing interest in long, straight magnetic systems with plasma heated by electron and laser beams. The following encouraging experimental results have been obtained:

(a) The production and focusing of high-power electron and laser beams over a distance of a few metres has been proved.

(b) It was found that, by adjusting the plasma parameters, the energy deposition rate in the interaction region could be made as high as 10% per metre.

(c) The theory of multi-mirror end-stoppers has been verified.

Nonetheless, these systems require very strong magnetic fields and have to be very long (more than 100 metres) to counteract the end losses.

Of the pulsed magnetic systems, the so-called plasma focus, which is perhaps the least understood of all simple systems is amongst the most effective in producing simultaneously high values of electron and ion temperatures, of nuclear fusion reactions and high values of the product $n\tau$ (about $10^{12} cm^{-3}$ s, with $T_e \cong T_i \cong 1$—3 keV, and $n = 10^{20} cm^{-3}$).

TABLE 1. Plasma parameters in toroidal pinches

Year	τ_e (s)	T_i (K)	$n\tau$ (cm^{-3} s)	Sustainment time (s)
1955	10^{-5}	10^5	10^9	10^{-4}
1960	10^{-4}	10^6	10^{10}	3×10^{-3}
1965	2×10^{-3}	10^6	10^{11}	2×10^{-2}
1970	10^{-2}	5×10^6	5×10^{11}	10^{-1}
1976	5×10^{-2}	2×10^7	10^{13}	10^0
Reactor requirements	10^0	10^8	10^{14}	$\gtrsim 10$

2.2. Inertial confinement

Inertial confinement fusion research is directed towards demonstrating the scientific feasibility of very rapidly heating and compressing small pellets of suitable fuel until conditions exist where thermonuclear fusion can occur and useful amounts of power can be produced. Such pellets may be heated up to the required temperatures by means of lasers or beams (electron or ion), or by magnetic compression.

2.2.1 LASERS

Inertial confinement fusion research to date has produced implosions of D-T-filled pellets, with observed thermonuclear neutron production, thus verifying theoretical predictions in a satisfactory manner for low power levels. Pellet compressions now yield of the order of 10^9 thermonuclear neutrons, several orders of magnitude more than those first observed only three years ago. Scientific uncertainties remain about the precise nature of the physics of beam absorption by target materials and the manner in which implosion phenomena observed at low energy levels scale to higher powers.

Rapid advances are being made in the development of high-power lasers and the associated optical engineering needed to bring this system to fruition. An encouraging recent result is that compression has been obtained using CO_2 lasers whose energy efficiency can approach that necessary (>5%) to get a net energy yield.

2.2.2. ELECTRON AND ION BEAMS

The last few years have witnessed progress in further development studies of the technology of relativistic electron beams to accomplish micro-explosions. The main results here are as follows:

(a) It was experimentally proved that a number of ways exist for magnetic focusing of electron beams on the surface of targets.

(b) Processes of energy absorption and transfer during acceleration of the shell up to a velocity of 10^7 cm/s (that is, only two times less than that required to initiate the fusion ignition), 1000-fold compression of fusion fuel and its heating to kilovolt temperatures were verified experimentally. These measurements are confirmed by measurements of output and energy of fusion neutrons (1—3×10^6 per impulse in pure deuterium targets).

Quite recently, intense pulsed ion beams with energy per particle ~ 1MeV and energy per pulse ~ 10 kJ were obtained. Intense ion beams have potential advantages over electron beams for achieving ignition of fusion targets. Since the stopping length is much less for ions than for electrons of comparable energy, lighter targets can be used. Many ideas for the use of ions are therefore being studied.

2.2.3. MAGNETIC COMPRESSION BY MEANS OF IMPLODING LINERS

Progress has also been made in the field of magnetic compression of plasma targets by means of imploding liners, though the combined experiment on plasma compression and heating by accelerated shells has not yet been carried out. Results to date are the achievement of volume symmetric compression inside shells by a hundred times for the cylindrical case and by up to 1000 times for the spherical case. Megagauss magnetic fields and plasma pressures of up to hundreds of kilobars were obtained.

3. Fusion reactors: engineering and technology

Since 1970, studies of envisaged fusion reactors and their engineering problems have been undertaken in most countries with fusion research programmes, so that overall about 10% of current efforts are devoted to this topic. By comparison with the magnitude of the technical developments needed, these efforts are preliminary; they have served to define the main outlines of the problems, to identify outline solutions and to give assessments of the potential feasibility of practical fusion reactors. They have laid the foundations of planning for development programmes in engineering and technology, provided a basis for outline costing, and identified the areas of plasma physics research needing attention.

Essentially all the work has been devoted to reactors based on the D-T thermonuclear reaction, because the physical conditions required for these reactions will be reached first, and because, for a given plasma pressure and volume, this reaction yields the highest power output. The reaction itself defines some of the principal features of an electricity generating reactor. The tritium has to be bred from lithium in a blanket surrounding the thermonuclear plasma; most of the reaction energy is deposited in this blanket region by 14 MeV neutrons from the D-T reactions and from ^{6}Li(n)T reactions (the blanket has to be of the order of 1 metre thick); the heat has to be transferred by a coolant from the blanket to a generating plant driven by conventional thermal engines; and the blanket has to be supplemented by a biological shield region to reduce the neutron and gamma radiation to safe values.

3.1 Systems studies (magnetic)

Most of the recent conceptual designs for magnetic fusion reactors have been based on the tokamak system. About a dozen tokamak reference designs are extant today, covering both experimental and commercial systems. They have provided many fundamental insights regarding tokamaks as fusion reactors, and have identified and defined key technological problems and assessed the potential for solving them. After a generation of studies, a convergence of solutions and a process of optimization are beginning to emerge.

The main common features of the conceptual tokamak reactors considered so far are:

Thermal power in the range	2—5 GW
Overall conversion efficiency	30—40%
First wall minor radius	2—5 m
Major radius	10—15 m
Toroidal magnetic field (produced with superconducting D-shaped coils of NbTi)	3—8 T
Plasma current	10—20 MA
Current pulse duration	100—1000 s

Some of the studies have been carried out in considerable depth and detail, and achieved a substantial degree of self-consistency. Thus they give considerable confidence that a tokamak-based electricity generating system can be built. At the same time they involve suppositions which, though plausible, impinge strongly on practicability and cost factors which are vital if thermonuclear power is to become a reality. Examples are:

(a) The values of beta assumed, 5—10%, are higher than the 1% achieved experimentally.

(b) The plasma has to be kept stable and clean for times of 100—1000 s.

(c) Refuelling and divertor systems are assumed to give a steady state, i.e. a balance of energy and particle throughput for long burn-times.

(d) The power loading of the first wall (and hence of the blanket) can be in the range 1—10 MW/m^2 without producing radiation damage or other effects leading to loss of integrity such that the first wall has to be replaced frequently.

Naturally, other confinement systems having potentially advantageous features, such as DC operation, high beta, or built-in refuelling, have also been studied. In general, studies of reactors based on other systems have involved greater extrapolation from present experimental achievement or theoretical understanding, and have not been so detailed. As a result, the choice of the most practical system for a fusion reactor remains an open question. It is an important task for the immediate future to pursue urgently these studies of alternative systems.

The class of 'fusion energy multipliers', whose main representative was always the open-ended mirror concept, has recently been extended to toroidal systems such as the 'two-component tokamak' and the 'fission-fusion hybrid system', on which reactor schemes have been proposed, With the mirror concept, they have in common: an energy amplification factor in the range 1—10, less severe Lawson conditions ($n\tau \sim 10^{13}$), a possible DC operation, smaller size and no need for special fuel supply arrangements. The relatively large circulating power requires high conversion efficiency and imposes a cost penalty which must be offset by, for example, elimination of separate heating and refuelling systems, or by the reduced values of $n\tau$ required. Proposals for reducing the circulating power in a mirror reactor seem conceptually attractive and worthy of more extensive experimental study.

The pioneering work on conceptual studies of a stellarator reactor was done in the early decades of fusion research. More recent studies have shown that helical external magnetic windings can be both expensive and difficult to assemble and maintain. It is therefore important that new theoretical and experimental work has identified simpler forms of external windings that are more applicable to reactor construction and have been tested experimentally. Now that the plasma physics problems of stellarators are yielding to experiment, a resurgence of reactor interest may be expected. An important need is to demonstrate stellarators operating at a value of beta in the range of 10% or more, which will be the task of plasma physics for the coming years.

3.2. Development of technology for magnetic systems

The problems of the D-T reactor can be classified under two main headings: those common to all magnetic confinement systems, and those special to the system proposed.

3.2.1. COMMON PROBLEMS

(a) REACTOR BLANKETS. The thermonuclear plasma is surrounded by a blanket region which captures the neutrons in lithium to breed tritium, provides the primary heat removal region of the nuclear energy and shields the magnetic coil system from nuclear radiation. A number of blanket geometries have now been considered, and breeding ratios greater than unity can readily be obtained, with a blanket thickness of the order of 1 metre, within established nuclear engineering technology. For the coolant, liquid lithium is attractive from the viewpoint of tritium breeding and heat characteristics, but has less desirable features in safety and corrosion resistance, and flow characteristics in the presence of strong magnetic fields. New concepts use helium cooling, together with the lithium encapsulated either as a metal, oxide or salt. Modular design is thereby simplified, but a neutron multiplier with a high (n-2n) cross-section is found necessary in some designs. Verification of the neutronics of blanket designs by detailed comparison with experiment is required, and the first experiments with simple configurations are under way.

(b) TRITIUM PROCESSING. Preliminary studies show that the quantities of tritium present in a fusion reactor, up to 10 kg/GW(e), can be safely processed and stored. Detailed design studies and experiments, however, have not yet been carried out.

(c) VACUUM WALL. In the reactor design concepts the vacuum container (or first wall exposed to the thermonuclear plasma) will be subjected to 30-40 MW·year/m^2 of fusion radiation energy in the form of neutrons, energetic particles and photons. Early data imply a radiation limit at around 5—10 MW· year/m^2, and a better material operating at the expected temperatures in a reactor must be developed. Relatively little is known today of the mechanical integrity and ductility of materials subjected to radiation damage from 14 MeV neutrons. Thermal and mechanical recycling effects which will occur in pulsed systems are an additional feature requiring attention.

The control of wall material dislodged by bombardment of energetic particles by the well-established mechanisms, including evaporation, sputtering and unipolar arcing, is expected to be feasible by: (1) selection of the optimum low-Z material (perhaps as coating), and (2) the use of divertors or of a gas blanket to reduce exposure of the wall to high-energy particles.

(d) DIVERTOR. Magnetic divertors are being designed to restrict contamination from the wall and to exhaust the large quantities of unburnt plasma and reaction products. A promising experimental start has been made on evaluating the performance of design concepts, and although much work remains, divertors so far have worked as planned. Divertors involve difficult special coil systems, and incorporating them into power reactors with modular construction and minimum circulating energy presents serious design problems.

Examination of the cold gas blanket concept for impurity control and refuelling will be possible on the large experiments now under design and construction.

(e) RADIOACTIVITY. Since 1970 much more detailed estimates of the neutron-induced activity of the structural material have been made. The stainless steel or nickel alloys and molybdenum seem to offer immediate prospects of combining practicality with the advantage of not very long-lived activity. Some very low-activity structural materials (V, Ti, Al alloys) have been suggested. These, together with a number of low-activity alloying or non-metallic elements (Si, C), offer possibilities which deserve greater attention because every reduction of radioactivity in the surrounding structure offers further improvement with respect to a key environmental advantage of fusion and eases the problems of maintenance and repair of the structure. Because existing commercially available materials have not been developed with fusion reactor needs in mind, a systematic investigation of new material, specifically optimized to minimize radioactivity and radiation damage in fusion reactors could well be very fruitful.

(f) MAGNETIC FIELDS. The design and construction of the superconducting magnetic field coils needed in many designs, although large and complex, would appear to require a straightforward engineering development programme, provided NbTi can be used. On the other hand, the construction of a large Nb_3Sn coil is a more formidable undertaking, including the production of the Nb_3Sn material and the containment of the stresses at the higher fields. A source of some anxiety is the relatively unknown behaviour of the superconducting coils in fields that vary by 0.5 T/s as are needed in some designs. There is now a strong collaborative effort by several countries in the construction of large coils.

(g) MAINTENANCE. A modular design concept of tokamak reactors has been explored to simplify the repair and replacement of parts. Remote handling techniques of radioactive components have to be further developed. These considerations have a major effect on the reactor configuration and mechanical design. The approximate weight of the modules in some designs is 100 tonnes.

3.2.2. SPECIAL PROBLEMS

(a) INJECTION OF COLD FUEL. Experiments on the injection of fuel during the burn-cycle required in some reactor designs are urgently needed. A number of questions on this important problem remain open, and more definitive experiments are now under way.

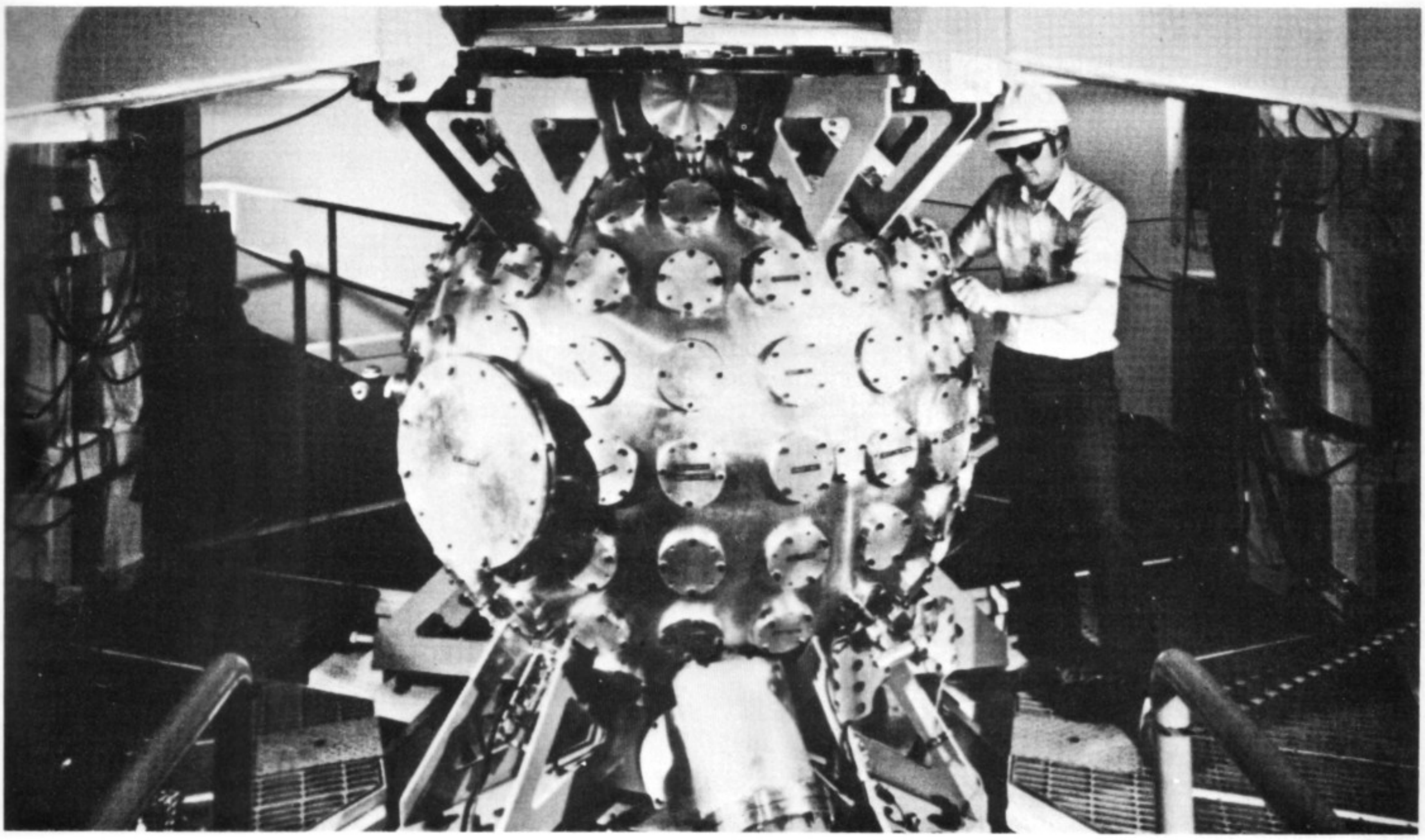
(b) HEATING. In addition to Ohmic heating produced by passing an electric current through the plasma, there are two main heating methods which are being developed: injection of energetic neutral atoms and application of radio-frequency power.

Striking progress has been made since the early 1970s in the neutral injection heating, with neutral beam injection power per module being raised from 10 kW to nearly 1 MW. The further development of injected power from 12 MW for 2—3 ms, at present used in some experiments, to that required in a reactor, 100 MW for 1 s, seems to be a relatively straightforward engineering development. But attention will have to be given to further increase the efficiency at high atom energies by exploiting injection concepts such as ripple diffusion, negative ions at higher energies and energy recovery from ion beams.

The achievement of these intense beams of neutral atoms has encouraged the concept of energy multiplying systems such as the two-component reactor plasma, i.e. energetic injected particles reacting with a relatively cold background plasma, as mentioned earlier.

Efficient heating by large RF systems has been proven for the ion cyclotron heating. To avoid a complicated launching assembly in the heart of the reactor, higher frequency resonances are preferable. The development of the required power supplies is a straightforward engineering development, but the coupling mechanism to the plasma needs more study, particularly under reactor conditions.

(c) ENERGY STORAGE. Some fusion power reactors could require reversible energy storage in the range of several gigajoules delivered in a period of a fraction of a second to several seconds. Initial progress has been achieved using two different technologies. Inductive storage devices using superconductive components have stored up to 500 kJ and have been discharged in ~1 ms. A reversible homopolar energy transfer system has been designed to discharge 10MJ of stored energy in 30 ms. Nonetheless, substantial development work is needed if



Target chamber for laser fusion at the Lawrence Livermore Laboratory, USA

these techniques are to be applied to gigajoule storage systems.

3.3. Inertial confinement fusion reactor concepts

A conceptual laser fusion reactor would consist of a reaction cavity in which the thermonuclear energy is released from deuterium-tritium reactions within a pellet, located at the centre of the cavity, with thermonuclear burn initiated by a laser pulse. A blanket of lithium surrounds the source of fusion neutrons.

A feature of laser fusion reactors that differs significantly from magnetically confined reactor concepts is the fact that the energy pulses represent substantial amounts of energy released on a very short time-scale. The minimum energy release, determined by both physical and economic considerations, is probably about 100 MJ (roughly equivalent to 20 kg of high explosive). Although the hydrodynamic blast created by the pellet micro-explosion can be controlled with relative ease (because the energy is carried by a small mass of high-energy particles), large stresses can result from high rates of neutron energy deposition in the blankets and structural materials. A major design problem in containing this energy is posed by the need for a low-pressure cavity in which the pellet can be heated and compressed by a laser pulse without prohibitive laser energy loss along the beam path, while at the same time a finite layer of blanket material that surrounds the pellet is maintained.

Several conceptual designs have been proposed for pure laser-fusion reactors to cope with the characteristic first-wall problems typical of inertially confined fusion reactors. Three different types of first wall have been proposed: a dry wall, a wet-wall and a magnetically shielded wall. Hundred-megajoule explosions could be contained in a chamber of $>$ 3.5 m diameter, without exceeding fatigue limits, using niobium, molybdenum or stainless steel at temperatures up to 1000 K in the wet-wall designs.

Many of these concepts can be taken over for electron beam and ion beam inertial confinement systems where the physical developments are rapid.

Other major engineering problems of laser fusion are the development of high-repetition-rate, highly efficient lasers, together with the associated high-reliability optical engineering that will be needed, and cheap and reliable fabrication of the target pellets. Progress with lasers and optical engineering is very rapid, so that the apparently extreme demands which have to be met for practical energy production should not, at the present stage, deter research on laser fusion.

3.4. Overall assessment and future needs of reactor engineering

No single technological obstacle which may make reactors impracticable has been found so far in these studies of the conceptual design of fusion reactors. However, much needs to be done in order to approach realistic engineer-stage reactor design, especially in the domain of electrotechnical engineering and in establishing the practicability of materials with the required properties. The accomplishing of conceptual designs of D-T tokamak fusion reactors gives rise to a much greater confidence in the outcome of fusion research.

The present conceptual designs, however, are by no means to be taken as final designs, because the development of plasma physics, the potential for developments in component quality and rating, and the introduction of new ideas will undoubtedly change the overall view of the reactor systems. These designs should rather be regarded as revealing critical features and so stimulate further studies in improving these aspects.

The phasing of individual technological development should be prudently chosen. Too early a detailed development of technology might become of no use, because the general design policy changes. On the other hand, materials development often requires a long period of time and it is better to initiate such a development in the early phases. To this category belong the superconducting materials and the first-wall materials, among others. These developments may require expensive special facilities, such as intense 14 MeV neutron sources. The provision of such facilities on an international basis would be very helpful.

4. Material Resources

Nuclear fusion will initially be based on the D-T reaction, and will therefore consume deuterium and lithium. The supply of deuterium is practically unlimited and the known high-grade reserves of lithium amount to about 10 million tonnes. Both ^6Li and ^7Li are consumed in tritium breeding, and although it is theoretically possible to consume all the lithium, current designs indicate that only 7—15% of all the lithium would be consumed. In addition, the lithium inventory needed in a reactor depends on blanket composition and loading; current designs indicate around 200 tonnes of natural lithium per GW(e). Thus 10^7 tonnes of lithium could provide the inventory for more than 10^4 GW(e) of reactors and represent an energy reserve of 200—500 Q (where $Q = 10^{21}$ joules). The current world consumption of energy is about 0.3 Q per year, but it might well rise to 1 Q or more in the next century. The current consumption of lithium for other purposes is assumed to amount to about 5000 tonnes per annum. Thus the known high-grade reserves are sufficient for more than a century of fusion power at negligible fuel cost.

Beyond this, one can envisage the use of lower-grade lithium reserves on land (the average concentration of lithium in the earth's crust is given variously as 20 and 65 g per tonne) and in the oceans (0.17 g per tonne), which could yield several million Q. Moreover, long before the high-grade reserves are exhausted, a pure deuterium fusion reactor may be shown to be feasible; for this the world's resources are about 10^{10} Q.

The question of whether or not other material requirements could ultimately restrict the use of fusion energy has also been looked at. No single element (other than the fuel) is essential to a fusion reactor, so that in general the question is intimately linked with detailed design and with costs. However, helium will be very important for superconducting coils in magnetic confinement and also as a blanket coolant. Inventories of the order of 100 tonnes per GW(e) are suggested, and if, as seems possible, the present cheap well-gas supplies become exhausted before the fusion investment is required, the more expensive atmospheric helium would have to be used. Likewise, the extensive consumption of beryllium as a neutron multiplier would be more limiting than lithium; but beryllium can be replaced by other (n,2n) materials.

The demanding environment of the vacuum wall is likely to require and justify the use of special and perhaps relatively scarce materials, and the component life may be finite because of radiation damage. Because these materials become activated, recycling may be long delayed or expensive. In the absence of recycling, materials such as molybdenum or niobium might in the long run become expensive or limiting and would therefore be replaced by cheaper materials, such as the relatively abundant titanium. In addition to limitation of resources, there may appear difficulties if an early and rapid penetration of fusion power in the energy market is envisaged. Thus, although no insurmountable supply barriers can be identified, there are constraints that may have to be faced by reactor designers.

5. Environmental/Impact

Several studies on the environmental impact of fusion reactors have been completed recently, including a report prepared by the IAEA at the request of the IFRC. Although fusion reactor design is still at the conceptual stage, these studies are sufficiently detailed to permit a preliminary assessment of the environmental impact of fusion power and, in particular, to conclude that the potential total biological radiation effect of the fusion reactor is one or two factors of ten less than that of the fission breeder reactor, even with the materials available at present.

5.1. Materials acquisition and reactor siting

The fuel of the D-T reactor, deuterium and lithium, has a large energy content and therefore only relatively small quantities are required: a 1 GW(e) reactor is envisaged to use a few tonnes per year. Deuterium is readily extracted from sea-water and involves negligible land despolliation. Lithium, if extracted from ore deposits at 0.1—1% concentrate, will involve only very modest mining operations, even less than for fission. The acquisition of materials for the components of the fusion reactor appears to have a despolliation and environmental impact similar to that of the fission reactor; there is a factor of 10 to 100 improvement over strip-mined coal.

Siting effects of fusion reactors are comparable with those of fission systems, and both systems have in common the need for waste heat rejection and the fact that there is no chemical exhaust. For fusion reactors there are no associated fuel reprocessing plants.

5.2. Routine reactor operation

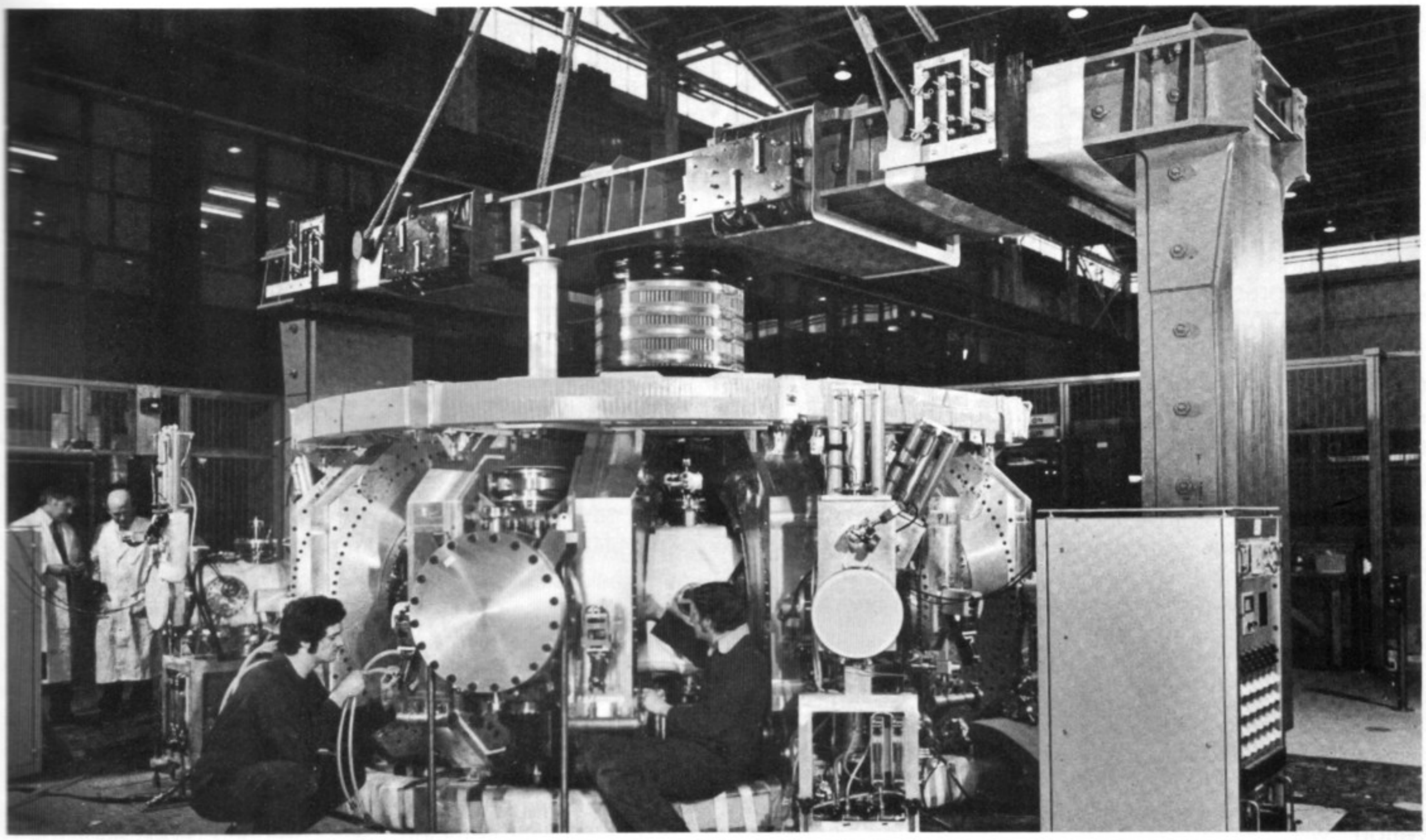
The ultimate products of the fuel cycle (mostly helium) are quite harmless. The most significant hazard generated on site during normal operation is the leakage of tritium (a low-energy beta emitter with a physical half-life of 12.3 years and a biological half-life of 12 days) into the biosphere. Present reactor designs envisage a tritium inventory of about 10kg per GW(e). Acceptable radiation hazards will be ensured for leakage rates up to $\sim 3 \times 10^{-4}$ of the inventory per year. This does not appear to present insurmountable design problems.

It will be necessary, during and after normal operation of the reactor, to replace and to dispose of activated structural components — particularly those that have suffered heavy radiation damage. Although the constraints on the selection of materials are not clear at this stage, it does appear that for all candidate materials the radioactive hazard potential is significantly less than for fission products, and for most the decay times are shorter as well. There are the additional advantages that the activated reactor components are in solid form and that no chemical reprocessing is essential. There are, of course, no actinides to be processed or stored, unless the fusion neutrons are used deliberately to breed fissile material for fission reactors.

Radiological hazards to operating personnel are likely to be comparable with those pertaining in fission reactors. Although no biological hazard to personnel has been demonstrated from the stray magnetic fields of magnetically confined reactors, this aspect deserves further study.

5.3. Reactor shut-down and accidents

Although no risk analysis can yet be done for fusion reactors, detailed estimates of radioactive inventories and their associated hazard potentials have been made. For describing short-term consequences of an accident, the appropriate measure is the biological hazard potential (BHP) in air, while the BHP in water or its time-integrated value is more relevant to long-term effects, including those of waste disposal. A comparison with studies for the fission breeder reactor suggests that fusion reactors employing



The DITE Tokamak at Culham

stainless-steel blanket structures will have one or two orders of magnitude lower hazard potentials, while other materials come out either higher (Nb-Zr) or lower (V) than stainless steel, depending on duration after shut-down. Although the metallurgical properties of the low-activity materials referred to in §3.2.1(e) are not sufficiently established to make sure that these materials can indeed be used, it is important at this stage to indicate their potential for strongly decreasing further the long-term environmental impact of fusion energy; for example, for vanadium-titanium there is essentially no activity after a hundred years.

As to the possibilities of actual releases of these inventories, it is important to note that fusion reactors have only small quantities of fuel in the reaction zone, so that there is no possibility of dangerous nuclear excursion or runaway. Also, decay heat due to activation of structural materials does not constitute a source of danger. Detailed risk analyses will further have to consider accidental releases of radioactive materials into the environment as a result of events such as chemical explosions, fires, release of stored magnetic energy and natural disasters. The use of non-metallic lithium mixtures for the blanket, which appears to be possible, will certainly reduce the probability, perhaps even exclude the possibility, of disastrous accidents.

5.4. Nuclear weapons implications

The operation of fusion reactors does not involve the production or use of plutonium or other weapons-grade materials in any way. Although it would be possible to use fusion neutrons to breed fissile materials, the production of such material by pure-fusion reactors would require significant reactor modifications and access to hot chemical processing facilities. Moreover, safeguards by surveillance would only require ensuring the total absence of fissile material and fission products on the reactor site; it is therefore much easier to apply safeguards to fusion operations than to the fission fuel cycle where diversion of small fractions of fissile material during commercial operation is possible.

The development of laser fusion systems does not, of itself, result in any addition to the nuclear arsenal, but the research seems to be adjacent to some fields of knowledge used in weapons development.

6. Time-scale, effort and cost

The development of fusion power into an economic electricity-producing source is a major scientific and technical challenge. On the path to the final goal, several milestones have to be passed which offer the opportunity of adjusting the forward strategy in the light both of progress and of anticipated needs.

Several of these important intermediate goals short of commercial demonstration could be made proximate objectives of international fusion programmes and co-operation:

(a) First, the demonstration and study of the physics of burning plasmas in ignition experiments. Such a goal, if the work is commenced promptly and adequately supported, might be achieved in 6—8 years.

(b) Next, the demonstration of a sustained net energy output from a fusion experiment, which then should be possible in a further 7—10 years' time.

(c) Development and demonstration of the technical practicability, economy and reliability of all necessary components for a fusion reactor plant, including the operation of a full demonstration plant.

(d) Comparison of the economy and reliability of different reactor types. An additional intermediate goal is being pursued in the USSR, namely the demonstration of breeding fissile material in a specially designed blanket by means of fusion neutrons.

The key goal is the fully operating demonstration plant, and this could be started before full information is available from earlier stages. It should be possible to infer the commercial practicability, or otherwise, of fusion from this stage, but demonstrated commercial competitiveness would follow later.

Cost estimates of generating electricity by fusion have the same general characteristics as reported in 1970; the costs of fuel and fuel processing are negligible, but the capital costs are likely to be high. A number of rough estimates from the systems studies indicate capital costs of the same order as those for the fast breeder and the associated fuel cycle. At present, one of the main purposes of fusion research is to find ways of bringing the capital costs down to economically desirable levels.

Estimates of the time and cost required for a demonstration plant have been made in the USA. The times range from 15 years (crash programme) to 45 years (still increased effort compared with today). The cost is estimated at US $\$15 \times 10^9$. The time and cost for fusion power development depend, within limits, on the national and international commitments to that goal, not only of financial but also of intellectual resources, institutional arrangements, the degree of international co-operation and the way of decision finding.

The estimates show that fusion power cannot solve the problems in connection with the expected world energy shortage before the end of this century, but they show that there is a realistic hope that fusion power can start to contribute to fill the increasing energy gap at the beginning of the next century, provided that an adequate world-wide effort will begin now. A substantial and increasing contribution to electricity production, however, can probably be expected only after the first two decades of the next century, because the high capital investment necessary for a fusion plant will make experience of the long-term reliability of such plants highly desirable before a large-scale introduction of fusion power can be started. As this introduction period can only be shortened by large financial risks, one has to save time when it is less expensive, that is now, at the beginning of the development period.

A consideration of these estimates of total cost and time for the development of fusion to the demonstration of practicability should recognize the following factors:

(a) Fusion research began 25 years ago, but it has been carried out on a relatively small scale in respect both of the size of the experimental devices and of the financial support provided.

(b) At the time of the last report of this Council in 1970, the total world expenditure was only US $\$100 \times 10^6$ per year. There have been significant increases in recent years in fusion research support in the USA (from US $\$44 \times 10^6$ in 1970 to US $\$234 \times 10^6$ in 1976), and in Japan (from 633×10^6 yen in 1970 to 8246×10^6 yen in 1976), but there have not been comparable increases in other nations. In particular, the programmes in the Soviet Union and Western Europe have remained almost constant in terms of scientific personnel engaged.

(c) Further research will require larger and more expensive experimental devices. It will also require new types of facilities as the work broadens to include many technological problems in addition to plasma physics which has been the major subject of research to this time.

(d) Conversely, much of the technology required for fusion, such as blanket design and coolants, radiation damage studies, shielding, remote maintenance in radiation fields and tritium processing, has already been developed extensively for fission reactors. This background should ease the schedule and cost for practical demonstration of fusion. Similarly, much of the professional training and experience required for the engineering aspects of fusion is already available from the fission reactor field.

The Council has concluded that, considering the significant technical progress since 1970, and given reasonable commitment of resources and effective programme, institutional and collaborative arrangements, the net generation of fusion energy within 15 years and the practical demonstration of an electricity-producing plant ten years later are reasonable goals for fusion research and development.

The Council recognizes that the costs projected for fusion development are great, and the times for its achievement long. But fusion, if demonstrated to be practical and economic, will be an enduring, ultimate energy resource. No further development of new basic energy resources for electricity production will be required. The development costs are modest when compared with current annual expenditure on electricity production and oil imports.

7. Recommendations

In view of the widespread and rapid progress achieved in fusion since 1970 and of the growth of anxiety about future energy supplies, the Council is convinced that the time is ripe to make a large and aggressive effort towards the practical demonstration of fusion power at the earliest possible date. Such an effort is needed now and could be maximized by efficient world-wide co-operation and planning in this field.

The Council therefore suggests that the IAEA make an important contribution to this goal by taking the following steps:

(a) Inviting interested Member States and regional institutions to submit to the IAEA their estimates of attainable fusion research and development schedules with the objective of helping to co-ordinate the necessary efforts for a rapid and most economic way of achieving this goal.

(b) Making its activities in the field of nuclear fusion better known to governments and to the scientific community as a whole, bearing in mind that fusion is now the outstanding major goal in nuclear energy research.

(c) Organizing a scientific session at the next General Conference of the IAEA to provide an opportunity to discuss this IFRC report and its implications.

(d) Appointing a scientist to co-ordinate and stimulate work on the environmental impact of fusion and to co-ordinate studies on future fusion reactor material requirements.

(e) Identifying problems where no large apparatuses are needed and which can be tackled by scientists in developing countries, and giving guidance to developing countries wishing to work in this area.

(f) Stimulating international co-operation by organizing and facilitating the 'circulation' of fusion scientists, establishing a 'mobility fund' for that purpose.

(g) Expanding its efforts to find the best means to establish and co-ordinate computer programs and systems for fusion research.

(h) Continuing to have the International Centre for Theoretical Physics involved in theoretical plasma physics, and broadening its work to include other scientific areas related to fusion. The participation of scientists from developing countries should be assured and their training in major fusion research centres facilitated.

NUCLEAR POWER AND THE ENVIRONMENT

There is no reason why the nuclear industry cannot provide Britain with all the power it requires, with less impact on the environment than alternative energy sources and with radiation levels so low that they will always be much less than variations in natural background radiation. This was Sir John Hill's central theme when he delivered the Sylvanus Thompson Memorial Lecture to the British Institute of Radiology, at its meeting in London on 14th April 1978.

There are so many aspects of nuclear power and the environment that it would be possible to give several quite different lectures all equally relevant to the title. There are, however, two quite separate aspects of the problem which are currently in the public eye and I would like today to concentrate on them. The first is the problem of the harmful effects of low levels of radiation which inevitably accompany any nuclear power programme and the other is the problem of radioactive waste management and the ultimate disposal of long lived fission products.

Let me deal first with low levels of radiation which accompany a nuclear power programme, and for that matter the whole radiological industry whether associated with hospital diagnosis, industrial X-ray examination and, for that matter, passenger baggage examination at our airports.

Table 1 shows the per caput radiation dose received by the population of this country at the present time. It will be seen that natural radiation is far and away the principal source of this radiation. Some of this natural radiation comes from outer space, but the majority is from naturally occurring radioactive substances on the surface of the earth. This naturally occurring radioactivity is dying away slowly with time and must have been considerably higher at the time when life was first evolving on this planet. The principal source of naturally-occurring radioactivity is now uranium 238 and its daughter products. Uranium 238 has a half-life of 4,500 million years, almost exactly the same as the life of earth itself. By this I mean that the radioactivity associated with U-238 has now fallen to half the level it was when the earth was created 4,500 million years ago.

Since radiation is harmful, it can be argued that it is unfortunate that God left uranium distributed throughout the earth's crust. However, this uranium also has beneficial effects. The radioactivity associated with U-238 is the principal source of heat in the depths of the earth and provides the energy for the building of mountains and the movements of continents. Without this continuous mountain building and earth movement the land masses would long ago have been eroded away by water and it is most unlikely that mankind could ever have evolved at all.

The level of natural radioactivity is not, of course, the same everywhere since it is largely dependent upon the nature of the rocks and the quantity of radioactive materials (essentially uranium and thorium) contained in them. In this country the granite rocks of the north and west contain significantly more uranium than the younger sedimentary rocks in the south-east and this results in differences in the total naturally occurring radioactivity levels; for example:

London — 67 mr per annum
Aberdeen — 106 mr per annum

These differences in radiation levels are substantially influenced by the materials from which houses are constructed. Houses reduce the amount of radiation coming from outside, but can increase the level of radiation to the occupants by virtue of their own contained radioactivity. In a brick house in London the level of terrestrial radiation can be as low as 30 mr per annum, while in an Aberdeen house built of granite the terrestrial radiation level can be as high as 150 mr per annum.

Table 1

Per Caput Radiation: UK 1978

SOURCE	mrem	%
Natural Background	**96**	**74**
Medical Irradiation	**~30***	**23**
Fallout	**2**	**1.5**
Nuclear Wastes	**0.2**	**0.2**
Occupational	**0.7**	**0.5**
Luminous Watches	**0.2**	**0.2**
Air Travel	**0.6**	**0.5**

***UKAEA estimate.**

But these changes are small by comparison with variations in radioactive levels in other parts of the world. If we ignore uranium mines and consider simply the activity levels on the ground we find that the highest radiation levels are usually associated with thorium deposits. Some of these deposits are very rich in thorium, approximately 10 per cent by weight. In India the thorium sands along the Kerala coast extend for about 55 kilometres and about 70,000 inhabitants live there in radiation fields of up to 2000 mr per annum, i.e. twenty times higher than in London. In Brazil some of the coastal resorts near Rio de Janeiro are built on similar thorium deposits and thousands of holiday makers flood annually to towns such as Guarapari which have similar radiation levels.

Potassium is another naturally-occurring radioactive material which contributes significantly to the dose rate received by the human body. The isotope K-40 has a half-life of 1,260 million years. It is important because it is an essential constituent of the body and contributes about 20 mr per annum from internal radiation. Having a sleeping partner incidentally increases this radiation by about 1 mr per annum.

Cosmic rays from outer space also contribute to naturally occurring radiation. The earth's atmosphere is, however, a very effective shield and reduces the level of radiation to about 28 mr per annum at sea level. At high altitudes, however, the screening effect is, of course, reduced and at 2,500 metres (about the height of Mexico City) the cosmic ray contribution is about double that at sea level. Flying in jet aircraft also increases radiation uptake. A long haul aircraft journey, say to the West Coast of the United States, will result in increased radiation of about 3 mr.

My object of discussing naturally occurring radiation at the start of this talk is not to attempt to prove that radiation is good for you, but to emphasise:

1. That radiation has always been present on the earth and that the levels have been higher in the past than they are today.

2. That there are very significant differences in the radiation levels at different places.

I would like now to turn to man-made radiation because this has become significant only recently since X-rays and radioactive materials have been exploited for man's use. In the UK (and for all other developed countries) the principal source of radiation after natural radiation results from medical diagnosis. In this country this amounts to about 30 mr per annum per caput. The average per caput radiation resulting from X-ray diagnosis differs markedly from country to country. In the less developed countries the figures are very low simply by virtue of lack of medical facilities.

The highest radiation levels are given in the United States, Sweden and Japan, and it is generally true that in spite of rapidly improving techniques radiation levels for X-ray diagnosis are increasing as more examinations are made. Japan has a quite unusual characteristic in that while the radiation levels resulting from the examination of the extremities are very similar to those here, the major source of radiation in that country comes from X-ray examination of the stomach and upper intestinal tract. This tendency is also noticeable in the United States, although not to the same extent as in Japan. The radiation levels received from diagnostic X-rays in Japan, Sweden and the United States are about three times higher than in the United Kingdom and are about the same as the natural background radiation in those countries. In other words, the medical professon has in those countries, doubled the average radiation level as far as humans are concerned.

After God and the medical profession the next largest source of radiation is the military. In the first weapons tests carried out in the atmosphere weapons of about 20,000 tons TNT equivalent contributed just over 1 kilogram of fission products and a few kilograms of plutonium to the atmosphere. This activity soon spread right round the northern hemisphere and could readily be detected as fall-out or in rainfall. The activity increased steadily with the size and number of weapons to be tested until finally, in 1962, a number of vast weapons were detonated by the Americans in the Pacific and by the Russians in the Arctic. These detonations of 1962 had a total yield of 217 megatons of TNT and a fission yield of 76 megatons. They released more activity to the world than all the other tests put together and, of course, vastly more than any peaceful nuclear programme. These explosions caused an immediate and significant increase in world radiation levels. Justifiable and profound concern was expressed by all thinking people about the resulting pollution of our planet.

But with the banning of atmospheric tests (except by the Chinese) the atmosphere has now almost cleansed itself again and activity levels have returned much nearer pre-test levels. This cleaning up process is, of course, a combination of two processes — fall-out — which is the process most important in the case of long activity and decay which is the dominant process for material of half-life less than about one year.

The dose commitment to the world's population of these tests has however been high, perhaps 150 mr to the population in the northern hemisphere and 100 mr to the world's population as a whole — an accumulative dose of perhaps 300,000,000 man rems or one year's contribution from natural radiation.

Of the other sources of radiation only three are of significance — nuclear power, industrial X-raying and luminous watches. I am not being completely facetious in comparing nuclear power with luminous watches. Nuclear power does contribute a greater radiation to the population at large than luminous watches, but they are of the same order. Wrist watches are estimated to contribute a total of about 10,000 man rem per annum in this country. The new reprocessing plant at Windscale about which there has been so much controversy is expected to discharge activity corresponding to a dose commitment of not more than 20,000 man rem per annum. About half this radiation will be due to the inert gas krypton-85 and when we are able to develop krypton removal this figure should be reduced to about 10,000 man rem. This plant will be capable of processing spent fuels from nuclear power stations equivalent to the burning of 100 million tons of coal per annum.

To get a full picture of the total radiation resulting from the nuclear industry in this country we must, however, consider all stages. The processing, enrichment and fabrication of uranium into fuel elements contributes a negligible routine dose as far as the public is concerned. As far as the workforce is concerned the degree of protection provided is that appropriate to a chemical industry dealing with a toxic product and radiation levels have only been a problem in instances of plant failure or failure of operating procedures leading to leakage or dust.

In the nuclear power stations the core of the reactor is intensely radioactive. This is, of course, where the fission takes place and is far and away the most active part of the whole nuclear industry. It is, however, not necessary to approach the core during operation and all movements of fuel or controls are carried out remotely. Furthermore the active nuclear fuel and all the fission products are clad in metal tubes and the release of activity from the fuel elements is therefore minimal. The discharge of activity from nuclear power stations to the environment is therefore small. It corresponds to the activity associated with corrosion products in the fuel element ponds, cooling air which has become slightly activated by neutrons escaping from the core, and small quantities of tritium and sulphur 35 which are produced by neutron capture by trace impurities of lithium and chlorine in the core graphite.

The dose to the public from normal operation of nuclear power stations is therefore very small. It is in fact substantially less than from the fuel reprocessing plants. The total dose commitment to the British public from the British nuclear power programmme is at present approximately 0.5 mr per annum and this will be reduced substantially when new plant comes on stream at Windscale. This dose commitment is much smaller than the variations in natural radiation levels or variations in the average dose to the population at large resulting from changes in attitudes to medical diagnosis.

This is not to argue for lax rules in the nuclear industry. Under normal operating conditions the discharges to the environment are such that the irradiation levels to the public are very low indeed. But it must be remembered that nuclear power stations and reprocessing plants contain hundreds if not thousands of megacuries of activity and very stringent precautions are taken to ensure that these quantities of fission products are not, through accident, released to the environment.

It is perhaps at this point worth mentioning the rules which apply to radioactive wastes and emissions in this country. 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 Command 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 county shall not receive an average dose of more than 1 rem per person in 30 years.

(iii) To do what is reasonably practicable, having regard to cost to reduce doses far below these levels.

These regulations are accepted by the nuclear industry as a fair interpretation of the ICRP recommendation and the nuclear industry works well within them. It is however interesting to note that the ICRP recommendation for the maximum dose to be received by any member of the public is 500 mr per annum. Although these rules do not apply to natural radiation or radiation given for medical reasons, it is interesting to speculate how they would be interpreted if God had created the thorium sand deposits along the Sussex cost instead of along the coast of India and Brazil where they contribute up to 2000 mr per annum.

There is no doubt that the nuclear industry operates under a particularly powerful microscope and in the foreword of the recent report by the Health and Safety Commission on the hazards of conventional sources of energy it states:

"In all countries with a well developed nuclear industry the work started as a Government enterprise in which money and resources for health and safety studies, if not unlimited, were at least freely available. In addition, the consequences of ionising radiation were fairly well understood even 20 years ago and to this has been added the increasing experience available from such studies as those on the survivors of the weapons explosions at Hiroshima and Nagasaki. There is perhaps less understanding of the possible health effects of conventional energy sources largely because detailed studies have not been thought necessary.

"Against this background the process of health and safety assessment in the nuclear industry has developed along characteristic and possibly unique lines. In particular the level of protection achieved has been so high that there has been no real possibility of there being sufficient effects on the health either of the workforce or a fortiori of members of the general public to provide information on the consequences of the exposures to radiation and radioactive materials. Assessments of possible effects have therefore been based on a cautious extrapolation from levels of radiation dose known to produce effects in man down to those which actually occur in practice. In the case of members of the public this extrapolation involves factors in excess of a thousand. These very small exposures are indeed much less than the variations in the natural exposure to background radiation.

"It has been conventional to assume that these very small doses may produce deleterious consequences if the number of people exposed is large enough even though the risk to the individual is genuinely trivial and certainly never going to be demonstrable. By contrast almost all work on conventional pollution such as that arising from conventional sources of energy has been concerned with demonstrating whether or not observable effects are detectable at levels currently found in the environment or occasionally extrapolating downwards by one, or at the most two, orders of magnitude from levels which are known to produce observable effects in man. Unless agreement can be reached of a consistent approach comparisons of the assessment of health and safety effects between nuclear and other sources of energy will always be unrealistic".

The information that we have on damage or injury by radiation is mostly derived from observable effects of high levels of radiation which resulted in the early days from the use of luminising paint and more recently the effect of X-ray therapy, the history of survivors of Hiroshima and Nagasaki and the effects of large doses of radiation received by workers involved in nuclear accidents.

From these large doses it is possible to deduce some correlation between the dose received and the increased probability of a cancer starting in subsequent years. This correlation is approximately 10^{-4} per man rem. By this it is meant that a dose of shall we say 100 rem would result in an increased probability of cancer of 1 per cent in subsequent years. What is not clear is whether this correlation is linear; does, for example, 1 rem give an increased probability of 10^{-4} of a cancer being produced in subsequent years? So far it has not been possible to establish whether or not this extrapolation is accurate because any figure such as 10^{-4} is completely swamped by the statistical variations of the population and other factors which can cause or prevent cancer.

While it must be accepted that all radiation — even at low levels — is damaging, we might nevertheless expect that low doses would be less damaging than a linear extrapolation would predict. This is almost certainly true in respect of cigarette smoking.

On the other hand there would appear to be an almost direct relationship between the amount of meat consumed and the incidence of cancer in the large intestine. Other factors such as lack of adequate roughage in the diet may, of course, be just as important.

For the public at large the average radiation received from the nuclear industry is so low that there is clearly no possibility of deducing anything about the effects of low levels of radiation from general health and mortality statistics. For radiation workers however the exposure to radiation can be up to 50 times higher than the natural background and exposures of up to 10 times the natural background are fairly common. Numerous statistical analyses have been carried out to try and ascertain whether these radiation levels can be shown to have any measurable effect on the health or longevity of radiation workers, and, in particular, whether the linear extrapolation hypothesis is valid.

Although from time to time workers in various parts of the world claim to have demonstrated that some particular cancer has a higher figure than would be predicted by the linear damage hypothesis I have not yet seen any convincing analysis. It is, of course, even more difficult to prove from mortality statistics that low levels of radiation are less damaging than the linear hypothesis would predict.

Table 2

	Cancer of Lung	Cancer of Stomach	Ischaemic Heart Disease
Northern region	**114**	**123**	**115**
Yorkshire and Humberside	**102**	**101**	**112**
North West	**110**	**117**	**111**
E. Midland	**90**	**90**	**98**
E. Anglia	**89**	**90**	**84**
South East	**103**	**89**	**91**
South West	**82**	**94**	**93**

In the recently published recommendations of the International Commission on Radiological Protection it states "There are radiobiological grounds for assuming that the dose response curve for low-LET radiation will generally increase in slope with increasing dose and dose rate . . ." and "For many effects studied experimentally, the response in this range (up to a few hundred rad) can be represented by an expression of the form $E = aD + bD^2$" and later "The use of linear extrapolations from the frequency of effects observed at high doses, may suffice to assess an upper limit of risk, with which the benefit of practice, or the hazard of an alternative practice — not involving radiation exposure — may be compared. However, the more cautious such an assumption of linearity is, the more important it becomes to recognise that it may lead to an overestimate of the radiation risks, which in time could result in the choice of alternatives that are more hazardous than practices involving radiation exposures. Thus, in the choice of alternative practices, radiation risk estimates should be used only with great caution and with explicit recognition of the possibility that the actual risk at low doses may be lower than that implied by a deliberately cautious assumption of proportionality".

The linear hypothesis is of importance to the nuclear industry in two ways — to determine compensation payable to workers who have accumulated a significant radiation dose and die of a form of cancer and as a basis for plant design.

A proportion of workers in any industry contract cancer, but in the case of radiation workers the linear damage theory can be used in the nature of an upper limit to establish the probability of the cancer being caused by radiation. Take for example a worker who has received a cumulative dose of 10R. Using the 10^{-4} correlation we would calculate an excess probability of all forms of cancer of 10^{-3} in subsequent years. The probability of a man of say 35 dying of cancer of the lung over a 30-year period is however much higher; 3.5×10^{-2} over the period from 35 to 65.

But if we consider a very rare form of cancer — myeloma in young people — the probability of contracting this disease from natural causes is 6×10^{-5} between the ages of 25 and 44. If such a person had received the same integrated dose the linear hypothesis could set the upper limit of this being due to radiation sufficiently high fr compensation to be payable.

From the point of view of plant design, it is extremely important for the nuclear industry to know to what extent the linear hypothesis is valid, not of course to avoid paying compensation to unfortunate employees who die of rare forms of cancer but so that realistic estimates can be made of how much money should be spent to reduce man rem exposure not only to our employees but to the public.

Again, referring to the Recommendations of the ICRP, it says in paragraph 130 "In these recommendations, therefore, the Commission does not propose dose limits for populations. Instead it wishes to emphasise that each man made contribution to population exposure has to be justified by its benefits . . . ." "The limit for irradiation of a whole population is thus clearly seen as the total reached by a summation of minimum necessary contributions and not as a permissible total apparently available for apportionment".

In the nuclear industry hundreds of millions of pounds are being spent on establishments such as Windscale on the basis of a hypothesis which is assumed to be linear right down to the origin. Almost every other industry assumes that their damage curve has a cut-off point at some level below which no damage occurs. This anomaly may well be leading to expenditure on nuclear plant to achieve minimum discharges to the environment, when the same money — and it is effectively all public money — could produce much greater benefits if applied to other pollutants.

I have discussed at some length the difficulty in obtaining information on radiation damage from the health and mortality statistics. It is not that there is any shortage of statistics, the real problem is that the variations in the statistics both for different occupations and different parts of the country are vast compared with anything that could be attributed to radiation.

I have picked out from the latest mortality statistics (Table 2) published by the Registrar General the standardised mortality rates for three common causes of death — cancer of the lung, cancer of the stomach and ischaemic heart disease. I have selected these particular causes of death because the numbers involved are large and therefore the statistical accuracy is much better than for rarer diseases. The figures given correspond to an average of 100 for the whole of England and Wales.

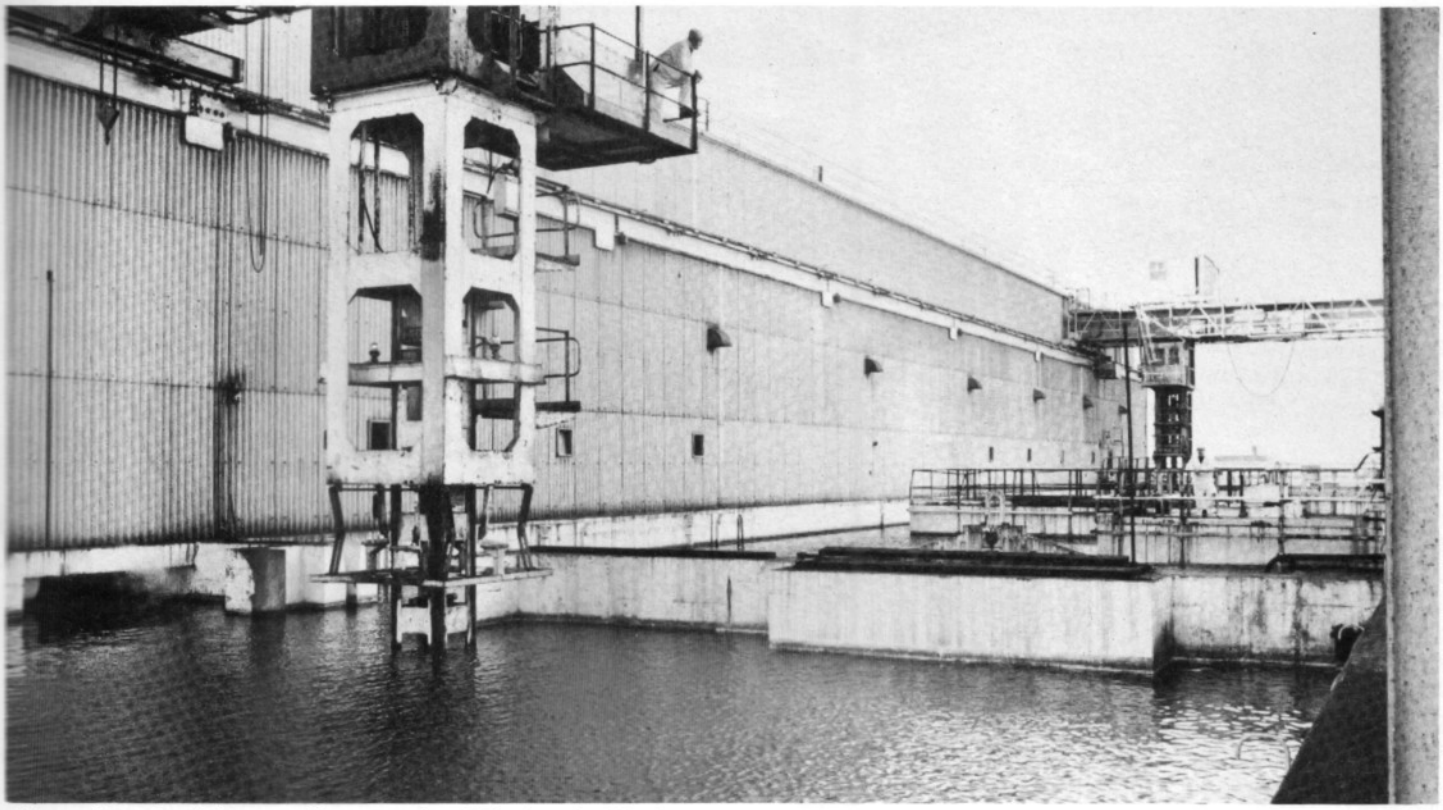
We see even greater variation when we study the mortality statistics of different industries. Let me give a few examples, again using the figure of 100 as standard for England and Wales:

Table 3

Professional occupations	**79**
Farmers	**91**
Woodworkers	**96**
Electrical workers	**104**
Construction workers	**111**
Forge and foundry workers	**122**
Miners and quarrymen	**144**

The only conclusion I want to draw from these two tables is the fairly obvious one that you get higher mortality figures in industries that are harsh and dirty and the same is true of those parts of the country where living conditions tend to be harder. But there may well be other reasons related to water supply, eating habits, social habits and so on. But with such large variations in different regions and different occupations is enough analysis being given to other pollutants or deficiencies that can influence the health and life expectancy of the population by comparison with the microscope focussed upon the effects of low level radiation?

It seems to me after studying the statistics produced by the Registrar General that if we want to improve the health and life expectancy of the population we want to move in the direction of cleaner and more professional industry and away from the dirty, dusty industries who employ unskilled manual workers. It is in this context that we, the nuclear industry and you the radiological industry, make our



View of part of the cooling pond at Windscale Works

contribution in spite of using radiation as one of our principal instruments.

The fission products

But we in the nuclear industry suffer a further disadvantage by comparison with the radiological industry. We have to deal with long life fission products whereas the radiographer can turn off the X-ray beam at the touch of a switch. I would like therefore to conclude by saying something of the treatment and storage of fission products in the nuclear industry.

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, and it is readily absorbed into the body. On the other hand the fuel can be left 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 to process. Ruthenium is an element with many possible valencies and whatever you do to effect a separation some of it always turns up in effluent streams one would like to discharge.

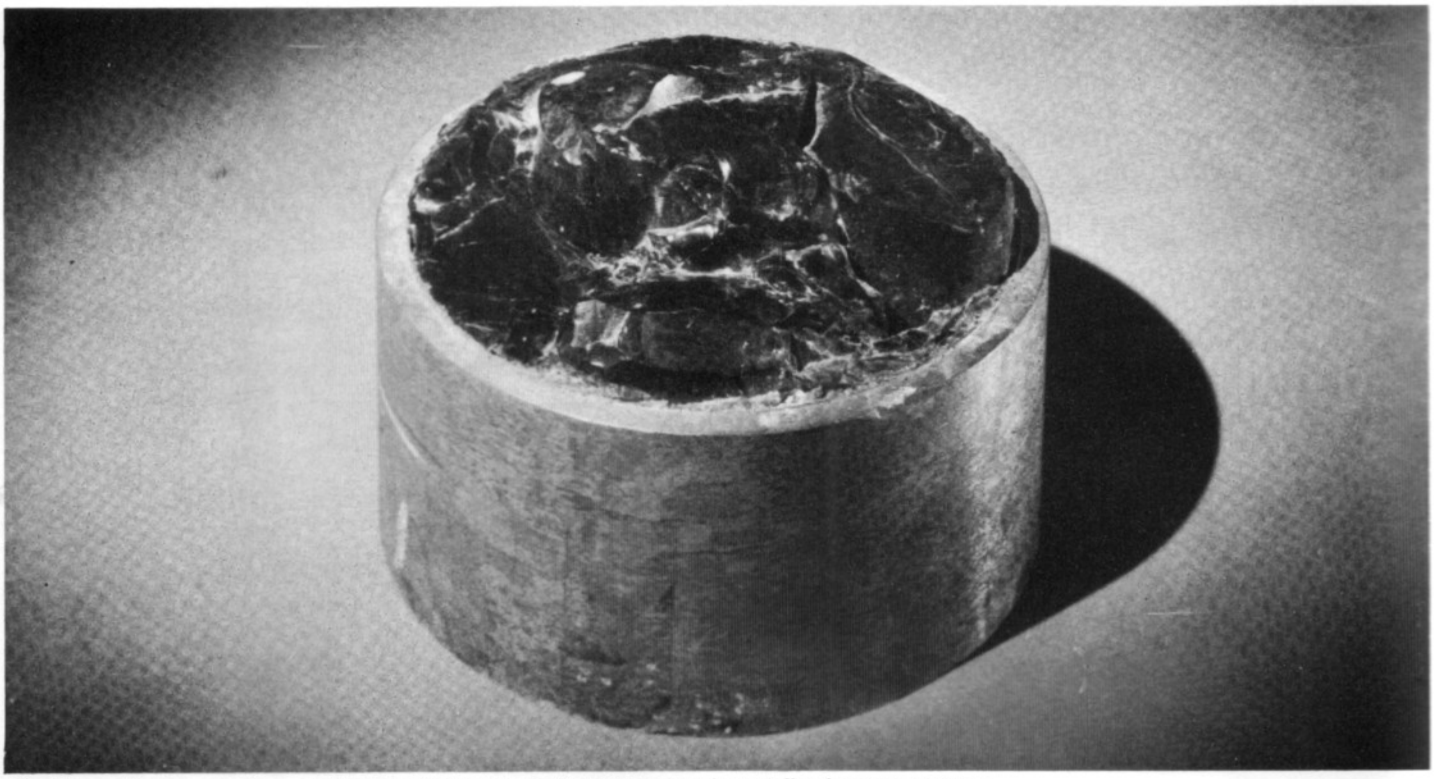
The most difficult fission products are, however, strontium 90 and particularly caesium 137. These are both abundant with yields of about 5 per cent and have half-lives of about 30 years. This is short enough for them to be very active and yet it is too long to be able to wait for them to decay away. 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 or even 1,000,000 years but these are present in very 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.

If one looks at how the activity of fission products decays with time, the important things one notes 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 demonstrated by the 30 year halving time of Cs137 and Sr90 and finally the very small residual activity of the weak long-lived products.

The fission products after separation from the plutonium and uranium, emerge from the reprocessing plant as a solution in nitric acid. It is at present concentrated as far as 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 and means are available to transfer liquors from one tank to another if a leak developed.

Although the storage of these high 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 require less supervision. It is therefore planned to glassify these wastes by mixing them with a



Section of a vessel containing vitrified waste with simulated fission products

slurry of the raw materials of glass and then raising the whole temperature to about 1000^{0}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 in glassmaking 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. The only question is what is the best way from the point of view of cost, ease of operation and maintenance.

Prototype plants are now under construction and in about eight years' time we shall have a first production plant in operation. These plants will produce glassified waste in stainless steel cylinders, each cylinder containing about 1 ton of glass which, in turn, will contain about 1/5 ton of fission products. Our nuclear programme is now equivalent to about 15 million tons of coal per year and produces about 5 tons of fission products which when glassified will amount to 25 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 be stored in deep ponds of water for another 20 to 30 years until the heat output is diminished sufficiently for the next stage of disposal.

These cylinders have to be kept away from man for about 500 years until all the caesium 137 has decayed. We are therefore 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. For the UK, granite structures would appear to be the most suitable because unfractured granite should be free from water and only percolating water could possibly transport activity back into the food chain and then back to humans. Clay and salt deposits are other possible formations which are being studied.

There is not really any great hurry to find an ultimate disposal site. If we bury fission products when they are still relatively young we will have problems of heat dissipation 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.

I would not like to give the impression that there are no problems in the nuclear industry. No large industry would claim that it is free of all problems. The amount of radioactivity in the core of a large power reactor is of the order of a thousand millions curies during operation. Very stringent precautions have to be taken to ensure that this activity cannot by accident be discharged to the environment. Even when the reactor is shut down the fission products in the fuel remain intensely active and all parts of the plant near the core become active and must be maintained remotely.

The reprocessing of nuclear fuel is similarly a difficult operation both because of the difficulty of the maintenance of a highly active plant and because in relation to the throughput of the plants much tighter controls are imposed upon the discharge of radioactive effluents than upon the discharges of most other industries.

But provided plants are properly designed and operated to high standards, there is no reason why the nuclear industry cannot provide this country with all the power it requires. Moreover it can do this with less impact upon the environment than that of alternative energy sources and with radiation levels to the population so low that they will always be much less than the variations in the level of natural radiation.

"ENERGY TODAY AND TOMORROW"

This was the theme of a conference organised by the National Federation of Womens' Institutes, the National Union of Townswomens' Guilds, the Electrical Association for Women and the Womens' Gas Federation and Young Homemakers, held at Central Hall, Westminster, on 12th April 1978. This report is by Len Brookes of the Authority's Economics and Programmes Branch.

This conference was chaired by the Rt. Hon. Baroness Pike, Chairman of the Womens' Royal Voluntary Service and was intended to inform members of womens' organisations about the energy problem. About 1000 people attended — the greater part of the main hall was filled and there were some spectators in the gallery. The conference was open to the public.

The speakers were stimulating and struck just the right level, and the audience was wide awake and responsive. The sole major defect in the arrangements was that no opportunity was given for making points from the floor. Instead, the audience was invited to write questions down on small forms so that a selection of these could be answered by four of the speakers acting as an 'open forum' in the latter part of the afternoon. The questions were read out, without attribution, by Baroness Pike. There was no opportunity, in some parts of the hall, to ask questions on the presentations made by the last two speakers — Dr. Peter Chapman and Sir Frederick Catherwood.

It was also a rather odd omission, given the present level of interest in nuclear energy and especially in the fast reactor, that no speaker dealt specifically with nuclear energy — although most speakers, including the Prime Minister, who made an excellent opening speech, made some passing reference to it. In the event, the principal statement of support for nuclear energy and the main attack came from unexpected quarters. Sir Monty Finniston, best known as a past chairman of British Steel, was down to speak against energy waste but volunteered that it was high time everyone stopped being absurd about plutonium and accepted the benefits of the fast reactor, and that he could not begin to understand President Carter's present stance on nuclear energy. Later, Sir Frederick Catherwood, Chairman of the British Overseas Trade Board, when speaking on "the moral dilemma" made an attack on the fast reactor, urging the audience to make it clear to the Government that they were not prepared to accept a technology simply because it conferred economic benefits. There was no opportunity to reply directly to this or to correct some of the misapprehensions on which it was based, but a true perspective on this and other matters was largely restored at 'open forum' time, mainly by Dr. John Cunningham, the junior Minister for Energy with special responsibility for energy conservation.

In opening the conference the Prime Minister went well beyond what would ordinarily be expected in a purely opening speech and gave an excellent account of the energy situation and the aims of energy policy, explaining, in an easily understood way, the importance of energy in the industrial sector and, particularly as regards electricity, in the lives of ordinary people. He referred to the decision to order further nuclear power stations and mentioned the great potential for nuclear fuel saving offered by the fast reactor "itself a controversial development". He also took the opportunity of announcing a plan for Government grants of up to £50 to householders to help meet the cost of insulating their houses. (The full text of the Prime Minister's speech is reproduced at the end of this report).

Mr. Michael Posner, one time economic adviser to the Department of Energy and currently a member of the Standing Commission on Energy and the Environment, explained how the energy problem looked to an economist. It manifested itself, he said, in terms of prices: whereas only a few years ago most economists had expected low energy prices to continue more or less indefinitely, most of them now expected prices to rise steadily. We should be on our guard when most economists seem to agree with one another — they had done this in the past and been wrong — but nevertheless it would be best to plan on the assumption that energy prices were much more likely to rise than stay level or fall.

Dr. Freddy Clarke, Research Director (Energy) at Harwell, spoke on the energy options, but explained that he intended to confine himself to what the so-called alternative energy sources had to offer. He combined his expression of support for work on these sources with warnings about the limited contribution that we could expect from them before the end of this century. He dealt specifically with the fallacy that they would quickly produce large returns if only large funds were devoted to their development. He said he was constantly going the rounds ensuring that the research teams had adequate funds at their disposal and was in some danger of being accused of urging people to spend money that they might not otherwise spend.

Sir Monty Finniston's presentation was mainly devoted to the importance of avoiding waste of energy but he made a number of other important points. His reference to plutonium and the fast reactor has already been mentioned. In addition, he disposed of any idea that our own energy reserves make it easier for us than for other countries when it comes to making long-term energy plans. He said it was ridiculous to see the energy problem in anything other than worldwide terms.

Dr. John Cunningham's presentation was concerned mainly with the importance of avoiding sloppy energy habits and what could and could not be done to get industrialists and private consumers to do the right things. There was no way, in a democratic society, of forcing people to do things for their own good. They could be encouraged towards sensible practices and they could be shown the consequences of their actions. The Government's measures and plans for what he called 'energy labelling' were good examples of what could be done. Motor car manufacturers must now state the petrol consumption of their products under certain controlled conditions; and manufacturers of electrical appliances must state the power consumption clearly on their products. But this did not prevent people from using the appliances wastefully or driving their cars in ways that resulted in high fuel consumption.

Both in his main presentation and at 'open forum' time he drew attention to the trade-offs in industrially developed societies. Was it better to leave future generations with the small problem of looking after some nuclear waste or the very much larger problem of having no fossil fuel reserves? If people wanted ample water supplies or low cost fuel and power, they had to accept the environmental consequences.

Dr. Peter Chapman, Director of the Energy Research Group of the Open University, challenged what he saw as three elements in the official energy policy — a commitment to growth, a commitment to a materialistic society, and the perpetuation of existing institutions. He believes that human welfare can be improved without raising gross national product, if people are prepared to revise their ideas about what is desirable; that, in any case, the current level of GNP can be maintained at a much lower level of energy consumption — especially if we stop using electricity for purposes for which it is not necessary; and that the present pattern follows from the nature of the decision-making and energy-producing institutions rather than deriving from what is best for society. He claimed that among his friends, it was the richer who were least happy and he attempted to persuade his listeners to reject gross national product as a measure of welfare.

During the 'open forum', Dr. Cunningham countered by saying that he believed most people were keen to maintain and, if possible, increase their material prosperity and that the trouble with long-lasting products was that they were expensive. He could, even today, buy a motor car that would probably last him all his life. It was called a Rolls Royce!

Sir Frederick Catherwood, in his short presentation on "the moral dilemma", concentrated on what might be called the intertemporal inequalities. Sir Frederick argued that each generation was the custodian of the planet's resources for ensuing generations with the obligation not to exhaust scarce resources or to leave dangerous wastes. It was from this starting point that he developed his comments on the fast reactor.

There was, right at the end of the proceedings, a short unscheduled intervention by a speaker from the European Economic Commission in Brussels, outlining Community energy policy. He reminded the audience of the extreme dependence of the Community as a whole upon external sources of fuel. Much of the Community's energy policy was directed towards tackling this problem: and they were in particular examining ways in which the energy/gross national product relationship might be uncoupled.

The main points made in the concluding 'open forum' have already been mentioned. It was generally noteworthy for the convergence of view that emerged, and which presented a much less confusing final picture to the audience than is usual on these occasions. Some of the credit for this must go to Peter Chapman, who managed to get his points of disagreement across without creating a confusing wrangle. It was altogether a very successful day in terms of casting light where there was darkness.

PRIME MINISTER'S ADDRESS

The following address was given to the conference by the Prime Minister, the Rt. Hon. James Callaghan MP.

Thank you for inviting me to open this conference today. I should like to congratulate you and express my appreciation to the National Union of Townswomen's Guilds for organising this extremely well attended gathering.

This is a most significant conference for you will be talking about the best way of using and developing our supplies of energy — a problem that was discussed only in expert circles 10 years ago but which since the Middle East War of 1973 has come home to every family in the land. We have all suddenly become aware that our conventional sources of energy are exhaustible, that they can be cut off and that they will not prove sufficient to meet the ever-growing demands of the world's population.

So what are we to do? The Government has published its views and called for a public debate so that we can make our choice while there is still time. Today you are responding to that invitation to look into the future and what you will say will be of the very greatest importance for your children's future.

To assist you in making up your minds, you will hear a number of most distinguished experts, and a Government Minister Dr. John Cunningham of the Department of Energy, who had a special role in preparing the Government's views, will be able to tell you about our thinking. This will be a real exercise in democratic participation.

From my knowledge of the experts, their views will differ. There will be plenty of argument because the future is bound to be uncertain. But we must come to some conclusions. For example it can take up to nine years to build a power station, from the decision to go ahead to the day it can be commissioned. But I believe that there is one part of the energy scene which will command general agreement: that is the need for the efficient and economical use of energy; how best to avoid wasting energy so that our supplies will go further.

The world has been spendthrift in its use of energy in the past, and against our knowledge that our supplies are daily getting scarcer and dearer it makes sense to use them sparingly.

So today I choose for my contribution to your discussion the subject of how to save energy.

The use of energy since 1945 has transformed our way of life, not only in industry, but also in the home. The washing machine, the spin-dryer, the dish-washer, the refrigerator, the freezer, the mixer and the motor mower were hardly known 30 years ago. Then there is the motor car, then owned by less than one family in ten, now by one in two.

Things that were luxuries have become conveniences and are now

The Prime Minister, The Rt. Hon. James Callaghan addressing the conference

being regarded as necessities. Our daily lives depend on regular and reliable energy supplies. For when energy supplies are interrupted, we appreciate that it is not only the conveniences and the luxuries that depend on it; society has organised itself in such a way that a major disruption of energy supplies is a threat to the essentials of life.

Although we have known short-term interruptions, we take regular supplies of energy on tap for granted, and expect them to continue indefinitely. For the short-term, this is perfectly reasonable. We have, for example, 300 years' reserves of recoverable coal at present rates of production. We are self-sufficient in natural gas for the time being. Within a couple of years our production of North Sea oil will match our consumption. And last year about 14 per cent of all the electricity we used was generated in nuclear power stations. This proportion will rise to 20 per cent by 1980 and we envisage the careful expansion of nuclear power in the years beyond.

So why are Governments concerned about energy for the future? The answer is very simple. The fuels I have mentioned are fossil fuels. Coal, gas, oil can obviously not be replaced once they are used.

Even uranium itself will not last for ever, though there is an enormous amount of additional energy locked up in it to which we can gain access through the fast reactor: itself a controversial development.

The fuels we are using up today were laid down geologically millions of years ago, and are, literally, irreplaceable. The world is exploiting these irreplaceable reserves at an ever-increasing and alarming rate. For instance, oil consumption has increased nine-fold since the war — in proportion, someone who then drove from Southampton to London is now driving to John O'Groats. So far as we can now tell, it is at least possible that conventional oil and natural gas could be largely exhausted within the lifetime of a child born this year.

I am always very sceptical when people try to forecast what will happen. They are so often wrong especially in economic matters. But it does seem reasonable to expect that, as the years go by, energy will become scarcer and much dearer. We cannot tell whether this will happen gradually, or whether we are to expect some sharp rises in the cost of fuel, rather like that which happened in 1973.

You may feel that scientists will find some new cheap method of supplying practically unlimited energy. Indeed, they may. But there is no way we can be sure of that. The energy of the winds, the waves, the tides, the heat of the sun, the heat inside the earth, nuclear fusion — all these have the potential to make useful contributions to our energy supplies, and some a great deal more.

But none of these prospects is yet proven and no Government could prudently base its policy for the future on the assumption that one of them will turn up trumps.

Another reason why we have to look so seriously at our energy use is the enormous inequalities, in energy as in many other things, between the developing world and the industrialised world.

For every unit of energy used by the average citizen of India, the average person in the United States uses 50. In Britain we use 24, in the Soviet Union it is 25, in Portugal 4.5, in Kenya 0.8 and in Ethiopia 0.15.

Now I know from my discussions with President Carter that the United States Government recognises that the American appetite for energy has to be moderated. But as the standard of living of men and women in the under-privileged countries increases, as we expect it will, they are going to use much more energy than they do now. That will increase the rate at which world supplies are used up and will put on pressure for rising prices.

I am sure you are convinced already of the need for the maximum energy saving. I am not suggesting that we change our life style dramatically overnight. We cannot, and we need not. Britain is relatively fortunate by comparison with many other countries without our supplies.

But whereas the supply of energy is a matter that the individual citizen is perhaps entitled to look to Governments and the energy industries to provide, prudent and economical use of energy is something we can all help with.

In a democratic society like ours, the Government cannot dictate how we use energy. It can encourage us to use it sensibly, and try to influence economies through a number of ways including raising prices and taxes. But here we have to be careful. A year ago the Government came forward with a proposal to increase the petrol tax by 5p a gallon. And we got our fingers burned. Parliament threw the proposal out.

At the present time President Carter is in difficulties with his Congress about his proposals for fuel economy. So we haven't got the message across to people yet.

Just before Christmas the British Government made another attempt. This time we extended our programme to save energy in hospitals, schools, offices and council-owned houses by improving insulation and the control of heating, and so set an example. The experts have calculated that if we invest £320 million over four years (i.e. £80 million a year), and go on at that rate for ten years, we shall save energy worth around £700 million a year at present prices.

This brings me to some suggestions and proposals.

The first is that we use roughly a quarter of the energy consumed in Britain today in our homes and housewives have a great influence in controlling its use.

The home that is not insulated, does not enclose its tank or lag its pipes, has no draught-proofing, uses appliances thoughtlessly, is wasting energy. It will cost you more and it is anti-social.

We already have a programme for insulating public sector housing, and as you will have heard, the Chancellor yesterday announced our intention to make funds available to encourage insulation by the private householder. We are discussing the details of a scheme of grants with the local authority associations, but we intend to legislate urgently so that the scheme is in force before next winter. The scheme will cover loft insulation, pipe and tank lagging in the roof space and hot water tank lagging. Occupants, whether owners or tenants, and landlords will be able to apply to their local authority for a grant of 66 per cent of the cost of these insulation measures, with a maximum of £50 a house. I hope very many people will take advantage of this scheme to insulate their homes.

Second, you who are drivers of motor cars use a large quantity of the oil consumed by transport. New legislation just in force will provide comprehensive comparisons of the fuel consumption of new cars to be displayed on new cars in showrooms. For the future we should have cars more economical in using petrol and this is a step on the way.

Many of you here today will be concerned with conservation in industry as well as in the home, either directly because you are in business yourselves or indirectly because your husbands are.

I ask you to use your influence to make sure that industrial and commercial management and trade unions at all levels take energy conservation seriously. This will help the country, save money for the firm, make it more competitive and leave something over for the next generation.

If they ask you where they should go to get advice tell them that there are information, advisory and even subsidised consultancy schemes to help them cut out waste and they can find out about them from the Department of Energy or regional offices of the Department of Industry.

The Chancellor spoke in the Budget yesterday of a new scheme to be introduced shortly that will give considerable financial help to companies who make investment in certain types of energy-saving equipment. This could save many millions of pounds a year for industry if it is taken up.

Finally, I ask you to act as propagandists in this cause. Britain's energy supply problem is not as urgent as some other countries' but we must look to the medium and long-term. We should educate our children now to have a greater respect for energy than we have had in our generation.

Some economists argue that people won't really listen until energy is so expensive that everyone will have to do without. That is neither a sensible nor a humane solution.

Old people, in particular, are already facing difficulty with their fuel bills and the Government has been helping those receiving supplementary benefits.

So we must handle it in a different way. I have a great deal of confidence that over a period people will learn to use energy more economically, to save it where they can and to get good value from what we do use.

You are now going to hear and question some very distinguished experts, who will talk about matters other than saving energy. How it is to be developed for example; what type of energy we should develop and many similar problems. There are some difficult decisions but I am sure that after today you will feel better informed and I believe more concerned about the future.

Once again I congratulate the four organisations who have made the arrangements and wish the Conference every success.

BOOK REVIEW

"Must the World run out of Energy?"

A review by James Daglish, UKAEA Information Services Branch

It is a pleasure not often given to an author to review a booklet in which his own work appears. I am pleased, therefore, to draw attention to the winter 1977-78 number of the Crown Agents' **Quarterly***, which concerns itself with the world's energy future in the post-oil era and the extent to which so-called alternate energy sources might contribute toward meeting world demand.

I stress **world**, for it is all too easy for those concerned with the energy debate to use spectacles blinkered not only as to the contributions which might be made by sources other than their favourites, but as to the contributions they might make outside any given nation's borders. Secondly, these blinkered spectacles seem often not to correct the planners' most prevalent defect of vision: myopia. Forecasts made today, if they are to have any real chance of passing the test of time, have to concern themselves not just with the next 10 or 15 years, but with periods in excess of 25 years — that is, they have to pay at least some heed not merely to assuring energy supply **to** the end of this century, but **past** it, until sometime in the 21st century. At that, the forecasts must then contain at least some element indicating that the forecaster realises that the world will, we hope, still be alive and well and consuming for many years on from then.

That said, one can begin to appreciate the emphasis given increasingly to the so-called "renewable" sources of energy — those which will not, sooner or later, come up against constraints imposed by a limited resource base. Oil is already nearing that point; without the fast reactor, so may the nuclear

*"Must the World Run out of Energy?" The Crown Agents for Oversea Governments and Administrations, London, 1978. £1.50

industry; coal exists in large quantities but is also valuable as feedstock for petroleum product substitution and for conversion like oil to a bewildering variety of chemical products from dyes to plastics and pharmaceuticals; and so on.

In a keynote article in the **Quarterly** Noel Bott, a Crown Agents' consultant, says the nature of the problem to which mankind has now to address itself is "surely unique in human history. It is the global task of assuring a cheap and continuous flow of energy in the massive and increasing quantities which all modern societies need — in both the industrialised and the developing world — not only for the continuity of life as we know it but even for survival itself". Bott notes the critical historical dependence of "standard of living" on the usage of energy, and points out that "up till now the world's overall energy balance has depended on the availability of oil to make good any shortfall from other sources such as coal, gas, hydro and nuclear . . . The world's energy demand has risen from about 10 million barrels per day oil equivalent (MBDOE) in 1900 to 115 MBDOE in 1970. We have passed from the almost complete dominance of coal to that of oil. This pattern will continue, providing the OPEC countries do not lower their present production 'ceilings' or apply punitive price increases. But in relatively unconstrained demand conditions the energy 'gap' will continue to widen to an (estimated) 27 MBDOE by year 2000. To make up this shortfall we need the equivalent of the electrical output of 2500 one-million kilowatt power stations — each driven by some prime energy source **other than oil**". (His emphasis). Bott sees this gap arising even on a low-growth scenario; at a 5 per cent annual rate of growth in demand the gap would amount, by his reckoning, to 127 MBDOE, or three times present total oil production.

Further, he argues that despite the "tremendous potential" of coal and nuclear power, time precludes either of these sources making a sufficient impact to close the gap. The contribution he assumes from the "alternative" sources, wind, wave, geothermal, solar and "bio-mass conversion" is still low by the end of the century; to prevent the gap being felt in a series of major crises there needs therefore to be at least 27 MBDOE "negative contribution" from savings and the more efficient use of existing energy resources.

Bott is surely on safe ground when he writes that " the only correct world policy has to be to exert a maximum effort into developing every possible option in an attempt to reduce the time required to mount and execute the large engineering projects that are needed to produce extra energy". Teutonic as his dictum sounds, he may have less support in his urging that "each government, therefore, should set up its own special energy ministries in order to achieve energy self-sufficiency across a broad number of schemes", and "there is a case for setting up a World Energy Council financed by research funds from the world's aid organisations. This could bring together all existing research and inaugurate pilot schemes which might be beyond the means of individual countries". "Jaw jaw" is surely better than "war war"; but the history of world co-operative ventures of this kind does not give one great confidence that such a Council would have a measurable impact: at least in the time available to it to do its work. Bott himself acknowledges that not only time but money is required to mount large industrial engineering projects — and "it is clear that a vast number of projects will have to proceed simultaneously which, in turn, means that they will have to be identified, surveyed, assessed, designed and promoted within the next five years at latest".

Co-operation does seem likely to be the key — but co-operation on a longer timescale, I would suggest, than Bott feels necessary. In other articles in the **Quarterly** authors review the contribution which might be made toward meeting energy demand by solar sources (including bio-mass conversion); wind power; wave power (one of the many alternate energy sources being studied actively in the UK, and supported here by a description of a research project which is being carried out in Mauritius); geothermal energy (an article contributed by Dr. John Garnish, of the Energy Technology Support Unit at Harwell); nuclear energy; and the possible contribution of conservation.

In my article I argue that nuclear energy's contribution is likely to remain greatest in the most advanced nations. I say this not in a spirit of industrial paternalism, but recognising that nuclear power — like many other advanced technologies — benefits its users most when deployed on a large scale. True economies begin to be made when the power station is of 600 megawatts or more; modern stations in Britain are today of around 1250 megawatts. Such a station could not easily be used in a country having a decentralized, rural economy. Better by far for those nations which are already some way down the industrial road and who have experience of nuclear technology to build on their experience, thereby lessening their demand for oil and indeed for other fuels — at the same time undertaking vigorous development of **all** alternative sources of energy and of means of energy conversion and conservation. (Perhaps I should add that even in the **Quarterly** my piece runs with a footnote to the effect that the views expressed are my own.)

Prof. M.W. Thring, of Queen Mary College London, suggests in the final article that the problem now faced by the world is two-fold:

"How can we provide 8000 million people" (say) "in the next century with all the good consequences of the industrial revolution using not more than the present world average figure of 1.8 TCE (tons of coal equivalent) per head per year?

"At the same time, we must find how to provide twice as much total energy as the world has at present, and to avoid the bad consequences of the industrial revolution such as pollution . . . inhumanly repetitive work, traffic jams, noise, stress and built-in obsolescence".

Prof. Thring says he believes we can find the engineering solution to both these groups of problems, "provided we can persuade enough thoughtful people to take a long-term look and see that the alternative is inevitable worldwide disaster with hundreds of millions of people being killed by famine, pestilence, worldwide war or violence . . . Mankind **can** reach a stable equilibrium with the environment in the next century, but only if the developed countries shift the major part of their research effort to the solving of these problems". A conclusion with which I concur.

Gear tribology 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.

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.

ENVIRONMENTAL PROTECTION

The principles involved in the setting of radiological protection standards are reviewed, and the differences in procedures used by various countries in implementing them are outlined in this report* published by NRPB in April 1978.

1. Introduction

Some people consider that environmental radiation protection standards in the United Kingdom are less restrictive than those imposed elsewhere in the world, and particularly in the USA. This view may well stem from a misunderstanding of the procedural differences in the various countries which adds to the confusion surrounding the argument over nuclear power. In an attempt to eliminate some of the misunderstanding, the principles involved in setting standards and the procedural differences are indicated below. The procedures must be considered in the light of governmental and regulatory systems and the structure of the nuclear power industries.

For the purpose of this report, "standards" are taken as specific numerical limits relating to radiation doses to people or to amounts of radioactive materials released into the environment.

2. General approaches to dose limitation

The system of dose limitation recommended by ICRP[1-3] is the basis of most if not all national procedures for controlling exposure. It has, for example, been adopted by the European Communities and a Directive [4] has been made establishing radiation protection standards for the nine Member States. The system of dose limitation requires that a practice giving rise to an exposure shall be justified by the benefit it confers and, given this, that the exposure is reduced to a level which is as low as reasonably achievable. Further, exposure from all sources of radiation, except that from medical practice and natural background, should not exceed certain specific dose equivalent limits.

There are two main approaches to applying this system of dose limitation. In the first, the national authorities take the ICRP overall dose-equivalent limits as the appropriate standards and apply, practice by practice, the requirement that exposure must be kept as low as reasonably achievable. The decision on what is "as low as reasonably achievable" is made by these authorities on a case-by-case basis. For example, in considering an application to discharge radioactive waste to the environment, the authorities would consider the particular circumstances of the installation involved, the ways in which people might be exposed to radiation and the discharge limits necessary for proper safety to be ensured. They would act similarly with regard to other practices leading to exposure.

In the second approach, the national authorities publish "standards" specific to a particular type of practice which incorporate a general judgement on what is as low as reasonably achievable; for example, dose equivalent limits or discharge limits in respect of radioactive waste from a defined type of practice or, occasionally, into a specified environment. Such limits are often derived on general grounds and cannot therefore take account of variations in local circumstances. The authorities may accordingly require a particular installation to operate at a lower level than a standard demands. It should be noted that some standards derived in this second way are less rigorously based than others.

Large differences are to be expected and are apparent in the dose equivalent limits used in various countries as a result of one or other or a combination of these two approaches. Such differences certainly will not, *a priori* as some people suggest, cause differences in actual levels of exposure when respective "standards" are applied to any given practice. Actual doses received from a given practice would be unlikely to differ significantly from one country to another if the environmental characteristics are similar and if the value judgments, which precede the determination of what is "as low as reasonably achievable" are the same. But, of course, this is not necessarily so. Social and economic conditions and governmental attitudes will vary from one country to another and each could influence the judgments, some of which must be subjective.

In the developed "western" countries the variability in value judgments is unlikely to lead to significant differences in actual doses received from a given practice; certainly such differences would be small compared to those claimed by some to exist merely because different dose-equivalent limits have been published as standards. In less well developed countries greater differences might be apparent, although not necessarily so. In any country, anxiety about the availability of energy sources, for example, might lead to the acceptance of a level of dose, and therefore risk, in that country higher than that tolerated elsewhere at the time. That is not to say that the associated increased risk will have significant consequences with regard to the general health of the population concerned when compared with other risks they may bear, including the risks they might have to take from alternative courses of action which avoid higher radiation risks or avoid them altogether. Other countries, whose populations may be potentially affected by such decisions, will have an interest and

*"Environmental Radiation Protection Standards: an Appreciation" by L.D.G. Richings, F. Morley and G.N. Kelly, N.R.P.B. National Radiological Protection Board. April, 1978. (N.R.P.B.-R71) HMSO £1.00.

there are international arrangements for accommodating discussion in advance.

3. Comparison of UK and US approaches

In the UK, most radioactive wastes from the nuclear power programme are produced from two state-owned electricity-producing boards and one fuel fabrication and reprocessing company. The objectives of radioactive waste disposal policy in the UK laid down in 1959 by the White Paper[5], Cmnd 884, have been threefold. The first has been to ensure, irrespective of cost, that exposure to radiation of members of the public does not exceed ICRP dose equivalent limits; secondly, that the whole population should not receive an average genetically significant dose of more than 1 rem per person in 30 years from radioactive waste disposal practices; and finally, to do whatever is reasonably practicable to reduce exposures far below these levels.

These objectives require, as a minimum, that the authorising ministries rigorously compare the operator's proposal for discharge with the capacity of the particular environment to receive them, assessed in terms of the resulting doses to members of the public and in particular to critical groups of that public, and that they consider the availability and financial cost of waste treatment technology and the doses (to workers as well as to the public) resulting from the adoption of an alternative practice. An overall judgment has then to be made. The intent of "reasonably practicable" is to take technology and financial and other costs into account in reaching an overall judgment of what is best in the national interest. When the outcome of such considerations has been an authorisation to discharge waste, the authorisation, in the case of liquid effluent has contained numerical limits on the radioactivity to be released. Numerical limits have not been included in authorisations for airborne discharges. The requirement has been that "the best practicable means" should be used to limit discharges, subject to agreement between the authorities and operators on what level of discharge would be appropriate for particular plants. The formal inclusion of "numerical" limits in authorisations for airborne discharges would probably help remove some misunderstanding.

In the USA, both methods of approach to "standards" are used. In that country, electricity is produced by a large number of privately-owned utilities which have to comply with Federal and State requirements. The Federal Environmental Protection Agency (EPA) has issued generalised standards,[6] effective after 1979, applicable to most operations in the light water reactor uranium fuel cycle; exceptions include operations at uranium mines and waste disposal sites, and the re-use of plutonium recovered during fuel reprocessing. These standards are based mainly on considerations related to cost-effectiveness; dose-equivalent limits are specified for members of the public and other limits are imposed on the discharge to the environment of certain long-lived radionuclides in particular krypton-85, iodine-129 and alpha-emitting transuranic radionuclides with half-lives greater than one year. The annual whole body dose-equivalent limit stated in the standards is naturally lower than that recommended by IRCP which relates to the total dose from all sources of radiation.

These EPA standards will replace regulations[7] based on the Federal Radiation Protection Guides[8] (which state overall dose-equivalent limits which, over the years, have been consistent with those of ICRP) only in respect of operations in the light water reactor uranium fuel cycle as defined.

The Nuclear Regulatory Commission (NRC), the licensing authority for nuclear installations in the USA, has issued numerical guides[9] (not to be confused with the Federal Radiation Protection Guides), for design objectives and for limiting conditions of operation in respect of radioactivity in effluents from individual light water reactors. These guides incorporate NRC judgments of what is "as low as reasonably achievable". The numerical values of the guides are naturally, once again, considerably lower than the dose-equivalent limits recommended by ICRP as the total for all sources.

For classes of nuclear installation not covered by either EPA standards or the numerical guides, NRC act in a similar way to the UK authorities, namely, the adoption of ICRP's dose-equivalent limits as the standards and the determination of what is "as low as reasonably achievable" on a case by case basis. It remains to be seen whether or not when sufficient operating experience has been acquired NRC, following their custom, issue further numerical guidance.

The fact that some countries publish particular dose-equivalent limits does not mean that the actual doses received by people from any given practice are lower in those countries than elsewhere. The vital consideration is deciding what is as low as reasonably achievable.

4. Discharge limits

The limits imposed by the EPA standards on the discharges of krypton 85, iodine 109 and the alpha-emitting transuranic radionuclides referred to are often cited as evidence that US "standards" are considerably more restrictive than those of the UK. This is a mistake because the limits, based on cost-effectiveness considerations, are peculiar to the situations analysed and the value judgments used by EPA. These are not necessarily applicable to UK conditions. Indeed there are several important factors which affect the analysis of cost-effectiveness in the respective cases and these are discussed below. The failure to understand the differences confuses those aspects of the nuclear debate in the UK which relate to environmental matters.

The discharges of these radionuclides are essentially associated with operations during fuel reprocessing. The EPA limits were derived on cost-effectiveness considerations relating to reprocessing facilities either under construction or planned in the USA, none of which was to discharge these radionuclides in liquid effluents; the limits were derived assuming only airborne releases of radioactivity. They are therefore appropriate only in this context and in any case apply only in respect of radioactivity generated by the fission process after specified dates in the future. There is, however, no commercial reprocessing plant operating in the USA.

In the UK, on the other hand, magnox fuel is reprocessed at Windscale and there are discharges of radioactive wastes to the atmosphere and to the sea. The existence of both liquid and airborne effluents invalidates a direct comparison of the UK authorisations with these EPA standards. In any case, it is inappropriate to contrast EPA standards for future plant in US conditions with practices on quite different plants already operating in the UK. What may be cost-effective for a plant yet to be constructed must be different from that in respect of one already operating — a consequence of the greater cost of fitting major items of new equipment into existing facilities. Moreover, what is cost-effective for discharges to the atmosphere will not necessarily be so if the discharges were to the sea. For the purposes of radiological protection the sea is a more satisfactory medium than air for receiving radioactivity.

A comparison with the proposed Thermal Oxide Fuel Reprocessing Plant (THORP) at Windscale is more reasonable, but only in so far as its airborne effluents are concerned. British Nuclear Fuels Limited (BNFL) have predicted airborne discharges of iodine 129 and alpha-emitting transuranic radionuclides from THORP; depending on the degree of caution in these estimates, the discharges fall within or slightly exceed the EPA limits. That is not to say that these levels will be cost-effective. This can only be ascertained by the authorising ministries at a later stage in design or even after some operating experience. BNFL have also predicted airborne discharges of krypton 85 assuming its complete release. The predicted level is about six times greater than the EPA limit but it is a matter for the authorities to decide on what is to be permitted. Their decision, once again however, must depend on their view of what is cost-effective in conditions particular to the UK. There is no *a priori* reason for the results of such an evaluation to be the same as those deduced by EPA for US conditions. Evaluations are sensitive to the various value judgments, particularly on the weight to be attached to very small doses to large numbers of people and the international implications of this; the confidence that can be attached to the predicted costs of krypton removal plant which has yet to operate on a commercial scale; and the overall national economic and social needs.

5. Summary

So, while there are differences in the numerical limits described as "standards" in various countries, these do not mean that there will necessarily be significant differences in actual doses received from given practices. Differences in numerical limits reflect different procedural applications of the same basic philosophy and the circumstances existing in the countries concerned. Similarly, limits derived from cost-effectiveness analyses for the release of particular radionuclides in particular circumstances cannot be assumed to be generally valid. The very nature of cost-effectiveness analyses and of the other considerations taken into account in deciding what is "as low as reasonably achievable" means that results must be related to specific circumstances.

6. References

1. International Commission on Radiological Protection, Recommendations of the International Commission on Radiological Protection (adopted 17th September 1965). Oxford, Pergamon Press, ICRP Publication 9 (1966).

2. International Commission on Radiological Protection, Implications of Commission recommendations that doses be kept as low as readily achievable. Oxford, Pergamon Press, ICRP Publication 22 (1973).

3. International Commission on Radiological Protection, Recommendations of the International Commission on Radiological Protection (adopted 17th January 1977). Oxford, Pergamon Press, ICRP Publication 26 (1977).

4. Council Directive of 1st June 1976 laying down the new basic standards for the health protection of the general public and workers against the dangers of ionising radiations. European Communities, Official Journal, *19,* No.L187, 12th July 1976.

5. Great Britain, the Control of Radioactive Wastes. London, HMSO, Cmnd 884 (1959).

6. Environmental radiation protection standards for nuclear power operations. US Code of Federal Regulations, Title 40, Chapter 1, Subchapter F, Part 190 (1977).

7. Standards for protection against radiation. US Code of Federal Regulations, Title 10, Part 20 (1977).

8. Federal Radiation Council, Radiation protection guidance for federal agencies. US Federal Register, 18th May 1960.

9. Numerical guides for design objectives and limiting conditions for operation to meet the criterion "as low as practicable" for radioactive material in light-water-cooled nuclear power effluents. US Code of Federal Regulations, Title 10, Part 50, Appendix I (1977).

Further copies of this Report (NRPB-R71) are available from HMSO. price £1.

Courses at Harwell

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

Integrated circuits

3rd to 7th July, 1978

The course is intended for circuit designers and others engaged in electronic instrumentation implemented with integrated circuits. Fee: £185+VAT.

Two phase flow and heat transfer

10th to 14th July, 1978

An intensive course covering fundamentals and applications of two phase flow and heat transfer. Fee: £205+VAT.

IN PARLIAMENT

Nuclear Safeguards Debate

A REPORT BY A PARLIAMENTARY CORRESPONDENT

The Nuclear Safeguards and Electricity (Finance) Bill was given an unopposed second reading in the Commons on Monday, 24th April. The Bill has two main purposes. The first is to make provisions to give effect to an agreement concluded in September, 1976, between the United Kingdom, the European Atomic Energy Community and the International Atomic Energy Agency for the application of safeguards in the United Kingdom in connection with the Treaty on the Non-Proliferation of Nuclear Weapons. It also enables the Secretary of State for Energy to make certain payments to the Central Electricity Generating Board in connection with the building of the Drax B coal-fired power station.

Moving the second reading, Mr. Tony Benn, Secretary of State for Energy, said the Non-Proliferation Treaty (NPT), of which Britain was one of the three depository powers, came into effect in 1970. Each non-nuclear weapon state party to the treaty undertook to accept International Atomic Energy Agency safeguards.

As a nuclear weapon state, Britain was not obliged to be subject to safeguards.

However, during negotiations the Government had volunteered that, at such time as IAEA safeguards were put into effect in the non-nuclear weapon states, they would be prepared to accept the application of those safeguards in the United Kingdom, subject to exclusions for national security reasons only. Britain would retain its full powers under the provisions it had as a nuclear weapon state.

The object of the offer and of a similar offer made by the United States was to encourage non-nuclear weapon states to become parties to the Non-Proliferation Treaty. For example, France, though not a party to the treaty, had negotiated an agreement with the European Economic Energy Community and with the IAEA for the application of IAEA safeguards in France.

Further reasons for the British and American offers was to demonstrate that they were not seeking to maintain the commercial advantage that they might be thought to have by not submitting their installations to IAEA inspection. The offer had led to the conclusion of the safeguards agreement between the UK, the IAEA, and EURATOM to whose safeguards they had already been subject since 1st January, 1973.

Mr. Benn went on the explain the operation of the safeguards. He said that they included the maintenance of accounts and submission of reports by nuclear operators, of receipts, shipments and stocks of nuclear materials; and the inspection of facilities to verify the reports and to provide assurance that the relevant material was present at the facility.

The Bill would give power of entry to IAEA inspectors to make the inspections permitted by the agreement. The inspections would be limited to civil nuclear activities and would not in any way prejudice national security interests.

Britain would be given full particulars of the inspectors the agency wished to designate to have access to civil nuclear installations under the proposed legislation and would have the right to object to anyone not acceptable to the United Kingdom. The agreement also gave EURATOM and the United Kingdom the right to have IAEA inspectors accompanied during their inspections by EURATOM inspectors and UK representatives. That would avoid unnecessary duplication of safeguard activities.

The Government whole-heartedly supported the safeguards regime administered by the agency. It was the front line of defence against the proliferation of nuclear weapons to countries which did not now have them. International safeguards could not by themselves guarantee to prevent a country from acquiring nuclear weapons technology but they could be made to provide sufficient and timely warning of the diversion of nuclear materials from civil use to enable other governments to take action.

There was already a very detailed nuclear accountancy system in Britain to ensure that there was no diversion or loss of materials. There was also two other levels, the IAEA and the EURATOM safeguards arrangement. No responsible minister, even if there were no intentional safeguards, would do other than apply the most rigid and careful security provisions to installations in his own country.

The treaty had been designed to prevent the diversion of civil technology into military technology in countries which were not then nuclear powers. To the extent the safeguards could be made to stick and to be effective, the prospect of expanding the use of nuclear power for civil purposes would be possible without running into the hazard of proliferating nuclear weapons.

Mr. Tom King, Conservative spokesman on energy, gave a general welcome to the nuclear safeguards provisions of the Bill.

"This is an excellent example to set and I understand that that is why we entered into this arrangement", he said of the Government's voluntary offer.

He found it slightly bizarre that £1,000 was the fine for any breaches of the safeguards. They were dealing, not with a recalcitrant storeman who refused to open his store and had to be severely punished, but with non-co-operation by governments, he said.

He was slightly disappointed, however, that Mr. Benn had not made clear the Government's determination to ensure that the safeguards system was "beefed up".

Mr. Arthur Palmer (Lab), a former editor of the Electrical Power Engineer, said that there were those who took the view, as he did that energy use in the world would continue to grow. It might be somewhat modified, but not greatly by conservation and so-called benign sources, if they proved practical. His view was that in spite of that modification the total installed nuclear capacity in the world would grow in proportion to general energy advance.

The number of reactors in the world was rising fast. In many cases perhaps most, the spent fuel was being left in ponds at power stations and was not being reprocessed as in the United Kingdom. Some people argued, for that reason, that the spent fuel was best left where it was as the plutonium was for the time being virtually inaccessible and that was perhaps the safest way of dealing with it.

However radioactivity decayed and dispersed plutonium, in time, become much more accessible and the risk was of creating a considerable number of points where potentially dangerous spent fuel was available.

Mr. Frank Hooley (Lab) said that the treaty posed a fundamental problem in that nuclear power and nuclear weapons went hand in hand. There was no way of saying that there was not a danger of production and development of nuclear weapons if any country developed nuclear power.

It would not be possible effectively to prevent many countries from obtaining nuclear weapons if there was a general desire to go along the road of nuclear fission to satisfy the world energy needs.

The safeguards of the Non-Proliferation Treaty did not prevent India from producing an atomic explosion.

They must provide the world with alternative energy systems because, so long as they depended on nuclear power, the offshoot of nuclear weapons would continue. So long as the nuclear technology loomed large in the economy and began to do so in the economies of other countries that technology would lead to the production of the dangerous substance plutonium which in turn would lead to the production of nuclear weapons and then to nuclear war.

Mr. Leo Abse (Lab) said they would deceive themselves if they believed that the international agency, undermanned, under-financed and staffed by too many nuclear enthusiasts operating tardy warning systems would be capable of pulling them back from the ultimate disaster.

Mr. Eldon Griffiths (Con) was concerned about submitting the British nuclear power industry to a one-sided international inspection which was not being applied to the Soviet Union's nuclear industry.

Inspectors could move in and out of Britain's installation obtaining information which, if leaked, could be damaging to the public interest. He had nuclear terrorism in mind, he said.

Mr. Hamish Gray, winding up for the Opposition, said that the organisation and administration of the British nuclear industry had been subjected to the most rigorous examination not only by the inspectorate, but by every conservation body from the Friends of the Earth down and had withstood in splendid fashion the attacks and criticisms directed at it.

Mr. Alex Eadie, Under Secretary for Energy, winding up for the Government, said that design information on civil nuclear facilities would be sent to the IAEA inspectorate. The information would detail type and flow of nuclear material in each facility and the accountancy and control methods applied.

The data would be studied by the IAEA and they, with EURATOM and the UK would draw up a facility attachment for each individual facility setting out in detail how it would be safeguarded, by record keeping, reporting procedures, scope and frequency of inventory taking and methods of inspection and frequency and intensity of inspections.

QUESTION TIME

Commission on Energy and the Environment

6th April, 1978

Mr. Pavitt asked the Secretary of State for the Environment whether he will now make a further announcement about the membership of the Commission on Energy and the Environment.

Mr. Shore: On 2nd March I announced the establishment of the Commission on Energy and the Environment.

The following have now also accepted the Government's invitation to serve on the Commission under the Chairmanship of Sir Brian Flowers FRS.

Mrs. V. Milligan, BA, C Eng, MIEE
Mrs. N.E. McIntosh
R.N. Bottini, CBE
G. McGuire, OBE
D.E.T. Williams, MA, LLB

Nuclear fuel reprocessing

7th April, 1978

Mr. Charles Irving asked the Secretary of State for Energy how the overseas contracts for reprocessing fuel at the proposed plant would be affected if the reprocessed plutonium had to be irradiated to prevent its easy conversion into nuclear weapons before it was returned to its country of origin, given that to achieve this fuel fabrication plants and irradiating facilities would have to be built in addition to the enlarged THORP.

Mr. Eadie: I am advised that the proposed contracts would not be affected if a decision were taken to return plutonium as slightly irradiated fuel elements.

Nuclear power costs

11th April, 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 give below the generation costs in p/kWh of Magnox, coal and oil fired plants up to 12 years old in 1974-75, 1975-76 and 1976-77. These figures are not, of course, a guide to future investment decisions.

	1974-75			1975-76			1976-77		
	Magnox	Coal	Oil	Magnox	Coal	Oil	Magnox	Coal	Oil
Fuel cost	0.13	0.55	0.71	0.25	0.75	0.87	0.34	0.86	1.05
Other operating costs	0.09	0.07	0.05	0.14	0.08	0.07	0.11	0.09	0.08
Capital charges	0.26	0.12	0.12	0.28	0.14	0.15	0.24	0.12	0.14
Total cost	0.48	0.74	0.88	0.67	0.97	1.09	0.69	1.07	1.27

Nuclear installation workers

11th April, 1978

Mr. Charles Irving asked the Secretary of State for Social Services what study he has made of the experience of other countries on the effects of low-level radiation on the incidence of cancer in workers at nuclear installations and in the willingness of workers to work in nuclear installations.

Mr. Moyle: There have been a number of comprehensive studies in the United States of America of cancer frequencies among workers in nuclear installations. The subject is being carefully reviewed by the National Radiological Protection Board, and in addition I intend to ask the protection against ionising radiations committee of the Medical Research Council to assess the relevant publications and to prepare a report on the scientific aspects of the studies. I am not aware of any reports on the willingness of workers to be employed in nuclear installations.

International Atomic Energy Agency

20th April, 1978

Mr. Forman asked the Secretary of State for Energy how much public money was allocated in the last full year for which figures are available to pay the United Kingdom subscription to the International Atomic Energy Agency; how many British nationals are now seconded to the International Atomic Energy Agency, to its safeguards department and to its promotional department, respectively; and what plans the Government have to increase either the British subscription to the International Atomic Energy Agency or the number of British officials seconded to its safeguards department.

Mr. Eadie: The United Kingdom's contribution to the International Atomic Energy Agency in 1978 is expected to be £1.625 million. The United Kingdom's quota for professional posts in the Agency is 30. United Kingdom nationals hold five posts in the safeguards department. We shall continue to nominate United Kingdom candidates for posts in this department. The Agency's budget for 1979 has yet to be agreed.

Magnox reactors

24th April, 1978

Mr. Hooley asked the Secretary of State for Energy

(1) what plans are being drawn up for the continued surveillance of Magnox reactors after their useful life is completed;

(2) who will bear the cost of dismantling the Magnox reactors at the end of their useful life and the disposal of radioactive waste; and if this has been calculated in the total cost of nuclear electricity;

(3) if the shell of Magnox reactors will be demolished, dismantled or removed at the end of the useful life of the reactor, or used for some other purpose;

(4) what research is in progress concerning the disposal of radioactive or contaminated components of Magnox reactors when their useful life is finished;

(5) if he will list the dates on which each of the Magnox reactors currently in service, will reach the end of its useful life; and what plans are being made to dismantle them.

Mr. Eadie: It is expected that the designed operating life of the Magnox stations will be exceeded, and the dates of the end of their useful lives are therefore uncertain.

The statutory responsibilities of the operators for the safety surveillance of Magnox reactors will continue after the end of their useful lives until the Nuclear Installations Inspectorate is satisfied that radioactivity has been reduced to a neglible level. As to plans for dismantling them, current studies suggest that this will probably begin with the removal of reactor fuel and other accessible components from the reactor core, leaving only the reactor vessel and its shielding together with the facilities needed for safety and maintenance and inspection. The length of time before these residual structures can be removed will depend on the rate of decay of the remaining radioactive products; it is expected that these structures would be disposed of ultimately as low-activity solid radioactive waste by burial at designated sites. Research is also being conducted into an alternative route, the possibility of landscaping over the residual structures.

I am advised that provision for the cost of decommissioning is already being made in the cost of electricity.

NUCLEAR POWER AND THE ENVIRONMENT: CBI COMMENTS

The sixth report of the Royal Commission on Environmental Pollution was published in September 1976 under the title 'Nuclear Power and the Environment'. The Government's response to this report was published in the form of a White Paper with the same title in May 1977. In January 1978 the Confederation of British Industry (CBI) submitted their comments on this White Paper to the Secretary of State for the Environment. The comments were assembled by the CBI's Environmental and Technical Legislation Committee in consultation with the Energy Policy and the Research and Technology Committees. It will be noted that the comments were prepared before the announcement on 25th January 1978, by the Secretary of State for Energy, of the Government's decision on the next stage of Britain's nuclear power programme.

The following comments represent the views of the CBI on certain selected topics contained in the Government's White Paper entitled 'Nuclear Power and the Environment'. These comments are not intended in any way to represent the CBI's only views on the White Paper which was issued in response to the Sixth Report of the Royal Commission on Environmental Pollution.

The CBI is firmly convinced of the need to maintain and develop a soundly based energy plant and equipment industry, incorporating the best aspects of modern design and manufacturing practice. This industry could have considerable potential in the export of both technology and hardware to the countries of the Third World as their energy needs grow and world supplies of fossil fuels are depleted.

The CBI considers that firm decisions on the choice of thermal reactor for future nuclear power programmes should be made now if the nuclear power industry is to avoid further decay and the resultant loss of technical know-how and staff. The choice of reactor should, moreover, be such as to aid and promote the export activities of the industry concerned.

Energy Policy (paragraphs 8-12)

The CBI is convinced that nuclear power is the UK's only proven and reasonably available means of making a substantial contribution in support of coal in meeting future electricity demands, thereby reducing our dependence on declining oil supplies within this century and well on into the next. This will require not only an increased power station building programme based on a proven series of reactor but also, in the CBI's opinion, the continuation of the development of the fast breeder reactor for possible introduction on a substantial scale in the next century. Development of new energy sources is a very long-term process, and it would be unwise to abandon the longer-term option which the fast breeder affords. However, the feasibility of moving straight to the fast breeder as a basis for meeting the UK's medium-term nuclear power needs is not tenable since it could well take 20 years to put a series into service. In just the same way to miss out the fast breeder stage and to attempt to move straight to nuclear fusion is not a tenable proposition either. The development of nuclear power must be progressive, but unacceptable industrial and social risks cannot be taken in attempting to accomplish changes of technology too quickly.

The CBI notes that the Commission accepted the need to maintain a nuclear option and furthermore did not, on environmental grounds, oppose the building of a first commercial scale fast breeder reactor. With regard to the alternative energy strategy as suggested by the Commission and accepted by the Government in paragraph 10 of the White Paper, the CBI supports the research and development of alternative energy resources, studies into combined heat and power and further investigation into the possibilities of energy conservation. However, the CBI believes that these measures must be carried out in conjunction with, and not as an alternative to, an eventual enlarged nuclear programme.

The CBI acknowledges the necessity for both public debate and understanding of the implications of decisions on nuclear development (para.12). However, the CBI believes that such debate will clearly demonstrate the necessity of increased development of nuclear power and that such development can be carried out in an environmentally acceptable manner. Furthermore, public debate must not be used as an excuse to put off awkward decisions — decisions which need to be taken in the near future in view of the long lead times associated with the nuclear industry and the relative nearness of a possible state of energy shortage.

Management of radioactive wastes (paras.13–22)

The CBI would support the view expressed in paragraph 13 that the management of radioactive wastes is a matter for Government responsibility in the Department of the Environment and independent from the Department (the Department of Energy) responsible for promoting nuclear power.

Furthermore the CBI would agree with the topics listed in paragraph 14(i)–(vi), and would endorse the view that the management of radioactive waste be a responsibility of the Secretary of State for the Environment, who would consult closely with the Secretary of State for Energy and other Ministers as considered necessary and appropriate.

The CBI would also subscribe to the view that a Nuclear Waste Management Advisory Committee (para.16) is both highly desirable and necessary: furthermore this Committee need not be a statutory body, provided that Government will take cognisance of its recommendations. It is felt that the Committee should be convened as soon as convenient to bring existing practice into line with the most recent technological developments (para.17).

The CBI would support the need for a regular report to be placed before Government to assist in the development of the best possible policy.

The CBI would also support the Governmental attitudes to existing controls on radioactive wastes, which include the review of current activity into research effort as indicated in paragraph 18.

With regard to the 'polluter pays' principle as detailed in paragraph 19 the CBI would support this attitude outlined in the White Paper and acknowledge that the cost of waste disposal should be taken into account when costing power generated from nuclear sources.

The CBI supports the Government's decision (para. 20) to await the advice of the Nuclear Waste Management Advisory Committee before establishing a Nuclear Waste Disposal Corporation. However, this may be considered to be an appropriate function for the United Kingdom Atomic Energy Authority. The CBI would seriously suggest that the need for a Nuclear Waste Management Advisory Committee is now a matter of some urgency.

The CBI obviously acknowledges the need to ensure that safe methods exist for the containment of long-lived, highly radioactive wastes. However, as the Commission themselves accept, these wastes already exist in substantial quantities and a safe method for their disposal will be required irrespective of future nuclear development. The CBI shares the Commission's confidence that a solution to this problem will be found (para.21).

Non-Proliferation (paras.32–34)

The CBI considers that the amount of plutonium which could constitute a security risk would be reduced by the introduction of fast reactors into the present system of thermal reactors.

Security (paras.35–38)

The CBI considers that the arrangements made for the transport and storage of plutonium will be sufficient to deal with any risk that may arise from action by a foreign power.

The need for public debate (paras.39–43)

The CBI welcomes the ideas advanced in paragraphs 39 and 41 and feels the publication by the Department of Environment of a Pollution Paper devoted to this topic could promote a constructive exchange of views in the public forum of a wide ranging debate. Furthermore, the CBI feels that any decisions should be taken only after a full, well-balanced assessment of all the technical considerations and should not be unduly influenced by emotive issues or pressures.

Annex A — Other conclusions and recommendations.

The CBI notes that no decisions have yet been reached regarding the role of the unified pollution inspectorate, but would again reaffirm the view propagated following the Fifth Report that the role of a unified pollution inspectorate is acceptable, providing this is not an executive function.

Radioactive emissions to the atmosphere (para.3) and disposal of high level wastes (paras 4–8)

The CBI does not feel able to comment on the matter of radioactive emissions to the atmosphere (para.3), or the disposal of high-level wastes (paras.4–7) at this time. With regard to the disposal of other wastes (para.8) the views of the CBI have been outlined under the comments applicable to paragraph 18 in the White Paper and basically the CBI would support the need for regular reports from the Nuclear Waste Management Advisory Committee.

Combined heat and power from nuclear reactors (paras.15 and 17)

With regard to combined heat and power from nuclear reactors the CBI has no additional comment to make at this stage. The possibility of using conserved power and heat, both in industry, and for district heating is being examined by the Department of Energy's Combined Heat and Power Group in which the CBI participates.

The CBI does not see any need to make any changes with regard to the work that is already being carried out by UKAEA on renewable energy sources, under the provision of the Science and Technology Act 1965.

ELECTRICITY SUPPLY REORGANISATION

"Recent Government proposals for the electricity supply industry would safeguard this industry against over-centralisation and help to meet the growing pressure for greater accountability and openness."

This was stated by Dr. J. Dickson Mabon, Minister of State for Energy, speaking to the annual conference of the Electrical Power Engineers Association, in Canterbury on 10th April.

Dr. Mabon said also that the two year public and parliamentary debate on nuclear reprocessing in the UK will have removed many of the fears which, in the past, have accompanied nuclear developments such as Windscale.

Discussing the recent White Paper on the reorganisation of the electricity supply industry which included a draft Bill, Dr. Mabon said:

"As the Plowden Committee itself recognised, there must be safeguards against over-centralisation and we must ensure that the industry continues to respond adequately to consumer's needs at local level. The draft Bill accordingly contains only the outline structure. It leaves the Minister, in consultation with the industry and subject to Parliament, to determine the exact form of internal organisation for the industry. This would take place from time to time as circumstances change.

"The new flexibility will ensure that developments in the organisation of the industry are evolutionary in nature — avoiding major upheavals — and can take place without the delays and uncertainties that inevitably go with primary legislation".

Against this background and that of last week's White paper on nationalised industries, Dr. Mabon said: "The draft Electricity Bill contains a far wider range of statutory duties for the proposed new Corporation than has appeared in previous nationalised industry legislation. In addition to its basic duty to develop and maintain "an efficient co-ordinated and economical system of electricity supply", the Corporation will be required to pay due regard to wider national energy objectives and to its social responsibilities. In particular, it must have regard to the needs of consumers for heat, light and power — a consideration now entrenched amongst its central duties.

"Taken together these new powers and duties and the framework of financial disciplines imposed from time to time by Governments should be help to meet the growing pressure for greater accountability and openness in the running not only of the electricity supply industry but also all nationalised industries.

"It is not, I am afraid, possible for me to forecast when the proposed legislation can be introduced. But the proposals contained in the draft Bill, which as you may be aware are about to be examined by the Select Committee on Nationalised Industries as the first stage of an inquiry into the industry, will provide a rare opportunity for a Government Bill to be subjected to detailed study before introduction. And it is hoped that publication of the Government's detailed proposals will pave the way for some at least of the more desirable changes to be introduced in full co-operation with the industry even before legislation is possible".

Commenting on the Government's decision to accept the conclusion of Mr. Justice Parker that British Nuclear Fuels Ltd. (BNFL) should proceed without delay with the proposed oxide reprocessing plants, Dr. Mabon said:

"This decision was endorsed on 22nd March by the House of Commons after a debate lasting more than six hours — a debate demanded by opposers of the scheme in Parliament and backed by the Secretary of State for the Environment following the publication of Mr. Justice Parker's report. In the event, despite a well-argued case from the objectors, the House voted by 186 to 56 in favour of the Windscale project. I think the magnitude of that majority is a very clear vindication of the open and cautious approach adopted by the Government towards nuclear reprocessing.

"Delegates will be aware that a special Development Order has now been laid before the House of Commons. This, subject to the negative resolution procedure, will grant BNFL outline planning permission with effect from 15th May.

"It has been said that economic gain was the decisive factor in determining the Government's decision. It is true that economic and financial advantages will flow to the nuclear industry and to the country as a whole and that the domestic electricity consumer will also benefit — there is nothing to be ashamed of in this. However, issues that go far beyond economic gain are involved".

"The Government has made it clear that it is in the interest of our non-proliferation policy that THORP should go ahead now. Part of our responsibility to future generations is to ensure that we deal with the waste arising from our existing nuclear stations and with least harm to the environment. The Government endorses the Inspector's view that AGR fuel reprocessing and vitrification enable us to meet that responsibility.

"I am confident that the public and parliamentary debate on BNFL's proposals which has continued over the last two years will have removed many of the fears which in the past have accompanied nuclear developments such as those at Windscale."

White Paper

The Government proposals were contained in a White Paper,* published on 4th April, by Mr. Tony Benn, the Secretary of State for Energy.

Parliamentary considerations have prevented the introduction in the present session of a Bill seeking to implement these proposals. The Government believes, however, that in view of the uncertainty prevailing in the industry it would be right to make its intentions clear. The White Paper, therefore, includes in full the draft clauses for a Bill which would reorganise the industry.

The White Paper states that the clauses of the Bill have been drafted with the following objectives in mind:-

The Government accepts the need for a new unified statutory framework which promotes more effective policy making for the industry as a whole.

There must be safeguards against over-centralisation and the industry must continue to be fully responsive to consumers' needs at local level.

The industry should pay due regard to wider national objectives and to its social responsibilities.

The main proposal in the White Paper is for the transformation of the Electricity Council into a new statutory Electricity Corporation (EC) responsible to the Secretary of State and through him, to Parliament for running the industry. New subsidiary boards corresponding to the present Central Electricity Generating Board, and to the 12 area electricity boards in England and Wales, would be set up within the new Corporation. The present boards would be dissolved and their assets and liabilities transferred to the Corporation.

The White Paper states:

"The Corporation would be under a duty to devolve to these boards the maximum managerial responsibility consistent with the proper discharge of its functions. The proposal to retain the names of the area boards would give continuity to consumers at the local level and lessen the impact of the change upon them. But the Corporation would be responsible for determining strategic policies for the industry as a whole."

The Corporation would have a general duty "to develop and maintain an efficient, co-ordinated and economical system of electricity supply in England and Wales." In doing this, the Corporation would be required to have regard to the requirements of national energy policy.

Among the Corporation's other principal duties are the requirements to:-

devolve maximum managerial responsibility to the boards

avoid undue preference in supplying electricity

have regard to the need of consumers for heat, light and power

promote the simplification and standardisation of methods of charging and the standardisation of systems of electricity supply and types of fittings

promote industrial democracy

consider the effects of its purchasing and manufacturing policies on suppliers

promote and carry out research and development

promote economy and efficiency in the use of energy

make available, as fully as practicable without breaching confidentiality, information about its policies, in particular by publishing codes of practice on consumer matters.

The new Corporation would be given power to manufacture and sell electrical plant or fittings and the by-products of electricity generation. The Corporation would be able to search for, and extract, any mineral except coal and petroleum which is used in the generation of electricity.

The existing power of the Secretary of State to give the industry directions of a general nature would be continued. A new power of specific direction has been included in the draft Bill.

The Secretary of State would be able to give general or specific directions to the Corporation on matters which appear to him to affect the national interest. These directions could override the Corporation's statutory obligations, but not its financial duty. There would be power for compensation to be paid to the Corporation, where the Secretary of State considers appropriate, for any net loss it suffers as a result of a direction. Directions would be subject to Parliamentary scrutiny.

The draft Bill does not determine the internal structure of the Corporation. The White Paper states:

"Instead the Secretary of State would be empowered to make Orders to prescribe the organisation of the industry for the time being. This use of secondary rather than primary

*"The Reorganisation of the Electricity Supply Industry in England and Wales". Cmnd 7134. Available from HMSO. Price £1.60.

legislation for future changes in organisation allows for flexibility to change the industry's organisation as circumstances change."

The Secretary of State would appoint the chairman and members of the Electricity Corporation and the Bill would enable him to appoint the members of its subsidiary boards.

A statutory Electricity Consumers Council would replace the existing Electricity Consultative Councils in England and Wales. The new Council would be responsible for considering the interests of consumers and for making representations to the Corporation and to the Secretary of State. The draft Bill would enable the Council to organise its affairs on a regional basis by the establishment of regional committees or regional offices, and would give the Secretary of State the power to direct them by order to do so. The chairman of the Electricity Consumers Council would be a member of the Electricity Corporation.

Publication of the White Paper follows wide consultations on the Plowden Report, published in 1976, which recommended that the industry be unified into a single statutory body. When he announced the Government's intention to legislate, Mr. Benn said in Parliament in July 1977 that he regarded it as essential to provide adequate safeguards against the dangers of excessive centralisation.

UKAEA information service for schools

As part of their effort to increase public understanding of nuclear power and of the need for its development, the Authority arrange for speakers to visit school sixth forms to talk about these issues which are currently the subject of much public attention and discussion.

After a short introductory talk, the speakers usually show a slide-tape programme which deals mainly with the safety aspects of nuclear power: the remainder of the session is then devoted to discussion and, in particular, to questions from the sixth formers. The Authority also have a small exhibition on nuclear power which can be made available to schools for a one-week period.

No charge is made to schools for the services of the speakers or for use of the exhibition. Enquiries from teachers are welcomed and should be addressed to:- Mr. T.G. Davies, Information Services Branch, UKAEA, 11 Charles II Street, London SW1Y 4QP.

UKAEA PRESS RELEASE

Research into waste disposal

"The research programme into granite rocks which the UK Atomic Energy Authority wants to carry out in Northumberland does not involve burial of any nuclear wastes", said Dr. J.B. Lewis, Head of the Industrial Chemistry Group at Harwell, speaking in Wooler, Northumberland, on 19th April. He was explaining to a public meeting in the Archbold Hall the background to the Authority's application for planning permission to drill bore-holes in the Chillingham and Usway Forests. A similar public meeting was held on 20th April at the Jubilee Hall, Rothbury. This was addressed by Dr. Allan Duncan, Head of the High Level Waste Disposal Section of the Industrial Chemistry Group at Harwell and Mr. Dennis George who is in charge of field studies in Northumberland.

Dr. Lewis reminded his audience that nuclear power was currently the cheapest and safest way of producing electricity. The first of Britain's nuclear power stations had already operated for over 21 years and nuclear waste had been accumulating for well over 20 years but the volumes of highly radioactive waste were very small. The wastes were stored as liquids in complete safety in a few tanks. It was intended, however, to make storage simpler and even safer by incorporating the waste in a glass-like solid. Ultimately a decision would have to be taken on disposal. The option currently being examined was for disposal in geological formations on land or perhaps on or under the sea.

Burial only a few feet beneath the surface of the earth would be sufficient to provide protection against any radiation. However, to ensure that material was not returned to man's immediate environment by any mechanism, even in such circumstances as another ice age, burial would be at a depth of 1000 feet.

At present, however, there was little information about the nature of rocks at such depth. It was necessary, before going further, to find out more about the heat properties of rock at such depths and whether there was any water movement. To do this it was necessary to bore holes and to carry out studies that might last some years.

Dr. Lewis said that the research into granite rocks was part of a programme financed by the European Economic Community under which other countries were carrying out research into clay and salt formations as possible formations for the disposal of nuclear waste. This did not mean that nuclear waste from other countries would be disposed of in Britain. It was hoped that Britain would have a national programme to study clay and salt. Furthermore a separate programme of research into disposal on to or under the sea bed in deep oceans was being carried out.

Besides Northumberland, research into granites was being undertaken in Scotland and the Atomic Energy Authority has applied for planning permission to drill bore-holes in the Kyle and Carrick Forest.

Research into the heat transfer properties of granite was being carried out in Cornwall. Research in any one particular location did not mean that a nuclear waste disposal facility would be built there. Such a decision was, in any case, several years away.

Mr. Dennis George, Harwell's Field Studies Officer, explaining details of the Authority's planning application said the drilling would be carried out with a minimum of inconvenience to local people. He said that the application referred to about 20 bore-holes but it was not expected that the Authority would in fact drill all of these. It was likely that about six would be drilled and only as deep as seemed necessary. After the research was completed the holes would be in-filled and capped. There would be no lasting environmental effects. The drilling operation itself would be on a comparatively modest scale using a drilling rig that could be carried on the back of a lorry. Perhaps three temporary buildings would be on the site during the research period for the storage of equipment and samples but would be removed at the end.

20th April, 1978

Radionuclides Determination Symposium

An International Symposium on the Determination of Radionuclides in Environmental and Biological Materials will be held from 9th–11th October, 1978 at the Central Electricity Generating Board Headquarters London.

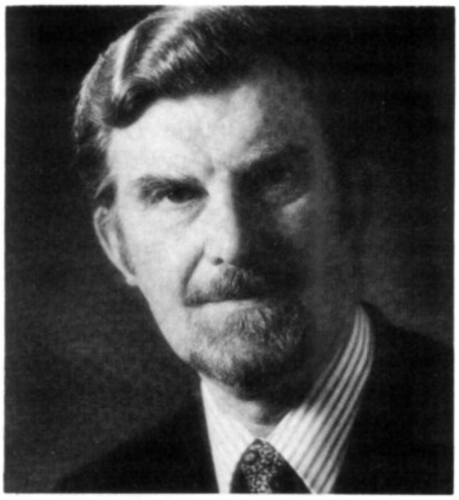
Full details of the Symposium may be obtained from the Administrative Secretary — Mr. G.D. Springett, Central Electricity Generating Board, Sudbury House, 15 Newgate Street, London EC1A 7AU.

UKAEA Member re-appointed

Mr. Tony Benn, Secretary of State for Energy, has re-appointed Mr. A.M. Allen as a member of the UK Atomic Energy Authority from 1st March 1978 for a period of five years.

Mr. Arnold Millman Allen, CBE., joined the Authority in 1959 as director of personnel and administration in the development and engineering group, subsequently reactor group. In 1963 Mr. Allen was appointed general manager of the British Waterways Board, and later he became a board member.

Mr. Allen rejoined the UKAEA in November 1968 as Authority personnel officer, and later assumed responsibility for economics and programming matters and public relations. In January 1971 he became secretary of the UKAEA, a post he retained when he became a fulltime member of the UKAEA on 1st July 1971. Mr. Allen was re-appointed to the board in July 1976 as member for finance and administration.



Under the Atomic Energy Authority Acts of 1954 and 1959 the Secretary of State for Energy appoints the chairman and members of the UKAEA.

New IEA Co-operative R & D Projects

Japan will head a new wave power research and development project costing in excess of 3 million US dollars equivalent, the Agreement on which was signed in Tokyo on 13th April by five Member countries of the International Energy Agency (IEA). A second project on biomass conversion is also being launched by five Member countries. In addition, Canada and Japan have joined in some other existing IEA energy R & D Agreements involving conservation, solar heating and cooling, wind energy and fusion power research.

For those countries in the world having reasonably constant, high waves near their coasts, **wave power** offers a potentially valuable source of energy, and one that is at its maximum in winter months, when energy demand is highest. Under the IEA project Canada, Japan, the UK, and US will collaborate to build, test and compare devices that harness wave power and use it to drive air turbines generating electricity. The turbines will all be tested in the Sea of Japan on the "Kaimei", an 80-metre long buoy in the shape of a small ship, constructed by the Japan Marine Science and Technology Centre.

In addition, five countries (Belgium, Canada, Ireland, Sweden and the US) are entering into a joint planning agreement in the field of biomass conversion, under which they will co-ordinate their national activities in research, development and demonstration into approaches for deriving energy in the form of clean fuels from forestry products and forestry residues.

Japan is also joining four existing R & D collaborative projects, of which two are in **fusion power**. In the first of these is a six-year hardware project centred on a facility now being built in the United States to test large superconducting magnets needed for the development of tokamak fusion reactors. Japan and Euratom (including Sweden by special arrangement) will each fabricate and ship to the US facility a superconducting magnetic coil of unique design. The other fusion project, which will last nine years, Canada, Japan, Turkey and the US will contribute specialised manpower towards the final design and construction of a tokamak plasma test bed, called TEXTOR, to be built in Germany. Euratom (including Sweden by special arrangement) and Germany are funding the construction of a plasma test device, which will help in the development of materials capable of withstanding the powerful forces and high temperatures occurring in future fusion power reactors. Switzerland is also expected to join both these projects at a later date.

In a third project covering **wind power**, Japan is joining Austria, Canada, Denmark, Germany, Ireland, Netherlands, New Zealand, Sweden and the US in studies on the basic problems involved in converting wind energy to electric power including environmental and meteorological aspects, siting, integration into electricity grids, and the design of rotor systems.

A fourth existing IEA R & D project which Canada and Japan are joining is concerned with a jointly-funded $700,000 study of opportunities for introducing **energy cascading** systems, i.e. using energy that is presently wasted to perform work that is matched to the characteristics of the energy available, such as district heating from the discharges of cooling water from electric power stations. Austria, Belgium, Germany, Netherlands, Sweden, Switzerland and the US are already participating.

Finally, Canada is joining an existing project which is concerned with **solar heating and cooling**, and involves a three-year programme of task sharing to develop cost-effective engineered systems and components for water heating, and space heating and cooling in residential buildings by means of heat derived from the sun. Austria, Belgium, Denmark, Germany, Italy, Japan, Netherlands, New Zealand, Spain, Switzerland, Sweden, United Kingdom, United States and the European Community are already participating in this joint programme.

The two new activities initiated are in addition to nine ongoing projects in coal technology and a coal hydrogenation planning activity, seven projects in energy conservation, one in nuclear fission safety, one in geothermal energy, six in solar energy, two in wind energy, three in thermonuclear fusion and one in hydrogen production.

US Waste Management Conference

The United States Regulatory Commission is sponsoring a conference on some technical aspects of nuclear waste management at the Denver, Colorado, Hilton Hotel from 19th-21st December, 1978.

There will be three half-days of technical presentation: on vitreous forms; encapsulation techniques and failure modes; and spent-fuel, crystalline and other forms.

Three concurrent work-shop sessions in each of two half-days will be held on: criteria for solid waste forms; comparative stability of alternate waste forms; and limitations in predicting long-term performance.

Further information is available from NRC Conference Manager, SCS Engineers, 11800 Sunrise Valley Drive, Reston, Va.

NAIR Performance

Radioactive materials are widely used for a variety of purposes in industry and medicine and they are being used with increasing frequency in devices such as luminous signs, and smoke detectors which are installed in public places. Consequently, there is always a possibility of incidents occurring involving such materials and devices.

For example, accidents can occur during transport and sources of radiation can be lost and subsequently discovered by members of the public.

Clearly, it is necessary by some means to provide expert advice quickly to bodies like the police to achieve the quickest and best means of removing any possibility of a public hazard or inconvenience, or merely to allay fears. Even if, as on many occasions, it is later discovered that radioactivity is not involved (e.g. when the incident involves empty containers), it is necessary for assistance to be provided quickly. Most events do not cause a hazard to the public but unless assistance is provided quickly there would, for instance, be disruption of traffic.

The arrangements for providing advice — the National Arrangements for Incidents Involving Radioactivity (NAIR) — have worked well, according to an article* published in "Radiological Protection Bulletin", on 27th April. The Bulletin is published quarterly by the National Radiological Protection Board (NRPB).

An important factor in dealing with incidents is speed and under NAIR each of the UK police areas has radiation protection experts on whom it can call for assistance. Many of the experts are provided by NHS hospitals, some by nuclear establishments and the Ministry of Defence and others by NRPB.

Assistance is provided to the police in two stages:

At **Stage 1**, a suitably qualified person can advise whether a hazard from radioactivity exists and, if so, recommend action to eliminate it or to contain it until further assistance can be obtained from

Stage 2, an establishment having emergency teams and equipment capable of dealing with any incident.

NAIR is co-ordinated by NRPB. In recent years the Arrangements have been re-organised to increase the number of participatory organisations. The Board has also organised a substantial training programme for technical experts, with over 240 attending seminars; in addition courses have been organised for police and fire services.

Incidents

NAIR covers the whole of Britain. It was established in 1964 and since then 190 incidents have been dealt with. In the new article data published previously in Bulletin No.13, October 1975 is up-dated and incidents are described.

There have been 36 false alarms, including those caused by a bar of soap trademarked 'Radium', 2 Vases from Hiroshima, and a small barrel from a Dinky toy marked with a sign similar to the radiation symbol and bearing the words 'Danger Waste Material'.

A total of 28 empty containers have been found, many with the radiation symbol embossed on them.

Over the years there have been 80 incidents involving undamaged radioactive sources, ranging from a contaminated £5 note to 54 radium needles which were found in a cellar.

Of the 29 incidents involving damaged sources or containers the most important in recent years occurred when two labelled glass phials, each with about 100 mCi of radium, were found on a tip used by children. Hospital staff checked 110 children as a precaution but no activity was detected.

*National Arrangements for Incidents Involving Radioactivity (NAIR) — Second Report, by E.T. Wray, Radiological Protection Bulletin No.23, April 1978.

Internal Combustion Engine Project

Harwell scientists working on the Internal Combustion Engine Project have achieved what they believe is the first successful measurement of fuel/air motion within the cylinder of a running petrol engine.

The experiment was a vital one, because an understanding of the fuel air mixing process is acknowledged to be a crucial factor in the design of more efficient and environmentally acceptable engines.

The experiment used an optical technique involving a laser beam. Such methods intrude to only a minimal extent upon the normal function of the engine.

The successful experiment concluded the first year of the project, which is supported by the Mechanical Engineering and Machine Tools Requirements Board of the Department of Industry.

The success gives credibility to the overall aim of the project, which is to develop a range of instruments for making detailed studies of the complex processes occurring inside internal combustion engines.

The automotive industry regards such instruments as important aids in the design of vehicles with lower emissions, lower fuel consumption and better driveability.

The in-cylinder experiment was carried out on an optically-accessed research engine installed on a test bed at Leyland Cars. The problems that had to be overcome included: engine vibration, the presence of liquid fuel on the inner surface of the viewing window, stray light, scattered or emitted from within the engine cylinder, and the electronic sorting, storing and retrieval of data arising from different sectors of the engine cycle.

In a separate in-cylinder study, optical signals have been obtained from within the cylinder of a motored diesel engine, in preparation for a study of a production diesel engine in collaboration with Perkins Engines.

In another section of the project, a detailed study has been made of air motion within a transparent manifold on a motored petrol engine, in association with Leyland Cars. The prospects for extending the study to a firing engine appear to be very good.

In addition to instruments for measuring air motion, steady progress is being made on laser-based techniques for the simultaneous measurement of fuel droplet sizes and fuel droplet velocities inside engines; and laboratory demonstrations on steady flames have confirmed that laser-Raman scattering shows distinct promise as a technique for measuring the composition and temperature of gases and vapours inside engines.

Advice on the direction of the work is provided by a panel of senior engineers representing CAV, Chrysler (UK), Ford (UK), Leyland Cars, Leyland Truck and Bus, Perkins Engines, Rolls Royce Motors, SU Fuel Systems, Zenith Carburettors, the Ministry of Defence and the Department of Industry.

CAV, Leyland Cars and Perkins Engines are involved in close and detailed collaboration on the demonstration experiments.

Emergency Reference Levels — Interim Guidance Recommended

Emergency Reference Levels (ERLs) of radiation dose are guidelines for the planning and implementation of counter-measures for protecting the public after an accidental release of radioactive material at a nuclear installation; they are levels of radiation dose to members of the public below which counter-measures (such as evacuation) by regulatory bodies, local authorities etc., are unlikely to be justified.

The National Radiological Protection Board (NRPB) was directed by the Health Ministers in 1977 to 'be responsible for specifying ERLs of dose' and 'for providing guidance to government departments and other appropriate bodies on the derivation of ERLs relating to radiation exposure and radioactive materials in the public environment'.

On 6th April the NRPB published interim guidance on ERLs. This states that the Board is consulting with regulatory bodies and the organisations who may have to utilise ERLs and that during the period when discussions will be taking place the recommendations made by the Medical Research Council in 1975, "Criteria for controlling radiation doses to the public after accidental escape of radioactive material" (HMSO, £1.30) should continue to apply.

The Board will specify ERLs of dose and derived ERLs corresponding to them in due course. It will do this in a new series of documents, established for this purpose, which will be sent to appropriate organisations and put on sale through HMSO; this first statement is "ERL 1, Emergency Reference Levels: interim guidance" (HMSO, 5p).

Further information is available from the Information Officer, National Radiological Protection Board, Harwell, Didcot, Oxfordshire, OX11 0RQ; telephone: Rowstock (023 583) 600 Ext. 410.

Slide-Tape Programmes

The Education and Training Centre of the Atomic Energy Research Establishment at Harwell have devised and compiled 17 new slide-tape programmes. The titles are:

Nuclear Physics:-

Z1 The Atom
Z2 Atomic Mass
Z3 Radioactivity
Z4 Radioactive Decay
Z5 Nuclear Energy
Z6 Nuclear Reactions
Z7 The Chart of the Nuclides
Z8 Gas-filled detectors
Z9 Solid State Detectors and Neutron Detectors
Z10 Radiological Protection
Z11 Radiation and Contamination
Z12 Nuclear Fission and Criticality

Digital Computer Fundamentals:-

Z13 Structure of a Computer
Z14 Bits, Bytes and Words
Z15 Programs
Z16 Number systems
Z17 Complement Arithmetic

Prices are available from: The Slide Centre Ltd, 143 Chatham Road, London, S.W.11. Tel: 01-223 3457.

US Firm to Market Refel

British Nuclear Fuels Ltd. (BNFL) has appointed the Pure Carbon Company of St. Mary's Pennyslvania as exclusive distributor in North and South America of REFEL* silicon carbide.

Pure Carbon will begin to market REFEL immediately using material from BNFL but the agreement also gives Pure Carbon the option to manufacture REFEL in the future.

REFEL has already established a reputation in the US market with marked success in two distinct fields; used as mechanical seal faces it has outperformed tungsten carbide in arduous operating conditions; used in prototype components for road vehicle gas turbines it has also been very successful. In the latter connection Ford, Detroit are on record as having described REFEL as ". . . the leading contender for ceramic combustors".

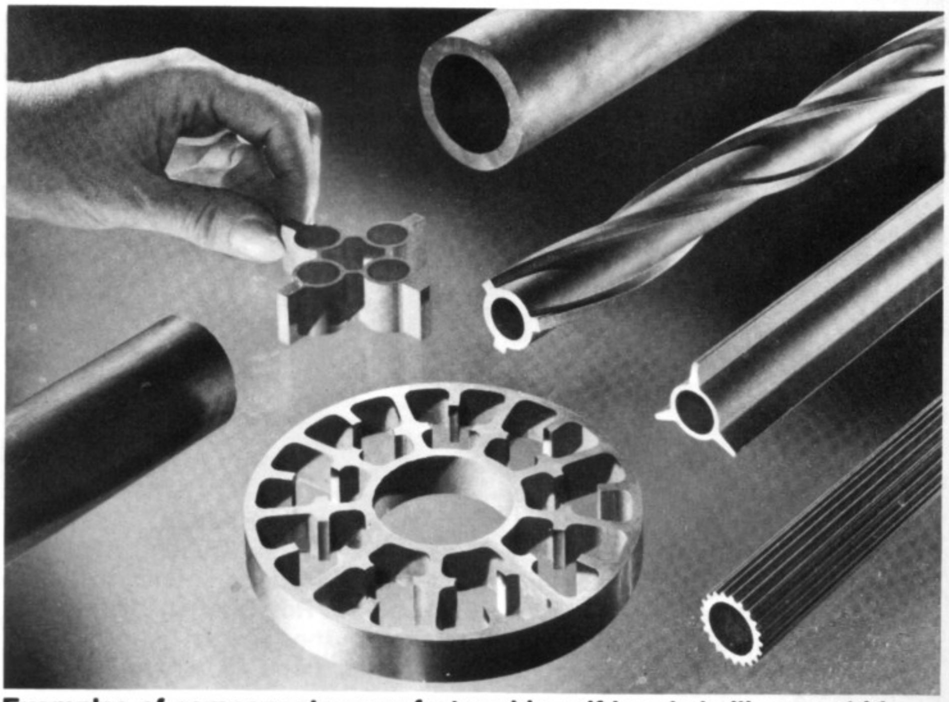
Expected sales in North and South America from the new marketing arrangement over the next three to four years could be around £2½ million.

REFEL was originally developed by the UKAEA as a cladding for nuclear fuel in high temperature gas-cooled reactors. Since then it has been used in many applications where high strength, abrasion resistance, and extreme heat resistance are required. Examples of its use include rubbing members for seals, bearings, dies, punches, forming tools, prototype components for vehicle gas turbine engines and rocket nozzles.

Pure Carbon's President, David Quinn, says that REFEL has physical properties at least ten times superior to those of carbon and is much harder than tungsten carbide and similar products. He said REFEL will add an upper dimension to Pure's already extensive line of high load capacity, abrasion resistant and self lubricating materials.

BNFL's own 10 tonne per year plant for the industrial scale manufacture of REFEL silicon carbide is now under construction at the Company's Springfields Uranium Fuels Centre near Preston, Lancashire.

*Registered Trademark of the United Kingdom Atomic Energy Authority.



Examples of components manufactured in self-bonded silicon carbide.

Queen's Award for NDT Centre

Harwell's Nondestructive Testing Centre and Rolls-Royce Limited have gained The Queen's Award for Technological Achievement for their joint development of the technique of 'Dynamic Radiography of Aero Engines'. Awards have been conferred jointly on the NDT Centre and the Advanced Projects Department, Test Operations, of Rolls-Royce Limited.

The announcement was made in a letter from The Awards Office to Mr. Roy Sharpe, Head of the NDT Centre, which read, "I have the honour to inform you that Her Majesty the Queen has been graciously pleased to approve the Prime Minister's recommendation that The Queen's Award for Technological Achievement should this year be conferred upon The Nondestructive Testing Centre at Harwell".

The accompanying citation reads, "The Centre gains the Award for the development, in collaboration with Rolls-Royce Limited, of techniques in high energy radiography. The process is used in the development of gas turbine aero engines where it is claimed to have brought about major improvements, shortened timescales and provided positive data where only references were available beforehand. By saving engine development time, considerable financial savings are achievable in the manufacture of aero engines".

Rolls-Royce themselves have put a figure of 20% on the reduction in development time that can be achieved and instance the Turbo Union RB199 (for Tornado) where the technique has shown significant savings in development time.

The dynamic radiography project, launched in March 1970, is Harwell's longest-running single collaborative venture. Since then, over 20 different engine types have been examined in detail and more than 19,000 radiographs have been taken.

Picture shows (left to right) Mr. Peter Stewart, Head of Advanced Developments Group, Rolls-Royce Ltd., Mr. Derek Pullen, who has provided a radiographic consultancy and applications service to Rolls-Royce since the project started in 1970, and Mr. Roy Sharpe, Head of the NDT Centre. The photograph also shows the special radiographic processing equipment which the Centre has used in support of this programme.

New Fracture Laboratory

A new laboratory has been set up in Harwell's Metallurgy Division to study the fracture behaviour of materials. It is being equipped with a comprehensive range of the latest testing machines that will make it one of the most advanced laboratories of its kind in Europe.

These machines give a capacity to measure a wide range of mechanical properties of metals and alloys, composite materials and ceramics. The properties being studied include conventional tensile, compression and bend properties, fracture toughness and impact properties, fatigue and creep.

The laboratory was established to meet the needs of the nuclear programme by carrying out research on metallurgical problems in nuclear plant. This is an area of vital importance in the present safety climate.

However, the laboratory is also seen as playing an important role in Harwell's industrial programme, particularly in carrying out research on the problems associated with the use of materials operating under onerous conditions in large plants.

The laboratory is already carrying out research of this sort for firms involved in the North Sea programme and in helping solve problems arising in the design and construction of large chemical plant.

To date the laboratory is equipped with nine servohydraulic machines, all of which can be linked directly to a computer for control, data acquisition and display of results. Four more are on order. Computerisation of all the equipment is in hand.

Dr. Brian Eyre, who heads the laboratory, said: "In 1978 we hope to be able to take on new work from industry. We are interested in hearing from firms looking for advanced research facilities to solve problems connected with materials for advanced plant — namely evaluating the properties and examining the safety of those materials.

"In addition we can offer contract R & D for organisations seeking simulation tests, fracture mechanics research and the acquisition of quality assurance data".

The fracture laboratory is supported by a physical metallurgical laboratory equipped with a range of thermal treatment furnaces, optical microscopes and three advanced electron microscopes. It also has the full range of Harwell research facilities — in particular those of advanced instrumentation and analysis — at its disposal.

Clayton Prize

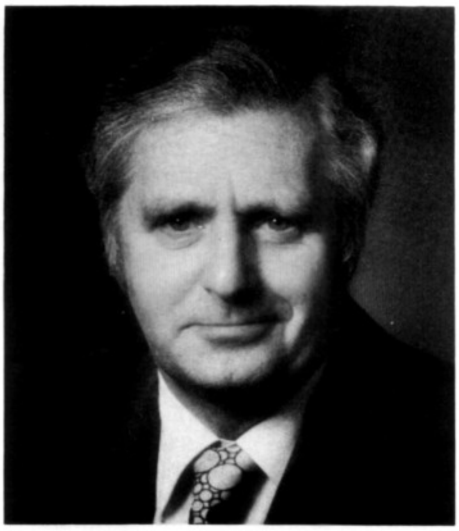
The 1977 James Clayton Prize of the Institution of Mechanical Engineers, worth £3000, has this year been awarded to two nuclear engineers responsible for the gas centrifuge process for uranium enrichment in this country.

John Tatlock MBE., CEng., FIMechE., Director of Reprocessing Division, BNFL, and Roy Lewis Pilling BA., CEng., FIMechE, Windscale General Manager, pioneered the process which is now in use at Capenhurst, near Chester.

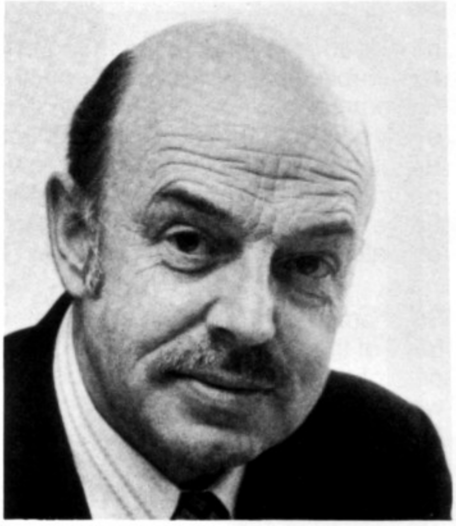
Their inspiration and leadership played a vital part in the completion of Capenhurst — the world's first full scale production plant.

They both work on the direction and developments of the process and for engineering and machine design for economic production.

The great majority of nuclear power stations use enriched uranium as fuel. Until now the process employed has been that of gaseous diffusion to increase the percentage of the lighter fissile uranium isotope of mass 235 from the natural level of 0.7 per cent, the complement being uranium 238; the gas employed in uranium hexafluoride. Very large diffusion plants have been in operation for over 25 years in the USA and the USSR, whilst a small plant has operated for some 20 years in Britain at Capenhurst, near Chester.



Mr. J. Tatlock



Mr. R.L. Pilling

The gas centrifuge process is an alternative to this diffusion process; it offers the prospect, now confirmed, of having a lower capital cost and of producing 'enrichment' with substantially lower specific electrical energy consumption.

The basic principal of the gas centrifuge for isotope separation has been known for many years. It was considered demonstrated in a high cost version and abandoned as part of the Manhattan Project.

Messrs. Tatlock and Pilling supervised the team responsible for designing the centrifuge. They played a vital part in bringing the centrifuge process for enrichment through the stage of operation of demonstration cascades to the point where a full-scale plant is now in construction at Capenhurst. This new plant is not only more economical and more flexible in matching capacity to demand but consumes only one tenth of the electrical energy required by the equivalent diffusion plant.

Aerial Survey Could Save Fuel

A countrywide aerial survey using infra-red scanning techniques to pinpoint heat losses from industrial and commercial buildings, residential areas and a city centre site, was conducted during April.

The survey was part of a research programme aimed at establishing the viability of airborne energy surveys in helping companies and other organisations analyse and control their energy use.

The programme was co-ordinated by Harwell and was estimated to cost up to £45,000 — to be shared by Department of Energy and a consortium of industrial and other organisations taking part.

The three aerial surveys, over sites in the North-West, the Midlands and the South took place at night to eliminate the reflection and warming effects of the sun, and lasted about six hours, scanning sites in a band about a third of a mile wide from a height of 1500 feet.

The data collected, together with ground information such as inside and outside temperatures, wind speed and humidity, will now be used to build up a photographic map of heat loss on the various sites. Ground surveys will be carried out by the companies together with spot measurements by Harwell's Non-destructive Testing Centre. Immediate results will illustrate problem areas such as poorly insulated roofs or leaks from lines of pipework carrying steam or hot water. However, the research is aimed at providing a detailed numerical analysis of heat loss from large areas of space heating.

From this information energy managers can work out economic levels of insulation, for example, along with other cost-effective energy-saving measures.

All objects emit infra-red radiation, the amount depending on the temperature and the nature of the surface. This emission can be picked up by instruments aboard aircraft and can be displayed as a map showing temperature differences as little as 0.3 degrees centigrade.

From this 'temperature map' actual heat loss to the atmosphere can be estimated using the other supporting measurements made on the ground.

Nuclex 78

The 5th International Fair of Nuclear Industries, Nuclex 78, from 3rd-7th October 1978 at the Swiss Industries Fair in Basle will as usual be accompanied by a programme of technical meetings and special colloquia.

The four main subjects of the technical meetings will be: Advanced reactor concepts: Fast breeder and high temperature gas-cooled reactors: spent fuel processing and nuclear waste management; operating experience with nuclear power plants; environmental and related safety aspects of nuclear technology.

Four plenary meetings, each supplemented by four special technical meetings and a panel discussion, will allow a wider and deeper treatment of the four subjects.

At the opening meeting on the day before the fair, Monday 2nd October, four speakers from the Federal Republic of Germany, France, Great Britain and Iran will read papers on the subject: "Nuclear energy: Its role and prospects in the frame of a changing energy situation".

On Tuesday 3rd October, a panel will be held on "Uranium Supply".

Wave Power Potential

"Wave power is likely to be a front-runner for this country among the renewable energy sources, and the Government is determined to give every encouragement to research and development work to explore the potential of these sources", Mr. Alex Eadie, Parliamentary Under Secretary of State for Energy, said on 19th April.

Mr. Eadie was speaking in Southampton after seeing the first sea-trials of the "Cockerell raft". The raft is one of four wave power machines* which, with financial support from the Department of Energy, is currently being tested.

He said: "The Government has already committed nearly £10 million to work on renewable energy sources.

"Today's sea-trials will show people that wave power is not just a boffin's pipe-dream, but a tangible, credible proposition.

"Surrounded as our island is by energetic waves, wave power probably offers a greater potential for the United Kingdom than any other natural renewable energy source, provided that technical problems can be overcome.

"Wave power is a concentrated source of energy that can be harnessed in volume to the electricity grid. The experts now say that there is a good chance of solving the considerable technical and engineering problems involved in getting the power out of the water and into the grid system.

"As world resources of fossil fuels become scarcer, the energy to be obtained from renewable energy sources — such as the waves, the sun, tides, winds and the heat of the earth itself — will assume increasing importance. These sources may ultimately play a valuable part in providing energy for the UK.

"The contribution that renewable energy sources can make to our energy supplies over the rest of this century is limited — perhaps to the equivalent of 10 million tons of coal a year, in 2000, compared to a total primary energy demand last year of 332 million tons of coal equivalent. We must therefore keep these renewable sources in perspective.

"But we must also remember that their contribution to our energy needs could begin to build up usefully in the first quarter of the next century.

"The present research into renewables will help to show just how far their development might be practicable and economic.

"Experts have worked out that a 600-mile stretch of wave energy machines set off the south west coast of England and off the north west of Scotland to capture the energy of the Atlantic waves could, in principle, provide about half of the UK's present electricity demand.

"Government is sometimes accused of being half-hearted in its support for renewable sources. But these sources are still at a very early stage. I must point out to the Government's critics that the problems of these teething stages will not vanish miraculously simply by having Government money thrown at them.

"The funds which are needed for, and capable of absorption in, a particular research and development project increase as the project progresses. The level of Government support that is currently going into work on renewable energy sources is, I believe, keeping pace with their progress.

"As the projects develop, the level of support is reviewed. Indeed last year Government support for the wave power programme was more than doubled.

"Of course, as we move out of research stages and into development, more money will be needed.

"The sea trials which I have seen today represent a new stage of development. And I may say that the level of support is once again under review. This new stage will take wave power out of the laboratory and into the real world of heavy engineering. It takes us a step nearer to realising the ambition of turning the immense power of the waves to man's own use."

*For details of all four machines, see "Status Report on the Alternative Energy Sources" by Dr. F.J.P. Clarke, Atom 252 October 1977.

AEA REPORTS

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

AERE-R 7897 The Computer Storage and Manipulation of Thermodynamic Data. By R.J. Dewey and M.H. Rand. February, 1978. 23pp. HMSO £1.00.
ISBN 0 70 580366 X

AERE-R 8866 Spark Source Mass Spectrometry Computer System, Part 1. Electrical Scanning Mode. By J.W. Giltrap, D. Mapper and J. Farren. January, 1978. 20pp. HMSO £1.00.
ISBN 0 70 580139 X

AERE-R 8933 Sabre. A System for the Assessment of Body Radioactivity. Part 2. Main Features of Sabre 3. By J.B. Venn. January, 1978. 31pp. HMSO £1.50.
ISBN 0 70 580059 8

AERE-R 9069 A Design for a General Purpose Computerised Information Retrieval System. By F.N. Teskey. February, 1978. 18pp. HMSO £1.00.
ISBN 0 70 580169 1

ND-R 122 (R) Calculations of Stress Intensity Factors Using the UNCLE Finite Element System and their Application in Fracture Mechanics. By J.H.B. Pearce, February, 1978. 18pp. HMSO £1.00.
ISBN 0 85 356104 4

AERE-R 8769 Modelling as an Aid to Solid Waste Management Planning, A State of the Art Report. By D.C. Wilson. May, 1977. 127pp. HMSO £3.00.
ISBN 0 70 580118 X

AERE-R 8903 Radioactive-Nuclide Decay Data for Reactor Calculations. Activation Products and Related Isotopes. By A.L. Nichols. September, 1977. 235pp. HMSO £4.50.
ISBN 0 70 580388 0

AERE-R 8925 Calibration of the Harwell Linac Mark 2 Total Scattering Spectrometer. By P.A.V. Johnson, A.C. Wright and R.N. Sinclair. January, 1978. 21pp. HMSO £1.00.
ISBN 0 70 580488 7

AERE-R 8946 Heat Transfer to Accelerating Gas Flows. By T.D.A. Kennedy. January, 1978. 18pp. HMSO £1.00.
ISBN 0 70 580019 9

AERE-R 8956 A Theoretical Investigation of Electron Microscope Observations of Fission Gas Bubble Distributions in a Mixed Oxide Fast Reactor Fuel Pin. By M.H. Wood and M.R. Hayns. November, 1977. 15pp. HMSO £1.00.
ISBN 0 70 580498 4

AERE-R 8971 A FORTRAN Subroutine for Comparing Two Files. By S. Marlow and J.K. Reid. January, 1978. 24pp. HMSO £1.00.
ISBN 0 70 580069 5