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**NUMBER 254** **DECEMBER 1977**

# atom

**The JET project**

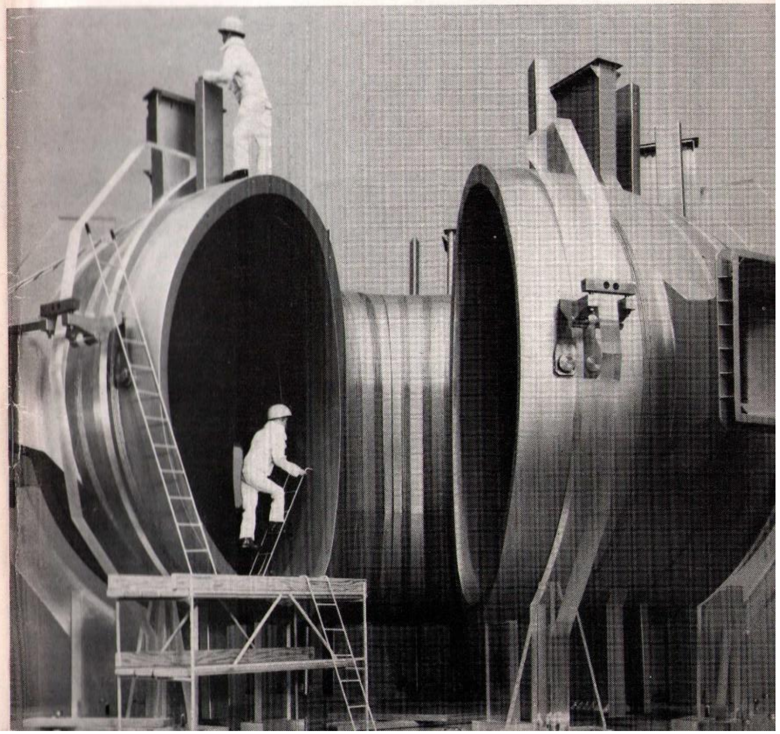
**The Culham Laboratory**

**The Energy Commission—UK energy policy**

**Nuclear power and the future of society**

**Nuclear power and the energy future**

**TRCL annual report**



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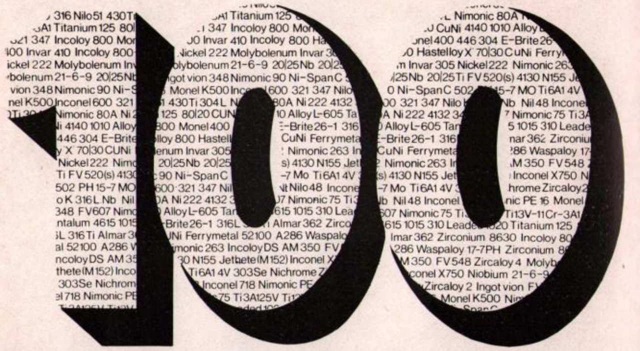

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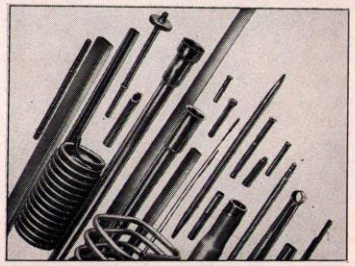

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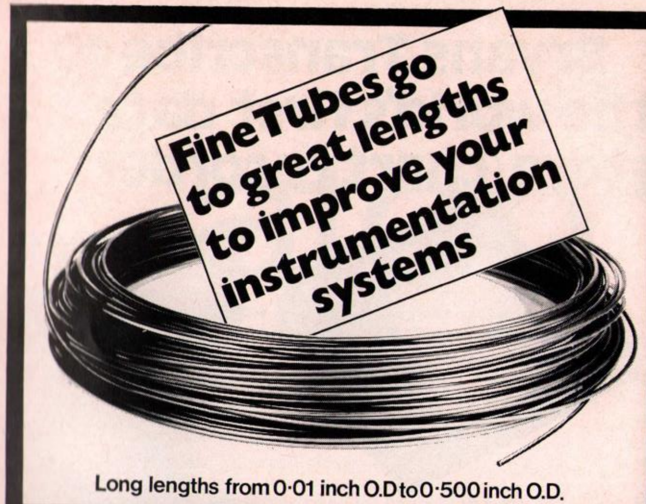


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| .090 | — | 200 | 300 | 1000 | 1200 | 1000 | 1000 | 800 | — | — | — | — | — | — | — | — |
| .080 | — | 150 | 300 | 1000 | 1100 | 800 | 800 | — | — | — | — | — | — | — | — | — |
| .070 | — | 150 | 300 | 500 | 700 | 600 | — | — | — | — | — | — | — | — | — | — |
| .060 | 100 | 150 | 300 | 400 | 600 | — | — | — | — | — | — | — | — | — | — | — |
| .050 | 100 | 150 | 300 | 400 | — | — | — | — | — | — | — | — | — | — | — | — |
| .040 | 100 | 150 | 300 | 400 | — | — | — | — | — | — | — | — | — | — | — | — |
| .030 | 100 | 150 | 200 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| .020 | 100 | 150 | 200 | — | — | — | — | — | — | — | — | — | — | — | — | — |
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| .076–.080 | .005 | .156–.160 | .010 |
| .081–.085 | .005 | .161–.165 | .010 |
| .086–.090 | .005 | .166–.170 | .011 |
| .091–.095 | .006 | .171–.175 | .011 |
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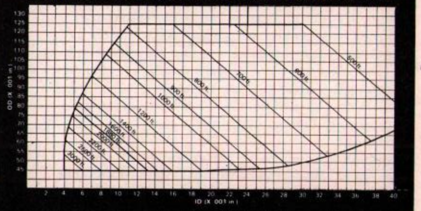


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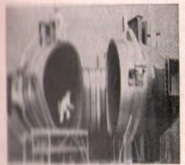

Front cover: A scale model of the vacuum chamber of JET.



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# THE JET PROJECT

by Dr. A. Gibson, Deputy Manager (Physics),
JET Design Team.

**JET is a proposed major European nuclear fusion experiment, intended to be the mainstay of the fusion programme of the European Communities for the next decade. The experiment has been designed by a team of European scientists and engineers seconded from their national laboratories and invited by the UKAEA to work at the Culham Laboratory.**

## Introduction

The production of energy by the nuclear fusion of light elements represents a vast resource for mankind. The most accessible reactions use deuterium and lithium as the primary fuels. The former is abundant and available as a common isotope of hydrogen while presently known and inferred reserves of lithium, extractable at present prices, have a fusion energy content of about 1 000Q (1Q = $10^{21}$ joules and present total world energy consumption is about 0·2Q). Further immense reserves of lithium exist in the oceans (equivalent to some $10^7$Q of fusion energy).

The release of this energy requires that very hot mixtures of hydrogen isotopes be contained together long enough for a significant number of reacting collisions to occur between atomic nuclei. The high temperatures are necessary in order that thermal collisions between the nuclei can overcome the Coulomb barrier between them. The temperatures ($\gtrsim$10keV or $10^8$K) and the densities (typically $>10^{14}$cm$^{-3}$) are such that the hydrogen atoms are fully ionised and a macroscopically electrically neutral, tenuous fluid of electrons and ions is formed. Such a fluid, whose constituents interact by long range Coulomb forces, is known as a plasma. The containment system in which the plasma resides must effectively insulate the plasma, to keep it hot, and must prevent contact with material walls which would otherwise be eroded, leading to contamination and radiation cooling of the plasma.

The large scale release of fusion energy has so far occurred only in the gravitationally confined stellar systems and in the inertially confined hydrogen bomb. The gravitational approach cannot be reproduced on a terrestrial scale and, while steam generation from subterranean nuclear explosions has been considered, the bomb approach is not being pursued at present. There remain two promising avenues to controlled fusion, the first is again based on inertial confinement but depends upon the implosion of small pellets of fusion fuel, the second depends upon magnetic confinement of the electrically conducting plasma. The advent of high powered lasers has meant that, for the first time, inertial confinement can be seriously considered on a laboratory scale and large research programmes in the USA and USSR are now undertaken in this area. Magnetic confinement on the other hand has been regarded as the most promising approach since the inception of fusion research in the 1950s and remains the main line in the world programme. The JET project is the major new European experiment proposed in this area of magnetic confinement.

## Requirements for a self-sustaining plasma

The most accessible reaction is:

$$^2_1D + ^3_1T \rightarrow ^4_2He + ^1_0n \qquad (1)$$
$$(3{\cdot}52MeV) + (14{\cdot}06MeV)$$

and for a power system this would have to be supplemented by the tritium breeding reactions

$$^1_0n + ^6_3Li \rightarrow ^3_1T + ^4_2He + 4{\cdot}8MeV \qquad (2)$$
$$^1_0n + ^7_3Li \rightarrow ^3_1T + ^4_2He + ^1_0n - 2{\cdot}5MeV \qquad (3)$$

Other reactions such as the D-D reactions (which use more abundant fuel) or the p—$^{11}$B reaction (which produces no neutrons) offer advantages but pose much more stringent conditions on the plasma containment system and are unlikely to be used in the first reactors.

The condition that the reaction (1) be self sustaining, i.e. that the energy deposited in the plasma by the fusion generated $\alpha$-particles, exceeds the energy loss from the plasma (characterised by an energy replacement time $\tau_E$) is:

$$n\tau_E > (2 \rightarrow 4) \times 10^{14}\text{cm}^{-3}\text{s}$$
$$\text{and } T_i \gtrsim 10\text{keV}$$

where n is the mean plasma density (particles/cm$^3$), $T_i$ is the ion temperature in energy units and the constant in the $\tau n_E$ value depends on the radial profiles and operating temperature.

## Magnetic confinement systems

A great many different magnetic confinement systems have been studied during the past twenty years. The fact that plasma can move freely along the direction of a magnetic field but much less easily across the field has given emphasis to toroidal systems where motion parallel to the magnetic field never leads out of the system. The simplest toroidal magnetic system is that formed by the closed field lines generated by a set of coils on a torus as in Fig. 1. This field is necessarily inhomogeneous and charged particle drifts in the inhomogeneous field are oppositely directed for ions and electrons. This gives rise to a charge separation electric field which ensures that the system gives no confinement of plasma at all. The simplest toroidal system which does exhibit confinement is shown in Fig. 2. The plasma current flowing parallel to field lines introduces a field in the poloidal direction so generating a system of toroidally helical field lines lying on nested magnetic surfaces which form a confinement system and which permit cancellation of the charge separation due to drifts. Classically in such a system the field of the plasma current (poloidal field) supplies the confinement of the plasma while the applied toroidal field is necessary to ensure magnetohydrodynamic (MHD) stability.

There are two variants of this toroidal pinch system: the first has the poloidal field greater than the applied toroidal field; the second has a greater toroidal field giving advantages for MHD stability. The second type of system was first studied in the USSR where it was given the name "Tokamak".

## Tokamak systems

There has been remarkable progress with tokamak systems over the past decade as is illustrated in Fig. 3 where the increases obtained in electron temperature, ion temperature and density-confinement time product are illustrated. Presently ion and electron temperatures of 2 keV have been obtained with $n\tau_E$ values of $10^{12}$cm$^{-3}$s. Larger $n\tau_E$

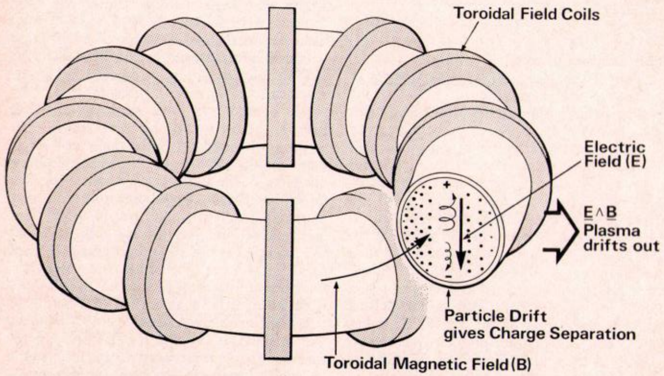


**Fig. 1 A toroidal magnetic field.**

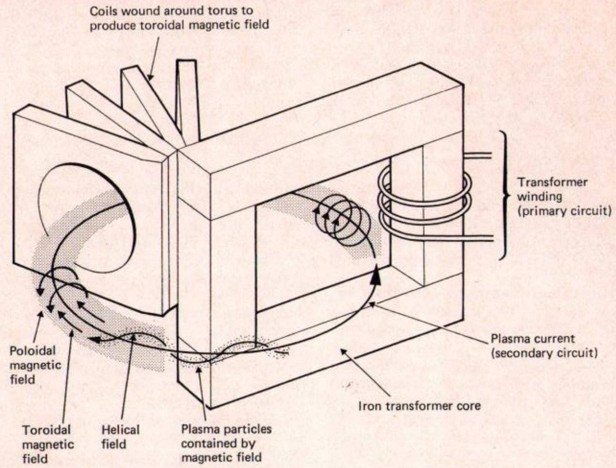


**Fig 2 Tokamak configuration.**

values ($10^{13}cm^{-3}s$.) are obtained in higher density tokamaks at temperatures of 0·8 keV. Thus further increases of a factor 5 in temperature and a factor 20 in $n\tau_E$ value are required to reach the minimum values necessary for a reactor.

## The design phase

In view of this progress, discussion began in Europe at the beginning of 1971 on the advisability of building a tokamak experiment, JET (Joint European Torus) large enough to bridge the gap between the largest experiment then planned (the US PLT experiment characterised by a design plasma current of 1MA, which came into operation in 1976) and a future experimental reactor, expected to require plasma currents in the range 10 to 30MA. The JET design team was established in September 1973 to design such an experiment, which was envisaged as having a plasma current of about 3MA with minor plasma radius in the region of 1m. Dr. P. H. Rebut (CEA) a French engineer-physicist was chosen to lead the team and the professional staff was seconded from the Associated European Fusion Laboratories (approximately seven each from: Federal Republic of Germany, France, Italy, and UK and one to two each from Belgium, Denmark, EURATOM, Holland and Sweden). The UKAEA invited the team to work at its Culham Laboratory and supplied the majority of the support staff.

This team completed the main design of the project by the summer of 1975 and it is fully described in the design proposal EUR-5516e (EUR-JET-R5). In the period from Summer 1975 detailed design has proceeded, tendering specifications have been prepared and some major components have been ordered (see below).

The construction of JET is the largest single item in the five year fusion programme (1976-80) of the European Communities. The target date for the crucial decisions on project approval, authority to recruit staff and selection of site, was 1st January, 1976 but the complexity of the European decision making process, including the need for unanimity of decision by the responsible body (Council of Ministers) has led to a period of delay and uncertainty. In October 1977 Culham was selected as the site for JET and the remaining decisions necessary for construction to begin are expected to be taken during an interim period scheduled to be complete early in 1978.



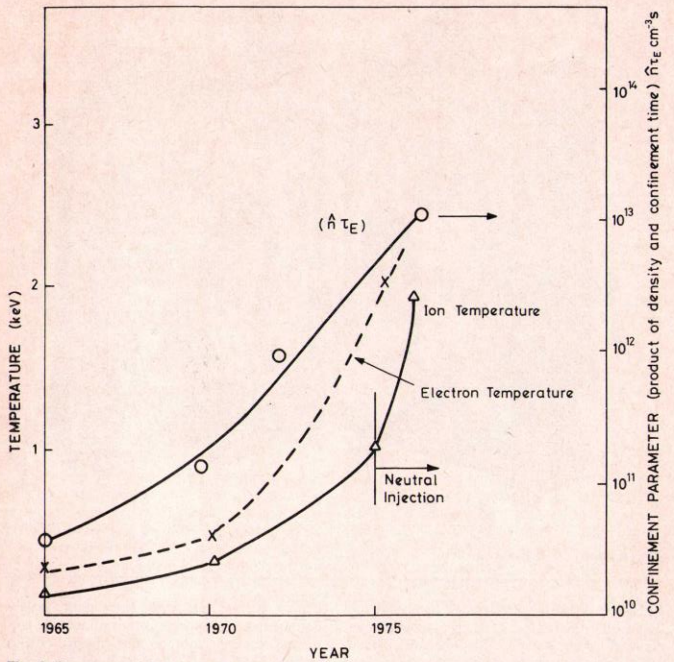


**Fig. 3 Progress with tokamak systems.**

## Objective

The objective of the JET experiment is to obtain and study a plasma in conditions and with dimensions which approach those needed in a fusion reactor (that is densities approaching $10^{14}$ $cm^{-3}$; temperatures exceeding 5 keV and plasma minor radius in excess of 1m). The realisation of this objective involves four main areas of work which are as follows:

(1) The study of the way the confinement properties scale as the dimensions and plasma parameters approach the reactor range.

(2) The study and control of plasma-wall interaction and impurity influx in these conditions.

(3) Demonstration of effective heating techniques capable of producing high temperatures in the presence of the prevailing loss processes.

(4) Operation in conditions where $\alpha$-particles from deuterium-tritium reactions are produced and confined and study of the subsequent plasma interaction and heating.

Completion of this experimental programme on JET will be sufficient to establish the dimensions, parameters and plasma behaviour to be expected in a future reactor.

## Choice of parameters

The plasma current in a tokamak controls the displacement of particle orbits from magnetic field lines and so determines the plasma collisional diffusion rate and the orbit con-

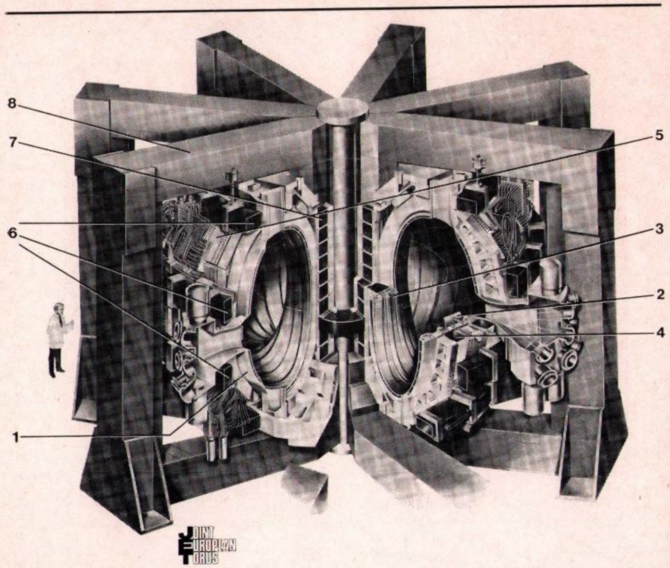


Fig. 4 The JET apparatus.

tainment of energetic particles such as fusion generated $a$ particles. The energy confinement time in tokamaks increases when the dimensions and magnetic fields and hence the plasma current increase. The ratio ($\beta$) of plasma pressure to magnetic field pressure (an important economic parameter) increases with plasma elongation. However, the detailed way in which the plasma performance will scale with dimensions and fields is not known and a variety of parameter choices are possible for an experiment with the JET objective. In JET the choice has been to maximise the plasma current, for given cost, while maintaining the operational flexibility to investigate a range of configurations and heating methods and while remaining within conventionally accepted stress limits on the magnetic field coils. This has led to a design with tight aspect ratio (i.e. a fat torus) which leads to larger plasma current and with a D-shaped minor cross section which increases the plasma current, reduces the coil stress and increases the sustainable $\beta$.

The requirement to contain the $a$ particle orbits and to have sufficiently good plasma confinement to approach thermonuclear conditions suggests a minimum plasma current around 3MA and JET is designed to operate in the 3 to 5MA range depending on the degree of plasma elongation which proves possible. The toroidal field required is then determined by the requirement for MHD stability. The apparatus dimensions are determined by the mechanical stress limits on the coils and the space required for the primary transformer flux.

## The apparatus

The JET apparatus is illustrated in Fig. 4 and consists essentially of a vacuum vessel, a toroidal field magnet, a transformer and its primary coils. The plasma forms the secondary of the transformer. The field created by the plasma and the transformer coils is the poloidal field. The poloidal field system both drives the plasma current and provides its equilibrium.

The vacuum chamber (1) is composed of a series of thick box sections and bellows and is made from Inconel. This structure is able to resist the forces which arise from atmospheric pressure and from the current induced during the rise of the toroidal field. At the same time it has a sufficiently large electrical resistance to restrict the flow of toroidal vessel current to an acceptable level.

The plasma edge is defined by a refractory metal limiter made from a series of sections forming an axisymmetric ring at large major radius (2). There is also a series of poloidal protective shields (3) which prevent the plasma touching the bellows and thin sections of the chamber. The vacuum vessel is designed to be baked to 300-500C°. The diagnostic and additional heating ports are as shown and have the following dimensions:

radial ports: 46 × 96 cm (28 cm quasi tangential)
straight-through vertical ports: 14 × 83 cm and: 7 × 28 cm

The toroidal field magnet is formed by 32 D-shaped coils (4). A mechanical shell (5) withstands the torque which arises when the poloidal field crosses the toroidal field coils, this shell also forms the interface between the toroidal and poloidal field coils.

The poloidal field coils (6) and (7) are connected in parallel in order to simulate a copper shell acting against axisymmetric deformations or displacements of the plasma. The poloidal field coils (7) around the central magnetic core create the primary flux, and are split into 12 identical coils, which are easier to manufacture than a single coil. In order to obtain the maximum flux, the central section of core is driven far into saturation. The external magnetic circuit (8) is made up of 8 limbs which do not saturate.

The toroidal and poloidal field power supplies are a combined static and flywheel system and the poloidal field supply makes provision for major radius compression of the plasma. Typical before and after positions of a compression plasma are shown in Fig. 5.

The neutron production from D-D and D-T discharges and the hard X-rays which can be produced in hydrogen discharges require that JET should be built inside a 2·5m thick protective concrete shield.

The main parameters of the JET apparatus are in Table I. It will be seen that while a plasma current of 2·6MA is available in a circular cross section plasma at basic performance this is increased to 3·8MA when the full D-shaped cross section is used and to 4·8MA at the extended performance (which requires extra power supplies beyond those in the basic performance cost estimate).

## Operating sequence

The operating sequence begins with the energising of the toroidal magnetic field coils and reverse magnetising of the transformer core. The plasma sequence is initiated by opening a circuit breaker in the primary circuit to induce ~ 150 volts/turn while filling the torus with hydrogen gas (typically $10^{-4}$ to $10^{-3}$ Torr) and suitably preionising it. The poloidal field circuit is then driven so as to increase the magnetisation in the opposite

**Table I Main JET parameters.***

| Parameter | | Value | |
|---|---|---|---|
| Plasma minor radius (horizontal) | a (m) | 1·25 | |
| Plasma minor radius (vertical) | b (m) | 2·10 | |
| Plasma major radius | $R_o$ (m) | 2·96 | |
| Plasma aspect ratio | $R_o/a$ | 2·37 | |
| Plasma elongation ratio | b/a | 1·68 | |
| Flat top pulse length | (s) | 20 | (10) |
| Toroidal magnetic field (at plasma centre) | (T) | 2·77 | (3·45) |
| Plasma current | | | |
| —circular plasma | (MA) | 2·6 | (3·2) |
| —D-shape plasma | (MA) | 3·8 | (4·8) |
| Volt-seconds available | (V.s) | 25 | (34) |
| Toroidal field peak power | (MW) | 250 | (380) |
| Poloidal field peak power | (MW) | 200 | (300) |
| Additional heating power (in the plasma) | (MW) | 10 | (25) |
| Weight of the vacuum vessel | (t) | 68 | |
| Weight of the toroidal field coils | (t) | 380 | |
| Weight of the iron core | (t) | 2 500 | |

*The first figure in each line is that realisable with the initially planned power supplies. The figures in brackets correspond to the performance obtainable (within the design thermal and stress limits) by extending the power supply at extra cost.

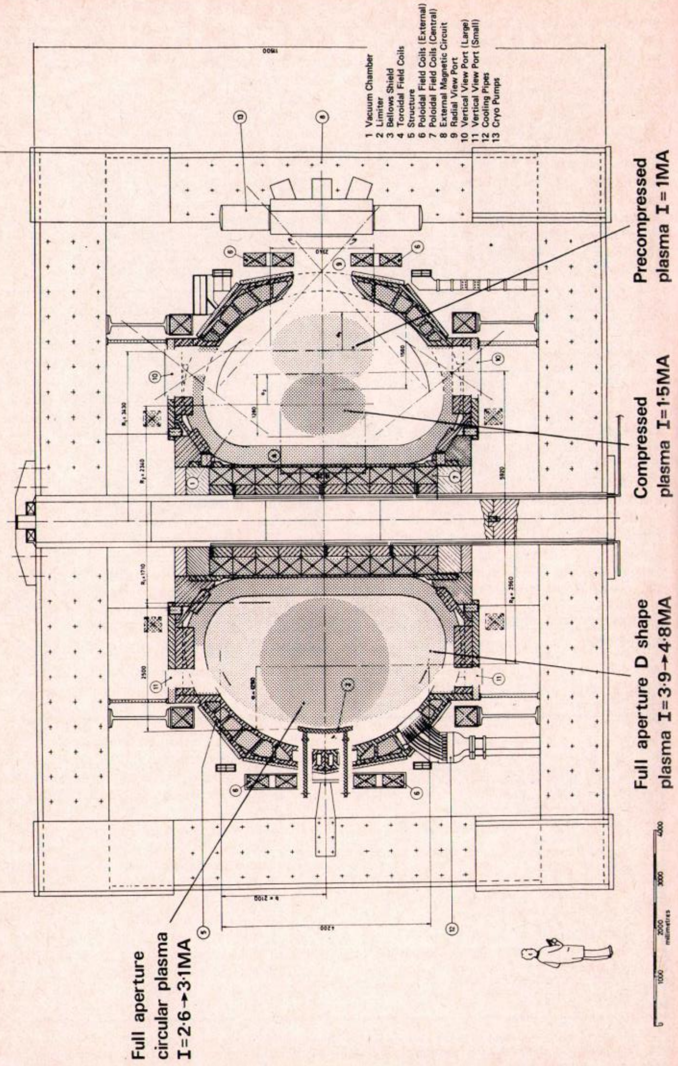


Fig. 5 Plasma configurations in JET.





**Table II Outline of Experimental Programme.**

| 1983 | 1985 | 1986 |
|---|---|---|
| Phase I: Exploratory Studies using hydrogen plasma | †↑ Phase II: Improvement of Plasma Performance | Phase III: Fusion Studies using deuterium-tritium plasmas |
| —establish a range of operating conditions<br>—scaling studies<br><br>—work up to maxima plasma current for installed power supplies including use of D-shaped cross-section<br>—examine additional heating<br>—investigate impurity effects<br>—establish limits of operation<br>—decide on future power supplies<br>—decide whether a divertor is needed | —enhance power supplies<br><br>—examine heating methods using internal structures<br><br>—increase heating power<br>—fit divertor if necessary<br>—try new limiter or wall materials | initiate fusion experiments using:<br>(*a*) non-Maxwellian beam-plasma methods, with compression<br>(*b*) thermonuclear self-heating if possible |

†If results from Phase I are extremely favourable.

direction, build up the plasma current to its design value and maintain it for the pulse duration.

## The experimental programme

The objectives of JET will best be realised by a programme of phased exploitation. Such a programme is described below and summarised in Table II.

*Phase I: Exploratory studies*

This phase will begin in the final stages of machine commissioning when operating regimes at low plasma currents will be established. A period of several months will be necessary to establish reliable operation at currents up to 3MA. The plasma current will then gradually be increased taking advantage of the D-shaped cross section to the limit set by the power supplies and plasma behaviour. A decision will be taken as to whether to order further power supplies for later phases of operation. During this phase no internal structures will be allowed in the torus, and the vacuum vessel will be opened as infrequently as possible. Reliability will thus be maximised and wall conditions will be as constant as possible.

Experimental data (densities, temperatures, profiles, fluctuation behaviour etc.) will be compared with transport and stability computer codes, which in turn should suggest optimum regimes of operation. The importance of wall interaction and impurity effects will be assessed, and a range of heating methods, including neutral injection, high frequency heating and plasma compression will be examined. By the end of the phase the full range of parameters possible with the available power supplies and heating methods will have been established. This phase of operation may well occupy two to three years.

*Phase II: Improvement of plasma performance*

The form of Phase II operation will depend on the outcome of Phase I. At one extreme, if very favourable plasma parameters are obtained, it will be possible to go directly to Phase III; at the other extreme Phase II will constitute the bulk of the experimental programme and will involve the exploration of heating and impurity control for future experiments. In this phase, internal structures (for example radio frequency antennae) will be allowed so that a wider range of heating methods can be investigated. It may prove necessary to enhance the power supplies or to install a modified vacuum vessel assembly for impurity control (e.g. divertor*, special wall, etc.).

*Phase III: Fusion studies*

The object of experiments in this phase will be to establish the stability of plasmas with profiles controlled by the balance between fusion power generation and conduction and radiation losses. The effect of a third species (fast $\alpha$ particles from fusion reactions) on plasma behaviour will be evaluated. The

*A device for channelling the outer layers of plasma into a separate dump chamber.

**Table III**

| Situation | Possible Main Strategy |
|---|---|
| Control methods developed so that impurities and instabilities do not seriously limit performance | (a) Advance preparation for activation<br>(b) Develop JET towards maximum current<br>(c) Carry out D-T experiments |
| Instabilities appear and limit plasma parameters | (a) Study physics and scaling of dominant mode. Assess importance for reactor conditions<br>(b) Increase auxiliary heating; use major radius compression<br>(c) Use beam-plasma fusion to study $\alpha$-particle effects |
| Impurity influx limits plasma performance | (a) Consider intense high energy injection into a small hot plasma core separated from wall by cold plasma<br>(b) Consider adding a divertor |

diffusion and pressure of the $\alpha$ particles will modify the plasma equilibrium.

Discharges with appreciable fusion power generation may be produced either by an approach to true thermonuclear ignition (self sustaining condition) or by injection of high energy deuterons into tritium. In this latter case it is likely that a "break-even" condition will be reached where the total fusion power released is equal to the total beam power injected; however the plasma profiles will be controlled by the injected beams rather than by the fusion generation. Except in the case of $^3_2He$ injection there will be a large release of neutrons and the consequent activation problems will severely restrict access to the machine and in the event of a major failure, may result in only a relatively small number of discharges being available. Consequently the experimental programme for this phase will have to be very carefully planned, the maximum possible information being extracted from each shot (the discharge duration may be several seconds).

*Time scale*

The earliest starting dates for the various phases are as follows:

Phase I 1983
Phase II 1985
Phase III 1986 (or 1985 if results from Phase I are extremely favourable).

## Experimental strategies

Within the broad outline discussed above, the experimental programme must retain sufficient flexibility to respond to developments in the world-wide field of tokamak research. The lines along which the programme would develop for the three most likely situations are shown in Table III. The choice of strategy for JET will be determined by results from the European and World programmes during the construction of JET and by the results from the first phase of JET itself. Note that only if it is necessary to fit a divertor will there be a prolonged interruption of JET operations.

## Additional heating

The plasma current, necessary for confinement in a tokamak, also serves to heat the plasma ohmically. Until recently this was the only form of heating on tokamaks, but it has long been recognised that the decrease of plasma resistance with temperature requires that additional forms of heating be used to reach reactor conditions. The most successful additional heating method at present is neutral injection, in which beams of energetic (30 keV at present, up to 80 keV in JET) neutral hydrogen are injected into the plasma across the magnetic field. The first neutral beams were injected into the CLEO tokamak at Culham in 1972 and subsequently their use on other tokamaks (e.g. TFR in France) has increased the ion temperature from 1 keV to 2 keV (see Fig. 3).

In JET and also in a reactor the ohmic current density will be smaller and the required temperatures greater than in present devices so that additional heating becomes very important. In JET, 4 to 10MW of neutral injection heating will be supplied in Phase I increasing to 25MW or more if necessary, in later phases.

The development of neutral injectors for JET is being carried out by the Culham (UKAEA) and Fontenay (CEA) Associated Laboratories and 0·5 → 1MW test bed lines are expected to operate at 60 → 80 keV by early 1978. In addition to this work the Grenoble and Fontenay Laboratories (CEA) are developing radio-frequency methods of plasma heating which should be available, at least for evaluation, during Phase I of the JET programme.

## Operation in active conditions

The later phases of JET operations will involve the production of copious quantities of neutrons. Initial work using a D-D plasma will give rise to neutron production of up to a few × $10^{17}$ neutrons/pulse leading to appreciable activation of the inside of the torus after a few thousand pulses. This activation level will not seriously limit access to the outside of the torus. Beam-plasma, D-T operation near the "break-even" condition would lead to about $10^{19}$ neutrons/pulse, while achievement of true ignition could lead to up to $10^{20}$ neutrons/pulse (this is the figure used as an upper limit for safety assessments). These levels would make maintenance operations very difficult and time consuming after a few thousand or a few hundred discharges respectively.

To design JET at this stage for the complete remote repair of any failure which might occur in fully active conditions would lead to an unacceptable escalation in cost and construction time. This escalation is not justified at the present stage of tokamak research where the uncertainty in the predicted ($n\tau_E T$*) product for JET is more than an order of magnitude, and consequently the degree of activation to be produced is correspondingly uncertain. Rather, the extensive study of a self-sustained neutron-producing fusion system is the province of the stage after JET in the fusion research programme.

In these circumstances the design philosophy for active operations in JET is such that active operations will be considered only after a period of operation in hydrogen (or hydrogen-deuterium mixtures) has demonstrated that the apparatus is sufficiently reliable to give a reasonable expectancy of at least a few thousand D-T discharges, without the need for extensive modification or repair. As much diagnostic equipment as possible will be located outside the main shielding wall, rather than in the torus hall. Weak points at penetrations of the vacuum vessel such as windows and valves, will be minimised and subjected to rigorous design and testing procedures. During the construction and hydrogen operation periods there will be extensive development and practice related to the remote handling operations proposed. These include provision for remote replacement of peripheral equipment and, in the event of a major failure, remote removal and replacement of a complete octant of the apparatus.

## Operational flexibility

A special problem for large experiments such as JET is the long construction period involved (five years in this case). During construction, and for that matter the operation too, other experiments in World and European laboratories, including Culham, will continue to produce new information which should be allowed to influence the JET programme. On the other hand the design is already committed and could only be changed at considerable cost and delay of the operating date. Consequently the JET design has been chosen to permit operation over a wide range of plasma shapes, sizes, currents and magnetic fields. Good access has been provided to accommodate a variety of high power heating methods and the vacuum vessel and circuitry permit compression heating of the plasma. The large vessel dimensions allow the possibility of using the outer plasma layers as a cool blanket for impurity control while retaining a large aperture for hot plasma. A mode of operation is possible in which an initial small plasma is grown by the addition of energetic particles to an expanding plasma. These features are expected to enable JET to take advantage of developments as they occur without changing the design of the basic apparatus. Two recent examples are: (a) indications by simulation codes of effective impurity control by the use of a cool plasma blanket and (b) theoretical indications that higher plasma pressures might be achievable with a suitably profiled D-shaped plasma. These two developments took place after the design was fixed but the design flexibility is such that they can be investigated in the JET experimental programme.

Some possible developments such as the use of very large toroidal fields (the maximum in JET at reduced aperture is 4·4T), or the study of radically different toroidal configurations (reverse field pinches or stellarators) could only be studied by building a complete new load assembly. These approaches have to be, and are being, studied on smaller scale

*Product of mean density, energy replacement time and temperature which forms an approximate measure of the approach to the self sustaining condition when T is greater than ~5keV. As stated earlier the value at the self sustaining condition is $n\tau_E T^* \sim 4 \times 10^{15} cm^{-3}.s.keV$.

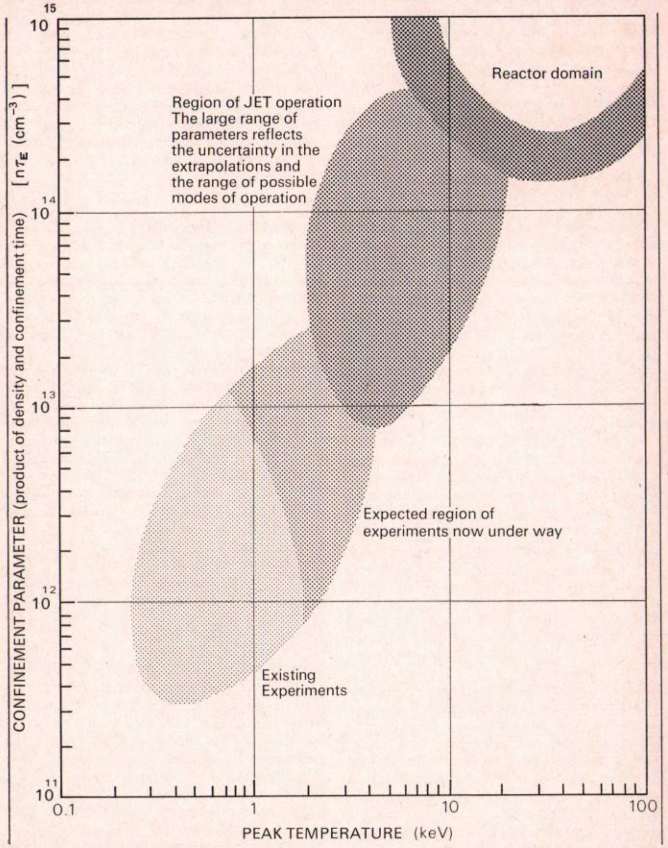


**Fig. 6 Performance predictions for JET.**

experiments before they are considered for apparatus on the scale of JET.

## Plasma parameters

The main reason for the JET experiment is to discover how the plasma density, temperature and confinement time scale as the current and physical dimensions increase from present day experiments. Consequently it is not possible to give accurate estimates of the parameters that will be obtained. Nevertheless a variety of predictions has been attempted, ranging from empirical extrapolation to advanced simulation codes. The simulation codes are valuable for studying the interaction of various processes such as the sputtering of wall materials, the transport of impurities and the stability with respect to specific theoretical modes. Of course, since the basic transport processes are not known, the absolute parameter predictions of these codes have to be treated with caution. However, the codes are developing and are being increasingly refined by detailed comparison with experiment so that they have become an essential tool of interpretation. The reliability of their predictions can be expected to improve as the experimental programme progresses.

The range of predictions for JET is compared with some present experiments in Fig. 6. The predictions indicate that, except for the most pessimistic theoretical loss processes, it should be possible to reach $n\tau_E$ values well in excess of $10^{13}$ $cm^{-3}s$. Peak ion and electron temperatures in excess of 5 keV should be possible even in the worst cases either by combining 10MW of injected power with plasma compression or by using ~25MW of injected power directly. In the most favourable cases, at extended performance, conditions may be reached in which a deuterium-tritium plasma would be self sustaining and in any case it will be possible to release substantial fusion energy by using reactions generated by an injected beam (e.g. 100→160 keV deuterium neutrals) on a tritium target plasma.

## Project cost and construction staff

The total cost of the project, including contingency, is estimated at $7{\cdot}5 \times 10^9$ Belgian francs at January 1977 prices or £119 million at the exchange rate of March 1977. This capital amount is distributed as follows:

| | |
|---|---|
| JET load assembly | 22 per cent |
| Power supply | 17 per cent |
| Staff costs | 24 per cent |
| Buildings | 11 per cent |
| Plasma heating, Control, Plasma diagnostics, Preparation for operation | 18 per cent |
| Special reserve | 8 per cent |

It is at present expected that 80 per cent of these funds will be provided through the EURATOM system while 10 per cent will come directly from the country in which the site is located and 10 per cent directly from all the partners.

The construction staff will come from all the community countries, although in the case of support staff it is probable that rather more will come from the host country than from elsewhere. The total staff is expected to build up to 390 by the end of the construction phase and of these about 120 will be professional engineers and scientists.

## Status

A system of staged contracts has been devised for the major machine components. The manufacturer is committed to a complete contract at fixed price (with an inflation clause) and the contract is released in stages, typically: detailed manufacturing design; construction of one unit; construction of remaining units. In this way contracts have already been placed for: the toroidal field coil copper (the first samples are already delivered to the coil manufacturer); the toroidal field coils; the large vacuum vessel bellows and the rigid sectors of the vacuum vessel. Significant dates in the development of the JET project are listed in Table IV.

## Relation to other projects

The JET construction budget represents about 25 per cent of the total proposed five-year European Fusion Programme. Thus, in parallel with the construction of JET, other fusion programmes, including that at Culham, will be producing information relevant to tokamak systems. The most important areas for JET on which progress can be expected during the next five years are as follows:

(a) Understanding of plasma transport processes.

(b) Study of methods of plasma heating.

(c) Plasma impurity behaviour and the control of impurity influx.

(d) Control of plasma profiles (current, density and temperature).

Projects of similar magnitude to JET are also being undertaken outside the Community. These projects show sufficient similarities to and differences from JET to both complement and supplement the JET programme. Thus the TFTR project in the USA is approved at a similar capital cost to JET and the site and principal industrial subcontractors have been selected. The project concentrates on circular cross section plasmas with somewhat smaller plasma currents and dimensions than JET (2·4MA with a minor radius of 0·85m) but somewhat larger toroidal field (5·2T with consideration of the possibility of limited 6·0T operation). The project lays great emphasis on the injected beam/target plasma mode of operation and will move to operation with tritium at the earliest possible date.

The JT-60 project in Japan has received development funding and full approval is said to be imminent. The plasma current is to be 3MA with a minor radius of 0·8m inside a much larger toroidal coil. The apparatus is

Table IV Significant dates in the progress of JET.

| | | | | |
|---|---|---|---|---|
| | 1960 | — | Soviet tokamak programme begins | 1960→1969 International preliminaries |
| | 1969 | — | Culham Laser Diagnostics Group confirms high performance of Soviet tokamak T-3 | |
| | | — | Rapid expansion in world tokamak programme | |
| EARLY | 1971 | — | Tokamak Advisory Group first discussions of a European large tokamak | 1971→1973 European discussions |
| FEBRUARY | 1972 | — | European torus working group meets | |
| MARCH | 1973 | — | ETWG proposes a 3MA tokamak for Europe | |
| JULY | 1973 | — | Agreement to set up a design team | |
| SEPTEMBER | 1973 | — | Design team assembles at Culham | 1973→1975 JET Design evolved |
| JANUARY | 1974 | — | Outline design and first set of dimensions | |
| APRIL | 1974 | — | First proposal EUR-JET-R2 available | |
| JULY | 1974 | — | Cost estimate available | |
| SEPTEMBER | 1974 | — | JET parameters approved by EURATOM Groupe de Liaison | |
| MAY | 1975 | — | Design proposal submitted to JET Supervisory Board (EUR-JET-R5) | |
| MAY | 1975 | — | Funds for certain long delivery items released (total 3MUC = £1·3m) | |
| JANUARY | 1976 | — | Orders for certain preproduction coils and bellows approved (total £1m) | |
| TIME ZERO | | — | Site decision to be reached | Proposed construction schedule |
| TIME ZERO | | — | Main funds to be released | |
| YEARS 1-3 | | — | Main components to be manufactured | |
| YEAR 1 | | — | Building construction to begin | |
| YEAR 3 | | — | Begin on-site assembly | |
| YEAR 5 | | — | Construction to be completed | |
| YEAR 6 | | — | Start experimental programme | |

being designed for operation in hydrogen only. Plasma performance has been sacrificed in order to introduce an axisymmetric divertor which should magnetically channel escaping plasma into a dump and so facilitate plasma-wall interaction studies.

The T-20 project in the USSR represents a stage of development beyond that of JET. It aims at plasma currents of 5MA with a minor plasma radius of 1·8m and a toroidal field of 3·5T. Tests of breeding blanket and hybrid fissile blanket modules are planned. The project is in the detailed conceptual design phase and the target date for operation is 1985. Project approval has not yet been sought.

The Doublet III project at the General Atomic Company USA (US ERDA funded) is in an advanced stage of construction. It aims at examining more elongated and complex cross section shapes than JET with plasma minor dimensions of 0·45m × 1·5m; if the shape is fully effective currents of 2·5MA and later 5MA could be achieved.

A number of TNS (The Next Step!) designs are at conceptual design stage in the USA and some of these have very similar parameters to JET. The combination of a TFTR and TNS can be regarded as a two step approach to a JET like design, which may well be appropriate to the large funding and rapid decision making which characterises the American programme.

## Conclusions

A tokamak in the 3 to 5MA range is expected to produce plasma conditions similar to those expected in a reactor. Solutions to the main problems of heating, confinement and impurity control will have to be demonstrated in this current range before further progress is possible. JET is designed to operate in this current range and to investigate these problems in an experimental programme which should start in the early 1980s. The most important information relevant to the tokamak programme during the construction of JET is expected in the areas of: (*a*) stability and confinement behaviour in large minor radius (~0·5m) systems with large amounts of additional heating power; (*b*) the control of radial profiles of current, density and temperature; (*c*) the control of impurity influx and the study of plasma wall interactions. The JET design is sufficiently flexible to permit results in all these areas to influence the experimental programme without changing the basic apparatus design. The JET experimental programme will give a realistic assessment of the potential of the tokamak system and will provide the design parameters for the next stage of development.



# THE CULHAM LABORATORY

by J. H. C. Maple and D. J. Dancy.

Following the recent announcement that the nuclear fusion project JET (Joint European Torus) would be built at Culham Laboratory the Secretary of State for Energy, Mr. Antony Wedgwood Benn said that ". . . Culham is going to be one of the greatest scientific centres in the world". Culham Laboratory has in fact, had an excellent reputation internationally for its fusion research for many years, the Laboratory being the UKAEA centre for this work. Fusion was first studied, however, in the UK in the Universities of Oxford, Liverpool and London (Imperial College) but in the late 1940s was classified and transferred to Harwell and AEI Laboratories at Aldermaston; later other controlled fusion research started at the Atomic Weapons Establishment at Aldermaston. During this time the work progressed well and led to construction of large apparatus such as ZETA at Harwell. Although this period has often been described as a false dawn for fusion, ZETA was in fact a very successful experiment, albeit ahead of its time, which laid down the foundations for present-day toroidal fusion systems such as JET. In 1958 world-wide work on fusion was declassified and agreements made for the complete exchange of information and the interchange of staff. The Atomic Energy Authority therefore decided to bring together the teams of researchers at Harwell and Aldermaston to a new site free from security restrictions. A disused naval airfield at Culham was eventually chosen for, amongst other reasons, its close proximity to both Harwell and the University town of Oxford. Construction work started in 1960 under the guidance of the first director Dr. J. B. Adams who had previously been Director-General of CERN near Geneva. Two years later the first phase of staff transferred to Culham. By 1964 construction was completed by which time staff numbers had increased to nearly 800; its size has remained roughly constant to the present day.

The Culham Laboratory has several distinctive features—many of which resemble CERN. All laboratories, workshops and offices, with the exception of the services buildings, are linked together via a main corridor about a quarter mile in length. This arrangement has proved to be very successful for ensuring good communications from one end of the site to the other, although the simple symmetry often causes great confusion to visitors. In the centre of the building there is a large well-equipped lecture theatre having facilities for simultaneous translations in four languages. The IAEA conference on plasma physics and nuclear fusion research in 1965 was held at Culham and the opening of the conference was regarded as the official opening of the Laboratory.

Culham today is the smallest of the Authority's "management units" with a permanent staff of just over 800. In 1967 the present director Dr. R. S. ("Bas") Pease succeeded Dr. J. B. Adams who later returned to Geneva to take charge of the CERN II project. Although originally intended as a centre solely for fusion research and associated plasma physics, for the last ten years the Laboratory has also been working in the field of commercial research. It also hosts the Astrophysics Research Division of the SRC's Appleton Laboratory.

On Britain's accession to the EEC in 1973 Culham's fusion research became part of a co-ordinated research programme under the auspices of EURATOM. EURATOM has a number of bilateral contracts with the various national bodies throughout the EEC including a Contract of Association with the UKAEA. Under this contract EURATOM pays part of the cost of Culham's fusion programme and shares in its management through a joint Culham/EURATOM Steering Committee. In general the EURATOM contribution is approximately 25 per cent of the Laboratory's fusion expenditure, rising to 44 per cent in the case of the capital cost of the "priority" projects—that is projects considered to be essential components of the European programme.

Today about three quarters of the scientific and engineering staff are engaged on fusion research and one quarter on commercial programmes. The objective of research into controlled nuclear power is to establish whether or not this process can be harnessed to provide a new source of energy which is essentially limitless and has potential environmental merits. The main part of the fusion programme revolves around the five toroidal experiments in which high temperature gases, known as plasmas, are both heated by large electric currents and confined away from the walls of the apparatus by complex magnetic fields. Research on the so-called tokamak system dominates this work; the tokamak being the system considered to be the most likely, in devices such as JET, to reach the plasma conditions required in a fusion reactor. Pioneer work on tokamaks was carried out in the Soviet Union but it was not until a team from Culham verified their encouraging results that other countries started building tokamaks. Today tokamaks routinely produce and confine plasmas of temperatures in excess of 10 million degrees.

At Culham there are two tokamaks, the larger machine called DITE (Divertor and Injection Tokamak Experiment) and a smaller device TOSCA. The DITE apparatus concentrates on two particular aspects of tokamak research; first, the machine has the unique facility of a divertor by means of which impurities resulting from the interaction of the plasma with the wall of the chamber are removed from the apparatus before they have a chance to have a harmful effect on the main plasma column. Secondly, DITE employs a system for increasing the temperature of the plasma by the injection of energetic neutral atoms, and during the last year this system has in fact doubled the temperature of the plasma ions. Plans are under way to increase the injected power still further so that temperatures greater than the present 10 million degrees can be obtained.

The smaller tokamak TOSCA was designed to study ways of improving the efficiency with which the magnetic field confines a plasma. TOSCA has in fact verified that there are two ways of improving this efficiency, namely by having plasmas with elliptical or triangular cross sections or by compressing the plasmas in the minor cross-section by rapidly increasing the magnetic field. These results are significant since reactor economics require an efficient use of the magnetic field.

There are other fusion experiments at Culham besides tokamaks including devices known as reversed-field pinches and stellarators. The reversed-field pinch system is very similar to the tokamak, but makes more efficient use of its magnetic field for confining plasma—potentially a great cost advantage in a reactor. Although less developed than the tokamak it is both a complementary physics research programme and an alternative reactor system.

The stellarator magnetic trap although more complex than the tokamak is the only toroidal system having reactor potential with a continuous, rather than pulsed mode of operation. Recent results on the Culham CLEO stellarator have given renewed confidence that this system can be made to work as well as the tokamak.

Finally fundamental studies of the confinement of plasma in toroidal magnetic fields are carried out in the superconducting Levitron. In this device a ring weighing 70 kg is made to float on magnetic fields whilst plasma is confined around it. This is perhaps the most technically advanced apparatus at Culham, but does not have reactor potential.

Fusion research in recent years has made very good progress on many fronts and Dr. Pease stated in the Laboratory's Annual Report last year that "there is little doubt therefore that the physical conditions required for net energy production can be achieved. What needs to be done is to build larger apparatus, to demonstrate and exhaustively research the details of these near-reactor plasma conditions". This is the purpose of the Joint European Torus (JET) described in detail in an accompanying article. The essential objective of JET is to obtain and study plasma in conditions and times approaching those needed in a fusion reactor.

In parallel with the plasma heating and confinement research programme, studies are being made on the design of fusion reactors for producing electricity. They embody the latest technology and identify the most promising and feasible system. Culham has always played a leading role in fusion reactor studies and was host to the first international conference on the subject in 1969. The latest conceptual reactor design is for a 2000 MW reactor based on the tokamak. Special attention has been made in this design to enable maintenance and repair of the internal structure of the reactor to be made. Less than a tonne of fuel (deuterium and lithium) will be consumed per year in such a reactor compared with about 5 million tonnes of fuel required for an equivalent coal-fired station. The reaction product of fusion is helium, a quite harmless and inert material. But fusion reactions will involve radioactive material such as tritium which is used in the reaction itself and the neutrons produced will activate structural materials—just as in a fission reactor. Reactor design studies have also been used to assess the potential environmental impact of fusion reactors.[1]

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1. Flakus F. N. "Fusion Power and the Environment," Atomic Energy Review **13** (3) pp. 588-614, 1975.



In the last ten years increasing effort at Culham has been devoted to areas of research, having a more immediate application to industrial and national needs. These areas of research are those in which Culham's scientists and engineers have developed a special expertise in the nuclear fusion research programme. The work is divided into three broad areas, Electrotechnology (Nuclear), Industrial Electrotechnology and Laser Applications. Work undertaken under the Electrotechnology (Nuclear) heading is closest to the design and development work carried out for Culham's own fusion programme. A number of contracts, mainly from overseas customers, have been received to design and build fusion experimental equipment. The work varies from the supply of standard electronic units, through larger items such as capacitor banks and high current ion sources, to the provision of complete experimental assemblies such as a small tokamak recently supplied to the University of Milan in Italy.

Industrial Electrotechnology seeks to exploit mainly the Laboratory's knowledge of high electric and magnetic fields. The Culham Lightning Studies Unit has facilities to simulate natural lightning and has been working for some years on the effects of lightning on aircraft structures. This work covers both basic research and the testing of actual aircraft components. Culham has also undertaken work for the shipping industry to determine mechanisms which cause explosions in large oil tankers of which there have been a number in recent years. A primary cause is thought to be the ignition of inflammable vapours in oil tankers by spark discharges caused by the movement of water used as ballast or for washing. Studies have been undertaken to examine the nature of such discharges, in both simulated situations and on oil tankers.

The Laser Applications Group has been concerned with the industrial applications and development of high-power lasers. These produce a steady beam of light of great energy which can be focused to produce great intensity in small areas. In principle such beams can be used for the cutting, welding and heat treatment of many materials, with the special advantage that the operations can be carried out in normal atmosphere, without physical contact, and without undesirable bulk heating effects. Successful systems for the cutting of cloth, glass and quartz, rubber, paper and wood have been developed using commercially-available lasers. The main prospective market is for metals treatment, for which present commercial lasers are barely adequate in power. Culham has therefore developed a 5 kW continuous laser which will be manufactured under licence by a commercial firm. One of the potential applications pioneered by Culham in conjunction with Dounreay is the remote cutting of fuel cans and elements after irradiation using a laser system.

The building of JET at Culham opens a new chapter in the site's history. There will be many changes; new staff will be joining, including many from overseas; new buildings will be constructed to house JET and its staff; some Authority staff will be seconded to JET. The main effect however is that the addition of JET to Culham will make the site a truly international one and, in Mr. Benn's words, ". . . people from all over the world will want to come to Culham to have a look".

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## AEA Reports

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

AEEW-R 962 *MURALB. A Programme for Calculating Neutron Fluxes in Many Groups.* By J. MacDougall. September, 1977. 58pp. HMSO £2·00. ISBN 0 85182 036 0

AERE-R 7477 (Supplement 2) *Harwell Subroutine Library. A Catalogue of Subroutines (1973). Supplement No. 2.* Compiled by M. J. Hopper. August, 1977. 11pp. HMSO £1·00. ISBN 0 70 580308 2

AERE-R 8603 *The Determination of Diffusion Coefficients of Cs and Ag in Pyrocarbon and Silicon Carbide by Post Irradiation Annealing of Coated Particle Fuels.* By P. E. Brown, M. Brownsword and E. W. Hooper. September, 1977. 16pp. HMSO £1·50. ISBN 0 70 580298 1

AERE-R 8730 *MA28. A Set of Fortran Subroutines for Sparse Unsymmetric Linear Equations.* By I. S. Duff. June, 1977. 153pp. HMSO £3·50. ISBN 0 70 580248 5

AERE-R 8856 *World Energy Resources.* By H. A. C. McKay. August, 1977. 17pp. HMSO £1·00. ISBN 0 70 580278 7

ND-R 7(S) *The Oxidation Kinetics of Zirconium Alloys Applicable to Loss-of-Coolant Accidents. A Review of Published Data.* By P. D. Parsons and W. N. Miller. October, 1977. 45pp. HMSO £1·50. ISBN 0 85 356093 5

## Sir John Hill

Mr. Tony Benn, Secretary of State for Energy, has reappointed Sir John Hill as chairman of the United Kingdom Atomic Energy Authority (UKAEA) with effect from 16th October, 1977. The appointment will terminate on 21st February, 1981.

Sir John McGregor Hill, BSc, PhD, FInstP, was educated at Richmond County Grammar School, at King's College, London, and St. John's College, Cambridge. After serving as a flight lieutenant in the RAF during the war he returned to Cambridge to do research work at the Cavendish Laboratory and subsequently became a lecturer at London University.

Sir John joined the UKAEA's predecessor organisation (the British Nuclear Energy Project) in 1950 and subsequently served the Authority as technical director and later as managing director of the production group. He became a member of the UKAEA with responsibility for production in 1964 and was appointed chairman in October 1967. He was reappointed chairman for a further five year term in October 1972. Since April 1971 he has also been chairman of British Nuclear Fuels Limited, which, under the Atomic Energy Authority Act, 1971, took over the nuclear fuel cycle business of the production group of the UKAEA.

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

## New smoke detector tester

Harwell scientists have developed a novel smoke detector tester which they believe will provide a much-needed means of testing the smoke detectors which are such an important part of fire precautions in hospitals, shops, hotels and many other buildings.

The instrument generates an aerosol with the same effect on a smoke detector as smoke from burning materials. The physical characteristics of the aerosol may be closely controlled. This allows the response of a smoke detector to a controlled simulated smoke to be monitored during the detector's working life. In this way essential information is obtained concerning the likely reliability of the detector when required to react to the smoke from a real fire.

Early laboratory-built versions of the tester, devised and built by scientists of the Environmental and Medical Sciences Division, Harwell, under contract to the DHSS, have already aroused considerable interest among safety experts. Engineered prototypes built at Harwell for the DHSS will be undergoing trials by regional health Authorities and the Fire Research Station in late 1977, with Harwell playing a co-ordinating role.

The DHSS, in sponsoring the research and development at Harwell that has produced this instrument, has responded to a pressing need recognised by all those responsible for the effectiveness of fire detection systems in hospitals and old peoples' homes for a portable device for testing smoke detectors. Statistics available for the incidence of fire in fairly high fire risk areas (such as hospital stores) suggest that only one detector in five will be required during its working life to respond to a real fire. However, the effective operation of a detector on such an occasion may be vital to the preservation of human life and property.

This Harwell instrument is expected to arouse great interest from all those who are concerned with the reliability of smoke detectors and Harwell's marketing department has already made contact with firms who may be interested in manufacturing the equipment on a production scale. Harwell would also like to hear from any organisation with an interest in the reliability of smoke detectors—for example, fire brigades, insurance companies, retail and industrial organisations, shipping companies and hotels—with suggestions to make on the future development of this instrument.

Initial enquiries (including those for more technical information) should be addressed to Dr. G. A. Fletcher, Marketing & Sales Department, Building 329, AERE Harwell, Oxfordshire OX11 0RA. Telephone Abingdon (0235) 24141, Ext. 2078.

## Harwell's income

For the first time in the 12-year history of the Harwell revenue earning programme half of the laboratory's costs have been met by income from customers.

This was revealed by Harwell's Commercial Director, Dr. R. G. Sowden, speaking at the annual Laboratory Trainees' prizegiving.

The actual amount earned by research and development activities in the last financial year was £16·6m. The remaining moneys come from central government funds, through the UK Atomic Energy Authority.



# THE ENERGY COMMISSION AND UK ENERGY POLICY

**The membership of the Energy Commission was announced by Mr. Tony Benn, Secretary of State for Energy, on 26th October, 1977. During the month, the Department of Energy also published the first two documents to be submitted to the Commission. Summaries of the Department's press releases on these and the establishment of the Commission are given below.**

### Membership

Of the 22 members, seven are drawn from the energy industries, seven are drawn from the TUC Fuel and Power Industries Committee and eight are drawn from other interests.

The Secretary of State for Energy will chair the Energy Commission. Mr. Gregor MacKenzie, Minister of State at the Scottish Office, will also be a member. Other Ministers with an interest in energy matters will be able to attend meetings. Names of other members are:

Mr. F. A. Baker, CBE, National Industrial Officer, National Union of General and Municipal Workers

Mr. M. C. J. Barnes, Member, National Consumers' Council and Chairman Designate, Electricity Consumers' Council

Mr. D. R. Berridge, Chairman, South of Scotland Electricity Board.

Mr. R. Birch, Executive Councilman, Amalgamated Union of Engineering Workers.

Mr. T. Carlile, CBE, Managing Director, Babcock and Wilcox Ltd.

Mr. F. J. Chapple, General Secretary, Electrical, Electronic, Telecommunications and Plumbing Union.

Mr. G. A. Drain, JP, General Secretary, National and Local Government Officers Association.

Sir Derek Ezra, MBE, Chairman, National Coal Board.

Sir Brian Flowers, FRS, Rector, Imperial College of Science and Technology.

Mr. J. Gormley, OBE, President, National Union of Mineworkers.

Professor Sir William Hawthorne, CBE, FRS, Chairman, Advisory Council on Energy Conservation.

Sir John Hill, Chairman, United Kingdom Atomic Energy Authority.

Lord Kearton, CBE, FRS, Chairman and Chief Executive, British National Oil Corporation.

Mr. R. L. E. Lawrence, CBE, Vice-Chairman, British Railways Board and Board Member, National Freight Corporation.

Mr. D. E. Lea, Secretary, TUC Fuel and Power Industries Committee.

Baroness Macleod of Borve, JP, Chairman, National Gas Consumers' Council.

Dr. A. W. Pearce, CBE, Chairman, United Kingdom Petroleum Industry Advisory Committee.

Sir Denis Rooke, CBE, Chairman, British Gas Corporation.

Mr. E. C. Sayers, Chairman, Dupont Industries Ltd.

Mr. D. E. Tench, Chairman, Domestic Coal Consumers' Council.

Mr. F. L. Tombs, Chairman, Electricity Council.

Mr. C. H. Urwin, Deputy General Secretary, Transport and General Workers Union.

Membership of the Commission will be on a part time and unpaid basis. It is envisaged that the Energy Commission will meet about four times a year. The first meeting will be held on 28th November, 1977.

### Working Document on Energy Policy

A Working Document on Energy Policy*, the first paper to be prepared for the Energy Commission, was published on 14th October by the Department of Energy. It will be considered by the Commission at its first meeting which is due to be held on 28th November.

The Document looks in detail towards the end of the century and, more tentatively, beyond and explains why a fixed blue-print for energy policy would not be appropriate. It examines a strategy and explains the need for that strategy to be kept under review and adjusted in the light of developments both world wide and in the United Kingdom.

It is not a statement of Government policy and has not been considered by Ministers collectively. The Government intends, in the light of comments received, and after the Energy Commission has considered the

*Working Document on Energy Policy for the Energy Commission. Energy Commission Paper No. 1. Published by the Department of Energy.

Working Document, to publish a Green Paper on energy policy.

The Document considers the objectives of energy policy and the means by which policies may be implemented. It sets the UK energy sector in a world context and considers the various component parts of energy policy—energy conservation, coal, oil, gas, electricity, nuclear power and research and development, including conservation and alternative sources of energy.

It also examines the environmental aspects of energy policy and the ways in which energy policy interacts with industrial, social and other policy considerations. Finally, the Document draws together the component parts to outline prospects, suggests a strategy and draws conclusions.

Energy Commission papers will generally be available on request as part of the policy of making information on energy policy matters widely available. Copies of the Working Document may be obtained free of charge from the Department of Energy Library, Thames House South, Millbank, London SW1 as part of this policy.

A summary of the Document follows.

## Objective of energy policy (Chapter 2)

The Document says that the traditional objectives of energy policy have been given as: that there should be adequate and secure energy supplies; that they should be efficiently used; and that these two objectives should be achieved at lowest practicable cost to the nation.

The Secretary of State for Energy suggested an alternative formulation in his note preceding the Energy Policy Review and this is that:

(i) everyone can afford adequate heat and light at home;

(ii) industry's needs for energy are fulfilled at a price which reflects full resource cost and has regard to the long-term availability of the various fuels;

(iii) these objectives are met on a long-term basis, taking account of risks; the depletion of our reserves of oil and gas is regulated; research and development in energy supply and use is adequately funded; and investment in energy industries to meet these objectives is properly planned;

(iv) freedom of the consumer to choose between fuels provided at a minimum price which reflect economic cost, should, where possible, be maintained and increased.

The Document says that it is, of course, for the Government, subject to the approval of Parliament, to set out appropriate objectives for an integrated energy policy for the nation.

It adds that these objectives can never be be pursued in isolation. Every energy policy decision is likely to involve some or all of a wide number of other considerations. It is not possible to find a general formula to express the right balance to strike in each individual decision.

What is important is that the difference in cost in resources between alternative courses of action should be determined as precisely as possible and borne prominently in mind when decisions are being taken. This is the first essential step in achieving reasonable consistency of policy.

The Document adds that the reduction of dependence on imported energy is often put forward as an objective of energy policy. Self-sufficiency, however, is desirable only in so far as indigenous sources may offer supplies which have a lower resource cost, and are more secure, or both, as compared with imports; it is not an objective in its own right.

In present circumstances, with energy supplies on world markets very expensive, and with indigenous resources in many countries capable of exploitation, it is reasonable for the UK, the EEC and others to measure progress towards their under-lying objectives of low cost and security in terms of reduction of import dependence.

## World background (Chapter 3)

The Document reviews the world background and records the conclusion that up to 1985 OPEC oil is likely to remain the world's marginal fuel. OPEC is likely to hold significant quantities of spare oil production capacity, but will nevertheless be able to maintain the real oil price and perhaps to increase it. By 2000, oil will almost certainly have ceased to be the world's marginal energy source, and its place will be taken by nuclear electricity or possibly coal.

Unless supply is at the top end of the forecast range and world demand is simultaneously at the bottom end of the range, there is likely to be a requirement for nuclear power which, on present uranium supply prospects, could only be satisfied by large scale recourse to the fast reactor in the longer term.

Even so, there may well still be a world "energy gap" which would lead to one or more of the following possibilities. Physical shortages of energy might lead to enforced conservation without affecting economic growth (e.g. colder homes). Alternatively, scarce energy supplies could constrain world economic growth to below what was assumed in making the demand forecasts. The final possibility—and this is probable—is that energy prices will be higher than was assumed, and they could well be more than double current levels in real terms.

## The UK scene (Chapter 4)

The Document says that looking to the future, the UK is, by comparison with most industrial countries, well placed. Although we have as yet no proven reserves of uranium ore, we have substantial reserves of oil and gas and very large reserves of coal. The depleted uranium resulting from past operations of our nuclear programmes constitutes a reserve of energy which, if used in fast reactors, would be equivalent to some 40 billion tons of coal.

We can expect to be at least self sufficient, and possibly net exporters of energy, for some years from 1980 onwards. But this prospect, however full of promise for the short and medium term, will not insulate us from the long term difficulties of energy supply which the world can expect to develop towards the end of the century.

While we consume over 3 per cent of the world's annual production of oil and gas, estimates of our total recoverable reserves suggest that they may amount to only 1-2 per cent of the world total. The likelihood is that supplies of North Sea oil will be declining towards the end of the century, at a time when imports will be increasingly costly. Indigenous natural gas supplies will also be declining by 2000 on a conservative estimate of reserves, though the decline would be somewhat later if more optimistic assessments proved justified.

The crucial question of energy policy is what, in the longer term, should be the respective contributions of energy conservation, of coal, nuclear-based electricity and renewable resources, such as wave and solar energy, and of fuel imports, to meeting the country's energy needs.

## The component parts

Chapters 5-11 deal with the component parts of the UK energy scene—conservation, coal, oil, gas, electricity, nuclear and research and development, including conservation and alternative sources. The conclusions reached are generally given at the end of each chapter. Among the points made are:

*Energy conservation*

For a variety of reasons, energy conservation is now seen by almost all countries as an integral part of energy policy. But to realise savings will require, among other things, continued efforts to achieve and sustain a widespread change of habits on the part of millions of individual consumers.

Stronger Government action will be required in future to achieve the optimum practical balance between energy conservation and energy production investment and to minimise the overall use of resources.

Failure to take vigorous steps to ensure improved efficiency of energy use in the years ahead, enabling the UK to achieve economic growth with a lower growth in energy consumption, might result in the longer term in the nation being forced to accept a reduction in the rate of economic growth. It might also result in UK industry becoming progressively less competitive since the need for energy efficiency is more obvious to competitors in other countries and since energy efficiency will become an increasingly important aspect of product design.

The demand estimates adopted by the Working Document allow for reduction in final energy consumption by the end of the century of about 20 per cent below what it otherwise might have been. But the Document says that with a really vigorous and sustained Government programme still larger savings would be achievable.

The difference between such a programme and a total absence of further Government action might make a difference of the order of 50 mtce to the level of primary energy consumption by the year 2000.

This would be a very substantial prize and underlines the necessity of making energy conservation an integral part of our energy policy.

*Alternative sources*

Expenditure on alternative energy sources is rising but is still comparatively modest. This is because we are still in the early feasibility stage. In eighteen months to two years we shall have to decide whether or not to mount large scale experiments on wave power; a positive decision would require a significant increase in expenditure.

Although we need to pursue energetically the most promising lines of research into renewable sources, their possible contribution over at least the rest of the century is limited and needs to be kept in perspective. We must at the same time, therefore, pursue energetically research into energy conservation, where the potential returns are much greater and more assured, as well as into the production, distribution and use of fossil fuels and of nuclear energy.

## Environmental aspects of energy policy (Chapter 12)

The consideration of environmental factors is one of the elements which must form an integral part of decision making about energy at all stages. The Government is determined to ensure that all work on future energy sources pays full attention to environmental considerations. It is also setting up a high-level independent body which will advise specifically on the interaction between energy policy and the environment.

It would be mistaken however to suppose that we could select one or a small number of energy sources which have minimal environmental impact, and obtain all our energy from them. Even renewable sources can have environmental drawbacks and there are in any case limitations on their potential contribution.

The very long term impact of nuclear wastes and fossil fuels is still attended by substantial uncertainties, which research will seek to resolve. The most prudent strategy from an environmental point of view therefore may well be to retain a mix of energy sources, and avoid excessive dependence on any one source.

## UK prospects and strategy (Chapter 14)

After reviewing social, industrial and other policy considerations in Chapter 13 the Document turns to UK prospects and strategy.

*Short and medium term prospects* (up to 1985)
The Document says that for some years ahead we are likely to have, in total, more capacity than we immediately need. Several problems will or could arise from this temporary abundance of supplies and it is important that any action taken to deal with immediate short-term problems is consistent with the policies we need to pursue for securing our long term needs.

*Longer term*
The Document says that the main influence on energy demand is likely to continue to be the rate of economic growth. The two assumptions in current forecasts represent (i) broadly a continuation of past trends corresponding to a growth rate of 3 per cent a year, tending to flatten out beyond 2000; and (ii) a lower rate falling to an annual rate of less than 2 per cent by the end of the century. (For estimates see under Annexes).

It adds that "the desire for higher national living standards is very widespread and the policies of almost all Governments are aimed at promoting them. In the UK as elsewhere a main aim of energy policy must be to ensure that lack of energy does not frustrate this aim."

The Document points out that if the higher demands forecast were to materialise, we should not be able to meet them from indigenous sources and should need to import some 45-85 mtce of primary fuel a year.

Such an import requirement would be supportable, but it must be remembered demand is likely to be continuing to rise and that there is a basic uncertainty as to the amount of recoverable oil and gas reserves; that the production figures, particularly for coal and nuclear, are upper limits and will not be achieved without great efforts; that the contribution from renewable sources is uncertain; that we cannot necessarily assume that supplies of oil will be available for import; and that, without substantially enhanced efforts to conserve energy, demand would, in all likelihood, be even higher than the Working Document assumes.

## Suggested long-term strategy

The Document says: "While we can foresee in general terms the nature of the problem likely to arise in meeting the UK's energy needs in 2000 and thereafter, we cannot forecast with any precision what combination of sources will in the event prove most advantageous. We cannot yet tell what combination of indigenous supplies, of energy conservation, and of imports, would provide the lowest cost solution .... Nevertheless, we must form the best judgements we can about future resources and requirements .... In particular, we must take those decisions that are necessary to ensure that, when we need to expand some sources of energy production, the required technologies and manufacturing capacity are available."

To enjoy freedom of manoeuvre in taking future decisions, the UK must now develop energy supply options on a broad front. This strategy requires the following action:

**Coal:** Using the appropriate financial tests, we should proceed with the creation of further new capacity, over and beyond the "Plan for Coal" to come into production in the late 1980s and 1990s.

The industry needs to be able to generate some four million tons a year of new and replacement capacity in the latter part of the century. We also need to ensure that there are ready markets for coal; in particular, the electricity industry should maintain its ability to burn large quantities of coal efficiently.

**Nuclear:** There is a need to have a capability to expand nuclear power rapidly in the late 1980s and 1990s if that course proves to be economically desirable and acceptable in other respects. This requires an established and proved reactor system or systems, which we can order in quantity as needed, and the development and maintenance of an adequate nuclear manufacturing industry. We need also either possession of or access to fast reactor technology, so that, subject to need and acceptability, fast reactors could be ordered to guard against the possibility of shortages of uranium restricting our option of securing a continuing contribution from nuclear power of the size we may need. Taking these decisions will not involve any commitment at this stage to a massive expansion of nuclear power.

**Oil:** "We should seek to ensure that, when our indigenous oil production runs down, it does not do so at such a rate as to cause unmanageable problems, either of switching to alternative indigenous supplies or of paying for increasing imports .... It is not yet clear how far, if at all, Government intervention may be needed to avoid too sharp a peak and too rapid a run-down, and for the present the prime need is to preserve the maximum practicable flexibility."

**Gas:** "As with oil, our objective should be to avoid too sharp a peak and too rapid a falling-off .... A variety of measures are open to the industry to vary the profile of their supplies, at least in some degree, and these options need to be kept under review and implemented as appropriate."

**Energy conservation:** Opportunities for using energy more economically must be exploited to the full. The Government is currently reviewing the scope for further action.

**Renewable resources:** The technological potential and economic viability of renewable resources needs to be established. A substantial increase in effort will be needed if the work is to move on from the present research phase into development and demonstration.

The Document suggests that the strategy above would give the UK the flexibility to take up a variety of options towards the end of the century as future developments enable their relative merits to be assessed more precisely.

It adds: "On most views of the future, the needs of coal, energy conservation and nuclear seem inescapable. Renewable sources could also make an increasing contribution. Nuclear power from thermal reactors has been an established, and generally acceptable, fact for some two decades. Concern for the future is centred on, though not confined to, the fast reactor, and on the problems which a large-scale reliance on plutonium could bring. Clearly these problems must be taken very seriously indeed and satisfactory answers found to them before there can be any commitment to the large-scale use of fast reactors.

"Since we cannot be sure that we can solve our future energy problems without reliance on fast reactors, we need to be sure that we have the ability to build them on a large-scale should it prove necessary to do so and the associated problems have been satisfactorily solved.

"Depending on many factors, including the course of world supply and demand for oil, we may find that we need to do more than now appears practicable, either to increase production of coal, nuclear or renewables, or to promote the conservation of energy. If we are unable to do so, the alternative could be an enforced reduction in economic growth, and hence in living standards."

## Conclusion and decisions required (Chapter 15)

The Document identifies seven decisions that will be required within the next two years to maintain a comprehensive energy policy, bearing in mind the long lead times. These are on:

(i) the choice of thermal reactors and on the placing of further nuclear orders both for the health of the nuclear industry and also so that the UK can establish a proven design for use on an expanding scale as and when required;
(ii) the fast reactor. The UK needs to have access to the technology so as to keep open the option of introducing it into the supply system towards the end of the century; the UK must choose which of the alternative courses of action to follow in order to secure this;
(iii) power station ordering beyond Drax B, bearing in mind electricity demand growth and the needs of the power plant industry;
(iv) the building of a gas gathering pipeline;
(v) the reinforcement of energy conservation policies;
(vi) the further development and regular review of a strategy on R & D, establishing priorities and timing, taking account of the opportunities for international collaboration. In particular it will be necessary to determine where to put the main weight of effort on renewable resources;
(vii) how best to apply in practice the principle that energy prices should reflect the real cost of providing continuing supplies.

**UK energy demand**

| | | 1975 | 1985 | 2000 |
|---|---|---|---|---|
| | | Million tons of coal equivalent (mtce) | | |
| *Higher growth* | Energy | 315 | 375 | 490 |
| | Non-energy | 25 | 40 | 70 |
| | Primary fuel demand | 340 | 415 | 560 |
| *Lower growth* | Energy | 315 | 350 | 390 |
| | Non-energy | 25 | 40 | 60 |
| | Primary fuel demand | 340 | 390 | 450 |

The Document also says that decisions will be needed on specific coal investment projects, including the sinking of new collieries in areas new to coalmining, and also those that will affect the rate of depletion of our reserves of oil and gas, or at least will affect the possibility of varying the rate at some later stage.

*Impact on consumers*
The Document says that the country's energy prospects at the turn of the century have a number of important implications for consumers:

(i) the average level of energy prices must be expected to rise, perhaps doubling by 2000 in real terms;
(ii) consumers will not necessarily be able to go on using the fuels they are using now. For example, oil may not be available for all the uses to which it is now put by the end of the century;
(iii) fuel price relativities will change.

## Resources required
The Document says that total capital expenditure by the UK energy industries at the end of the century may have built up to a level about 50 per cent higher, in real terms, than at present. But as a proportion of a greatly increased GDP, it may be no higher than the proportion required during the build up of the North Sea and of electricity supply in the 1960s and 1970s. There would however be a shift in investment towards the public sector industries and financing will be needed to support an expansion that the industries themselves might not be able to finance from their own resources unless prices are increased to well beyond the level of marginal costs. Moreover, investment in the North Sea has been funded in part by a substantial inflow of foreign capital and we cannot rely on a comparable inflow in the circumstances of 2000.

## Annexes
The Working Document contains six Annexes, covering: energy forecasts and methodology; factors affecting depletion policy; the sixth Report of the Royal Commission on Environmental Pollution: An alternative strategy; instruments for implementing energy policy; executive, advisory and international bodies on R & D; a glossary and conversion factors.

## Forecasts
The Document presents a table showing forecasts of energy demand up to the year 2000, based on two assumptions of economic growth. These are set out above.

The paper says that our indigenous energy supplies in 2000 might comprise:

**UK Energy supply**

| | *mtce* |
|---|---|
| Coal | 170 |
| Nuclear | 95 |
| Natural Gas | 50-90 |
| Indigenous Oil | 150 |
| Renewable Sources | 10 |
| | 475-515 |

## Depletion policy
*Oil:*
The Document describes present oil depletion policy and considers the effect that the exercise of a depletion policy has on the individual operator and on the nation. Because of the differences in these effects, there may well be a divergence between a depletion policy which Governments pursue in the national interest and that preferred by commercial operators.

Since the size of ultimately recoverable reserves is subject to a considerable amount of uncertainty, depletion policies must be flexible and capable of subsequent adjustment.

Depletion policy in the UK will evolve against a world background of pressure on supplies and higher prices. A blueprint over the next 10 or 15 years would be impractical in view of the uncertainties. There is uncertainty about the actual extent of the oil reserves under the UK Continental Shelf, about the course of oil prices, about the macro-economic framework within which depletion policy will need to evolve, and about how energy demand will develop. There is however a degree of flexibility through licensing policy and through the powers to delay development and curtail production.

It is unlikely that a conservationist depletion policy could affect output before 1982 because of earlier Government assurances but in the course of the next few years decisions will need to be taken which will offer scope for influencing depletion in the mid and later 1980s and beyond.

*Gas:*
Although many of the factors affecting gas depletion strategy are similar to those for oil, there are some significant differences. These are due mainly to the reduced flexibility available in dealing with associated gas, particularly when the quantities are small; in diverting supplies to other markets to overcome short term fluctuations of supply and demand; and the existence of long term contracts.

Although some non-premium sales cannot be avoided, the document says that there is a strong case for restricting gas sales as far as possible to the premium market, including the petrochemical market, both on economic and energy policy grounds.

## Prices
The Document comments upon the importance of the level and structure of energy prices. It says that prices are important above all because they are all pervasive, affecting the millions of individual decisions over which the Government can have no direct control. Under-pricing encourages consumers to waste scarce resources and may discourage additional supplies. Over-pricing may lead to consumers devoting undue effort and resources to the saving of energy, which is not the only scarce resource, and could have adverse social and industrial effects.

Energy prices should at least cover the cost at which supplies can be provided from new capacity, while yielding an adequate return to investment. Since these costs will vary from industry to industry, the price of each fuel should reflect its own circumstances. Consumers could be seriously misled about the economic costs imposed by their choice of fuel if all fuels, or a number of competing fuels, were supplied at a common price without regard to cost variation.

## Note
The forecast range of UK energy demand for the year 2000, shown in the Working Document on Energy Policy, is lower than that shown in Energy Policy Review (published by the Department of Energy in June 1977 as Energy Paper No. 22). The ranges are:

**Total forecast primary fuel demand in the year 2000** (in mtce)

| | *low* | *high* |
|---|---|---|
| Energy Policy Review | 500 | 650 |
| Working Document on Energy Policy | 450 | 560 |

The scaling down is because the upper end of the range shown in the Review was based on a scenario which included the assumption that oil prices would not rise in real terms. This is no longer regarded as probable. The depth and duration of the current recession have also led to expectations of lower levels of output being reached within the forecast period. The current lower forecasts of primary energy demand also reflect a lower electrical component in final demand (and hence lower conversion losses) and a larger allowance for conservation.

# Working Group on Energy Strategy
The annual report of the Working Group on Energy Strategy was released on 25th October, 1977. The Report is to be submitted for information to the Energy Commission and is being published by the Department of Energy as Energy Commission Paper No. 2.*

The Working Group was set up by the Secretary of State for Energy in 1975 with a membership drawn at Board level from the energy nationalised industries and from Government Departments.

Its remit is to explore a more co-ordinated approach between Government and the industries to the formulation of energy strategy and energy policies.

The Report says that the Working Group's discussions have been influenced by

the need for more emphasis in future on long term energy strategy and on the inter-relationship between fuels;

and by the importance of maintaining a flexible approach to formulating energy strategy, given that the uncertainties are too big and the penalties of failure too great for any one blue print for the energy sector to survive the realities of a complex and developing situation.

*Planning systems and timetables*
Given the wide variety of corporate planning systems, procedures and timetables used by

*Report of the Working Group on Energy Strategy. Published by the Department of Energy as Energy Commission Paper No. 2. Copies available from the Library, Department of Energy, Thames House South, Millbank, London SW1.

the industries, and the difficulties created in attempting to construct a picture for the energy sector as a whole and to make comparisons between the fuels, the Group agreed to:

- adopt a common minimum long term horizon for planning of 20 years ahead;
- develop strategies, policies and plans on at least one common scenario for the future;
- and to adopt one set of economic assumptions in common among the many used.

The Working Group has now also agreed that the Department of Energy should prepare annually an energy policy review which would be based on a detailed look at energy demand and supply balances for the UK, including imports and exports, over the medium-term and beyond.

The review would also examine the implications of certain policy and investment decisions for the industries and thereby aid marketing (including pricing) and investment decisions. It would draw heavily on the long term scenarios; on the Department's energy forecasts; and on the strategic thinking and development plans of the industries.

The Working Group has also proposed that the Department should in future issue a planning letter to each industry as early as possible in the annual planning cycle in order to:

- record the Secretary of State's first response to critical matters in the current corporate plan submitted by the industry;
- convey the Secretary of State's policy guidelines for the future development of the industry;
- note any specific strategic matters which the Department and the industry should examine later in the year and which should be featured in the next corporate plan.

The Report says that these changes in procedure should help policy formulation between the industries and the Department and, together with agreed changes in planning timetables, should permit a more orderly system for annual planning and analysis for the energy sector as a whole.

The new system has been designed to fit in also with the timetable for the annual public expenditure survey and the review of capital expenditure and financing.

*Energy forecasting*

An important aspect of the Group's work over the past year has been to examine the Department's energy forecasts. These set out to examine some of the prospects and problems which could arise in meeting the UK demand for energy over the next 20 years. The key factors in the Department's forecasts affecting demand are taken to be the average rate of GDP growth and the price of oil. The combination of various assumptions for these key factors, together with data on other factors such as output and costs, produce a wide range of possible energy demands of which eight sets of forecasts and related strategies were examined by the Group. This examination helped to bring out more clearly the views of both the Department and the industries on the main factors to be taken into account in strategic planning and the relative weights to be attached to them.

*Pricing regimes*

The Group also considered the basic principles underlying pricing policies and the setting of financial targets for the energy nationalised industries. They concluded that despite various inherent problems it should be possible to reconcile a proper financial regime with the objectives of energy policy.

*Energy Policy Review*

Among the matters examined by the Working Group was the Energy Policy Review prepared by the Department as a background for policy decisions and published in June of this year as Energy Paper No. 22.

The report says that industry members agreed with the emphasis in the Review on maintaining a flexible approach to energy policy. They pointed out, however, that decisions could not be put off indefinitely. The view that oil prices might double in real terms by the turn of the century was accepted as not unrealistic. The lack of information on comparative fuel costs was criticised, particularly as this made it difficult to assess the case for nuclear power in proper perspective. The wide range of energy forecasts was also criticised as providing no useful guide in practice for forward planning. It was also thought inappropriate to treat nuclear power as a residual supply.

*Future work*

The Working Group believes that for the future, and with the establishment of the Energy Commission, it could play a useful part in preliminary discussion of some matters to be submitted to the Commission, and in pursuing in further detail matters remitted from the Commission.

*Conclusion*

In the conclusion to its report, the Working Group says that over the past year it has made useful progress in terms of adopting a sufficient harmony in planning procedures and timetables between the industries and the Department so that rational analysis of the energy sector as a whole will become more practicable for the future.



# NUCLEAR POWER AND THE FUTURE OF SOCIETY

**The following address was given by Sir John Hill as President of the Fuel Luncheon Club in London on 18th October, 1977.**

It is difficult at this particular time to think of any topical subject for a Presidential Address to the Fuel Luncheon Club. Coming so soon after the World Energy Conference in Istanbul where all aspects of energy were discussed in the greatest of detail and where the three year study of the conservation commission produced the basic information on which the discussions took place, it is hardly possible to say anything about world energy resources which has not already been said half a dozen times before. I have spoken so often on nuclear matters that I wouldn't presume to use that as a subject for a Presidential Address. So what I would like to discuss today is the question of what sort of society the public wants, or what sort of society we may be forced into and how the leaders of public thinking as well as the technologists and engineers can work together to meet these aspirations.

Since the beginning of time the population of this planet, whether mankind or other forms of life, has been limited by the availability of resources. Even in the period of human civilisation resource limitation has until very recently determined the maximum population that could be supported in any particular area. The last fifty or perhaps a hundred years has been quite abnormal in evolutionary terms in that mankind has been able to increase his numbers so far beyond what was ever possible before. This has resulted from mankind getting access to resources that nature has husbanded and saved over hundreds of millions of years.

Until the invention of the steam engine, the amount of power at man's disposal was either the strength of his own arm or the strength of a horse or oxen supplemented in favourable circumstances by perhaps windmills.

But the invention of the steam engine which enabled heat to be converted into power, albeit at low efficiency, was an enormous step forward and man was able to use this power to obtain more fuel, to grow more food, to make tractors and machines and increase greatly the resources at his disposal. This led immediately to an increase in the standard of living, the first effect being that the children of large families no longer died in their early youth as most had done before, but they survived and the world population explosion was upon us.

But we recognise that the exponential growth in energy demand that we have seen for so many decades cannot go on for ever. A growth of electricity of 7 per cent per annum which for so many decades was regarded as normal leads to a multiplication factor of a thousand every hundred years. We see limiting factors coming into effect in the wealthy countries. But the poorer countries have hardly started to climb the curve of affluence.

Many environmentalists in this and other countries recognise the impossibility of continuing with this rate of growth and argue that we have already gone far enough in standard of living. They see a wasteful society all round us, a vast consumption of energy, of metals and a carelessness with the world resources. They argue that if we are to have a stable society in the future we must limit our demands on the planet, limit our material demands to something which can be sustained. In this one cannot but agree with the environmentalists. It is true that mankind is vastly wasteful of the earth's resources and must husband these resources much more carefully in the future.

President Carter sees clearly that the prodigal use of energy which is typical of the United States and the American way of life cannot continue in the future as it has in the past and must be brought under control as quickly as possible. He has spelled out the situation in words of one syllable. He has proposed various measures to Congress which would restrain the use of energy by legislative measures most of which are essentially financial. He has, however, received no support whatsoever from Congress where the politicians realise that such measures would be highly unpopular to the American public. The American public prefers to believe that the whole thing is a put-up job by the oil companies to increase their profits. It is not only the American public that finds such moves to reduce energy consumption by pricing policies unpalatable. The same is true in this country and, for that matter, in most other countries as well.

The result is that the wealthy countries continue to consume the world's finite stocks of gas and oil at a disproportionately high rate and the poorer countries, who are unable to get their share of the oil now because of their lack of money will be unable to get it in the future either because so much will have been squandered.

If one looks at the poorer countries of the world we see a discouraging situation. Population is rising rapidly and, with the preponderance of young people, will continue to rise for at least fifty years yet. We see a low standard of living and recognise that the demand for food and energy will go up proportionately with the population even if there is no increase in the standard of living at all.

All of us who have been concerned with energy planning are familiar with graphs of consumption going up fast, production going up more slowly or reaching its peak and coming down again, and at some point in the future perhaps in the 1980s comes the cross-over point marked by an arrow "oil crisis starts here".

But what do we actually expect to see happen at that point in time? It is self evident that consumption will equal production. There will still be a large production in the world and consequently a large consumption. But what is it that is going to reduce the consumption of energy by a few per cent below the level it would have been had it not been for the energy crisis? It could be rationing, which could be rationing by price to the individual consumer, it could be rationing for the poor countries who do not have the foreign exchange, it could be rationing by political strength, the strong countries getting what they want, the weak countries getting nothing.

I don't think anybody is in a position to determine which of these courses, or what combination of them, will in fact take place. I suspect that rationing by price will eventually emerge because I don't see the other methods giving any long term solution. If oil is to be rationed by price on a world scale, if consumption has to be reduced by 5 per cent or 10 per cent, where will the reduction take place?

Experience shows that in many areas consumption is very resistant to changes in price. For example most motorists are prepared to make considerable sacrifices in other fields rather than do without the petrol they need. Certainly a very big increase in price would lead to smaller motor cars being produced and the difference between American and European cars must be due in part to different petrol prices in the past.

However, although a big increase in the price of crude oil might not be particularly damaging to the motorist it would nevertheless have a dramatic effect on the balance of payments and the economies of many countries, but particularly the poorer countries. This is where I believe the forthcoming energy shortage, or perhaps more accurately the forthcoming world energy price increase is going to hurt most.

There is nothing much that the poor countries of the world can do about this situation. The savings must come from the big industrialised countries where at the present time the majority of the world's fuel is consumed.

It is fashionable these days to decry economics and the use of money as a yardstick to judge between, for example, conservation or additional production. There are certainly great energy resources in the world. This is not really in doubt. Similarly there is a great deal that can be done in terms of conservation. The real issue is how much does it cost in terms of money or man-hours or resources to get access to more fuel in the longer term and how much does it cost in terms of real resources to reduce consumption by an equivalent amount.

Eventually economics will determine what happens. If oil is short oil will become expensive. If all energy is short, all energy will become expensive and more conservation will be worthwhile.

At the present time the world adopts a *laissez faire* attitude to energy costs. The economics are the economics of today and the judgments that are made by the man in the street on the type of car he intends to buy, the amount of insulation he puts in his roof, whether he uses gas or coal or oil or electricity as his energy source are based on his assessment of what best suits his circumstances at the time when he makes the decision. There can be no doubt that the vast majority of such decisions are based on the energy costs of today with little weight being given to what might or might not happen in the future.

Perhaps we can leave things in this way. Certainly the history of forecasting energy costs has been so unsatisfactory as to make one very hesitant about interfering in individual choice by deliberate pricing policies. Certainly the public would resent any interference that raised energy costs. The only danger is that in energy supply it is very difficult to change the pattern rapidly, and if we leave most of our decisions on supply and consumption patterns to be based on the economics of today then when a sudden change in the world position does come about as it likely sometime in the next ten years, there may be a very painful and prolonged period while the world adjusts itself to the new situation.

The timescale for the building of new mines, of developing technologies for extracting oil from tar-sands, the construction of nuclear power stations or developing renewable sources of energy, are all of the order of ten years for each individual project or 20 years before there can be a significant change in the supply position.

If then we want to avoid the difficulties that we can see on the horizon those who feel able to look at least a few years into the future, those whose job it is to point the country in the right direction for the future, those who feel they can foresee the problems that mankind will face in the future, should argue that the economics of today should as far as we can foresee reflect more of the economics of the future so that we can adopt ourselves progressively to the changed situation that will arise.

This, as I mentioned at the beginning, is exactly what President Carter has attempted to do earlier this year. He made a very bold and courageous attempt to try and bring to the attention of the American public what the situation is likely to be and how they ought to adjust their style of life to meet the new situation. The result in Congress has been an enormous disappointment, the American public, as represented by their elected representatives do not want to know, they would prefer to have the good life continue as it is and they'll worry about the future only when something actually stops.

This is the way human beings are. It is not peculiar to the United States. What I think is doubly distressing is that many of those who advocate conservation, who claim to foresee how we should adjust our lifestyle, direct their energies not to advocating policies that would be really effective in reducing energy demand but would be unpopular, but direct them at the centres of production where they can claim immediate success by delaying construction, safe in the knowledge that the adverse effects of their intervention will not become apparent for ten years or more.

These attacks on centres of production of energy can do no good for mankind. When the energy shortage becomes apparent it will be the poorest people who will suffer most and those who have delayed the construction of additional energy sources have done much damage by the misdirection of their attacks.

I am in favour of conservation, I am in favour of making better use of our resources, I am in favour of leaving some of our natural resources for our grandchildren. If we are to chart the right course for ourselves we must I believe adjust our economic and pricing policies progressively so that both the public and the energy industries take decisions consistent with our longer term objectives.

Exhortation will do very little. Delaying the construction of additional energy supplies will be wholly harmful. The judgments must be to what extent pricing policies should be used to coax a reluctant public along a path it does not wish to follow.

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## International Conference

The OECD Nuclear Energy Agency and the United Kingdom Atomic Energy Authority with the co-operation of the International Atomic Energy Agency and the support of the Commission of European Communities Joint Research Centre Central Bureau for Nuclear Measurements are organising an International Conference on Nuclear Physics and Nuclear Data for Reactors and other Applied Purposes from 25th to 29th September, 1978 at Harwell. The aim of the Conference is to bring together scientists who are interested in the use, measurement, calculation and evaluation of neutron and nuclear data for applied purposes. The main emphasis will be on the data needed in the fission reactor programme—for the design, operation, safety and shielding of fission reactors, the processing of fuel and the storage or disposal of nuclear waste—but a large fraction of the time will be devoted to the data related to fusion reactors, to biomedical needs, and to other applied purposes.

The working languages of the Conference will be English and French.

The Conference is open to all those with a special interest in nuclear physics and nuclear data who are working in OECD or IAEA member countries. For reasons of space participants will be limited to about 200.

The Conference will be held at the Cockcroft Hall, Atomic Energy Research Establishment, Harwell, England with accommodation at St. Catherine's College, Oxford.

Those interested in attending should write for further details to Dr. G. D. James, Nuclear Physics Division 7.21, AERE Harwell, Didcot, Oxfordshire, England OX11 0RA.

# NUCLEAR POWER AND THE ENERGY FUTURE

**A two-day forum under this title was held in London on 11th and 12th October. It was organised by the Royal Institution and sponsored by the UKAEA, the Electricity Council, the Nuclear Power Company, Friends of the Earth, the National Council for Civil Liberties, the Council for the Protection of Rural England and the Conservation Society; the chairman was Sir George Porter, FRS, Director of the Royal Institution.**

**In this article, James Daglish, of the Information Services Branch, UKAEA, summarises those aspects of the debate which seemed to him to emerge as salients.**

The stated objective of the forum was "to inform the public and decision makers." Papers by each of the 12 main speakers were prepared in advance and circulated to all participants. In each of the six main sessions, the two principals outlined their arguments for about five minutes each, then debated them for about half an hour. Discussions were then opened to the floor. Two additional speakers made closing statements on what they saw as the next policy steps to be taken in the UK at the end of the second day.

The 468 participants in the forum came from a very wide range of organisations, having views both for and against nuclear power. The forum was open to the press; and it was also filmed for use in a television programme.

Dr. John Cunningham, Parliamentary Under-Secretary of State for Energy, who opened the debate, in the absence of the Secretary of State for Energy on Cabinet business, noted that the activities of the nuclear industry were subjected to intense public scrutiny and questioning; and that those who believe in nuclear power are finding themselves called on to defend their activities vigorously.

"Scrutiny, however, is nothing new for the industry," he went on. "From its inception attention has been paid to achieving a first-rate safety record; and the growth of the industry has been paralleled by the growth of the most careful oversight and regulation. I am well aware of this in my own constituency, where the Calder Hall nuclear reactor—the first commercial-scale reactor in the world—is about to celebrate its twenty-first anniversary.

"We hear a great deal about the energy gap which this country may face in the 1990s. One can argue that there will be an energy gap; or that there will not be; or that the only thing certain about forecasts is that they will be wrong. But whatever view one takes, the important point is that we must ensure that adequate supplies of energy are available to meet the country's energy needs. The costs and consequences of failing to meet those needs would be tremendous.

"We cannot be sure about the precise combination of components on which we shall want to draw to meet our energy requirements in the latter part of the century and beyond. But we have to plan and equip ourselves with the means, and a (forthcoming) Green Paper on energy policy will be looking to strategy.

"Major contributions will certainly be required from coal and from conservation policy. The renewable sources may also be able to contribute, although probably not on a significant scale before the end of this century.

"People sometimes question whether we need nuclear power at all. My own view is an unequivocal 'yes'. I have no doubt that any rational energy strategy must plan for a significant contribution from nuclear stations, and for a nuclear industry which can provide them. The central question for the future is not whether we should be planning for the option of nuclear power, but on what scale we should use it in the longer term.

"The extent of our eventual commitment to nuclear power is not something that can be decided upon, or even predicted, now. It can only be resolved in decisions taken progressively over the years in the light of national need and of acceptability to the country at large of the possible economic, social and environmental implications of not having such a programme.

"What we can and must do is to ensure that we make full use of the breathing space given to us by our fossil fuels to resolve the various questions which arise in connection with the development and use of nuclear power, so that when a decision about a large programme, and the role that fast reactors should play in it, has to be taken the Government of the day will be properly equipped to take it.

"There is no question, however, in my mind of our having plenty of time to prepare. We need to put the necessary policies in hand without further delay. We cannot fritter away our reserves of fossil fuels and then ask ourselves what we do next. That would be profligate in the extreme. We need to examine our energy future now, and we must plan for the future on the basis of what we know we can do, and not what people think we may be able to do.

"We must pursue with vigour the very important issues raised by the Royal Commission on Environmental Pollution, particularly those relating to the management of radioactive wastes, the avoidance of nuclear proliferation and the risks of diversion by terrorists. The Government have announced the first steps in a recent White Paper on nuclear power and the environment, and we shall be following that up.

"Secondly, we must ensure that we have a thermal reactor system of proven reliability and performance available when we come to order in quantity in the 1980s and 1990s if that proves necessary and acceptable at the time. The Government have the question of the choice of reactor for our next nuclear power station orders under review in the light of the recent report from the National Nuclear Corporation. We recognise the need for an early decision, and indeed that decision is now imminent.

"Finally, we need to ensure that the development of nuclear power does not outstrip public acceptance and understanding of what it involves. To say this is not to be anti-nuclear; it is simply to recognise that nuclear power raises fears and anxieties in people's minds, and that facing and answering these fears and genuine anxieties now is a more sensible course than ignoring them and risking a confrontation at some time in the future. Detailed public scrutiny of the issues takes time, but the Government is convinced it is the right way, indeed the only way, to proceed. It is only by debating rationally the wide-ranging issues involved that we can begin to reach any sort of consensus."

## The debate

The title of the first session was "what is the energy problem?" Lord Avebury, president of the Conservation Society, argued that if one concentrated on establishing what kind of lifestyles we expected people to have in the future one could then calculate likely future energy consumption. He believed that one could envisage very comfortable and adequate lifestyles which did not involve the vast increases in energy consumption which "the nuclear protagonists and others in the energy industries are calling for." In the paper supporting his presentation, Lord Avebury said: "Is the so-called civilised world really so bankrupt of ideas that the only major political goal is perpetually increasing consumption of material goods and thus of energy?

"In a country like Britain, which after all is no longer in the front rank economically, we consume more already than we need collectively to keep ourselves properly nourished; there is enough accommodation for all, we have enough fuel to keep warm, and there are the means of adequate mobility. The reasons why some people do not have enough of these goods still are not inadequacies of supply, but waste, misallocation and inefficiencies of distribution. And experience shows that continued growth does *not* solve the question of poverty, on a world scale or within one country. We need to consider urgently the alternative goals which might be presented to mankind, because it is only in the content of well-defined general aspirations that one can design appropriate energy strategies."

K. R. Williams, head of technological group planning of the Shell International Petroleum Co agreed that the pattern of exponential growth in energy demand which we had seen over the past 30 years could not continue and that we should save energy wherever this was possible and economically sound. However, "as a scientist I would feel very loth to say 'no, future generations shall not have this option or that'. The worst thing that could happen in my view is that there should be a major cutback in effort on such things as the fast reactor and reprocessing, because if at some future time it was necessary to develop these technologies we would have dissipated teams, and we would perhaps have to start rushing at the problems. That, as any technologist knows, is the one way to trouble and danger. Far better to develop options, so that they are available as a choice for future generations. I do not want to foreclose the options." In his paper, Mr. Williams said that provided the world behaves in an intelligent manner there is no reason why insuperable energy shortages should occur. What would be disastrous would be not to exploit all the economic energy sources other than oil. Alternative energy sources offered no "quick and cheap" solution.

Mr. Williams concluded that "much more is to be gained by trying to envisage the type of world we would like and hope to see 50 years hence and deciding how best the demands could be fulfilled, rather than continually extrapolating the present or alternatively postulating some Utopian dream world which bears no relation to either human behaviour or real costs."

In the second session strategies for the future were reviewed. Michael V. Posner, Fellow of Pembroke College, Cambridge, argued in his prepared paper that to ask the people of Britain to bet upon a world price of energy so low that any investment by us in nuclear power would turn out to be mistaken was to suggest a degree of willingness to gamble that in any other field of public policy would be rightly condemned. "Prudent management of our energy affairs requires at this stage that we exclude no options, and proceed with all deliberate haste along all reasonably plausible lines of development—probably rather faster, along all of them, than any politician has yet permitted himself to suggest." His strategy for the future was "to buy some of everything, up to and somewhat beyond the limits of what would be thought 'economic', on the basis of a real price of primary energy about three times its present level." More investment in nuclear energy would be wise.

Gerald Leach, Senior Fellow, International Institute for Environment and Development, agreed with "about 90 per cent" of Mr. Posner's paper; but he stressed that if one assumed increases in the cost of energy and a low discount rate, as Mr Posner did, this made conservation even more possible than nuclear. As he wrote in his paper, "a flowering of intensive work on fuel conservation and renewable energy supplies, which began only three to four years ago, is now beginning to bear fruit. Many new ideas for meeting energy needs sustainably, safely and at low cost are emerging. Indeed . . . it now seems plausible that the introduction of known technologies could hold UK primary fuel consumption at its present level while allowing for substantial material growth; and that official energy demand projections are beginning to fall as they recognise these facts.

"It would be foolish to make early, major commitments to expand nuclear power, especially the plutonium breeder. We need time to prove and cost the new alternatives. We need time to include them in a new range of alternative energy strategies and to debate these. We need time also to investigate solutions to the many difficult problems of nuclear power. I submit that we have the time: there is no urgency to the nuclear debate." His strategy was to delay the expansion of nuclear power for a few years to gain time and to use this period to grasp the most socially, economically and environmentally attractive long range energy strategies.

Mr. Posner said he could not pretend that the world would come to an end in 30 years' time if we spent another couple of years debating some of the issues. "But I see no reason why I have to have one or the other," he continued. "As far as I am concerned I can have both. I am in favour of quite a lot of straight and even a bit of adventurous investment in all the things which are available to us. But I also want to go ahead with a bit of adventurous investment in nuclear, as well as 'orthodox' investment in nuclear. I see no reason why these options are mutually exclusive."

Rob Francis (Friends of the Earth, Manchester) agreed with Mr. Posner that we have very little choice in the UK but to develop all sources of energy; but did he believe that we could do so sufficiently "if we commit £600 million or so to the nuclear option?" Mr. Posner replied that the sums of money required for the further development of "alternatives" were relatively small: as for R&D in relation to them "I don't think that is a matter which comes up against some vast capital constraint."

Arthur Palmer, MP, chairman of the Commons Select Committee on Science and Technology, noted that in a recent report the Committee "were driven on the evidence to the inescapable conclusion that if British industry is to have the massive blocks of power it will need in the future it certainly needs the further development of the nuclear industry." To Mr. Leach "and others who think like him," he would say as a practical politician "it is impossible to go on a public platform and say 'vote for me; I will guarantee to reduce your standard of life'." Mr. Leach replied that he thought this unwarranted; his assertion was that we could keep our standard of living and even increase it substantially if we took the right decision. Britain had made a premature decision on Concorde. "We put all our money on one horse, because we thought the future was with speed," he said. "The Americans thought it was with size; I think they have won in economic terms."

Frank Chapple, General Secretary of the EETPU*, said the view of the TUC Energy Committee corresponded more with Mr. Posner's argument than with Mr. Leach's. By any stretch of imagination, the risks faced by the nation were greater if we did not keep the nuclear option open.

There was a danger that if we did not, we could in future be propelled into a headlong rush to build nuclear power stations in the most unsafe manner conceivable. We should take the way out offered by Mr. Posner.

## Alternative energy sources

Dr. Peter Chapman, of the Open University Energy Research Group, opened the third session, on alternative energy sources. In a lengthy paper he argued that perhaps the highest priority objective of energy policy is to provide cheap fuel to industry, to maintain the competitiveness of UK goods in world markets. No government policy for energy should require changes in consumer lifestyles; and any resources used in an energy policy should be used at least as efficiently as in other sectors of the economy. Investments made in energy policy must therefore provide an adequate return on capital. His "alternate" energy strategy contained only those energy sources which had been studied in some detail at the Energy Research Group; the major source of energy in it in the year 2025 was coal, used to provide carbon feedstocks, to make substitute natural gas and to produce electricity and heat in combined heat and power stations. Solar energy was used to provide some domestic space heat requirements and a large fraction of domestic hot water; and wave power was used to provide about a third of all electricity, in conjunction with pumped storage schemes and consumer storage so as to provide a reliable source of supply. The information now available, Dr. Chapman argued, suggested that the least cost energy policy was likely to have a fairly small nuclear component.

In his presentation of this paper, Dr. Chapman said it seemed to him that everybody was arguing from fear toward conclusions which would alleviate their fears: half were saying that without nuclear energy we would face a future of poverty and cold, the other half that with nuclear energy we would face a future of death by war. Until these opposing points of view could be brought together we would have not a debate but a shouting match.

D. J. Miller, Director of Engineering of the South of Scotland Electricity Board, said in his paper that neither of the common predictions made by those who advocated increased use of "renewable" energy sources—that is, the rapid development to a significant level of one or more of these sources, and a reduction in the rate of growth in demand for energy—would be realised in this century. "If they are realised, however, it will not be because those who predict them have any particular foresight, but rather it will be in spite of the best judgment that can be made today," he said.

"Those who have the responsibility of ensuring that the country has the energy it requires, when it is required, at the lowest cost, must keep their options open all the time, and make decisions as and when necessary in the light of the best information available at the time. In the case of electricity, for instance, decisions have to be made about ten years ahead, and plans must be based on assured sources of energy, and on proven technology. As the demand cannot be forecast accurately, it is essential to make provision for over-capacity rather than under-capacity, as a shortage of energy would have disastrous effects on industry and the well-being of the people." To close the nuclear option would certainly be irresponsible; if the development of alternative sources succeeded sooner than could reasonably be expected, and they could be demonstrated to be competitive with nuclear power, then they would have a full part to play in meeting our energy needs.

In the discussion of these papers, L. G. Brookes, of the Economics and Programmes branch of the UKAEA, said the distinction between Mr. Chapman and Mr. Miller epitomised the dilemma: if energy is to be useful then it had to be made available at a price within the price bracket which enabled energy to substitute for land, labour and materials. If the prices of existing sources rose to a level at which some of these substitutions became uneconomic, it did not help to replace them with other energy sources which were subject to the same factors. The real "alternative" energy source was nuclear, which helped to keep costs down.

Sir Kelvin Spencer invited the audience to look at the "alternatives" from the historical perspective of the last two or three decades. Much had happened which had been unpredictable: the bomb, computers, calculators and so on. There was a fifty-fold discrepancy between the funding of nuclear energy and of

*Electrical, Electronic, Telecommunications and Plumbers' Union.

the alternatives which were only now beginning to be given adequate attention.

The first day ended with a question and answer session given by the Secretary of State for Energy, Mr. Wedgwood Benn. He said he did not think anybody doubted that energy policy was essential to the survival of any industrialised country. Within energy policy, nobody disputed the absolutely unrivalled safety of nuclear power compared with any other energy source. He was sceptical about the value of forecasts. "To be mesmerised by forecasts is a way of getting you to do what the forecaster wants you to do," he said. "I want to have elbow room." Secondly, there was a tendency in high technology areas for people to say "I am the expert, I will tell you."

Through the public discussion he had called for, Mr. Benn was trying to get access to information relevant to the problem he was considering. "I am not anti-nuclear," he said, "but I think it must stand alongside other fuels and answer questions. If I were in the nuclear industry I should be very nervous about maintaining such a big rate of 'spend' without being subject to the scrutiny that other industries are subject to."

One thing was clear: forecasts of energy demand made four years ago, even three years ago, had been wrong. The western world had gone into a slump, and we now had time to consider. "I am using the delay to think out in greater depth decisions that do not actually have to be taken now."

## The second day

The second day opened with a discussion of the technological demands of nuclear power, led by Dr. N. L. Franklin, chairman and managing director of the Nuclear Power Company Ltd., and Walter Patterson, of Friends of the Earth. Dr. Franklin said judgment must be made in three areas: first, was nuclear power worthwhile as an investment? He thought it was. Secondly, was it safe, particularly against accidents? In this respect, the technologist must persuade people that to achieve safety he was relying on units of known dependability, which the common-sense of the average individual could accept, and combining these wherever possible in such a way as to produce high levels of safety without demanding super-technology either in the people who did the construction, or in the components themselves. Thirdly, society would require assurances that we were not leaving a legacy of disadvantages greater than were at present supposed. Dr. Franklin said he found this the most difficult area in which to satisfy himself, but he did not regard the management of the legacy as beyond our capacity. In his paper, he concluded that none of the requirements for economic and safe nuclear power imposed inordinate demands upon the nuclear technologist in the field of technology or in the management and administration of groups of individuals who construct and operate the units which are the embodiment of the technology.

Mr. Patterson submitted in his paper that nothing about nuclear technology was in itself more esoteric than, say, computers or colour television. It was the view of Friends of the Earth that only one hazard of nuclear technology was qualititatively different from hazards arising in other industries, but this overshadowed all others. Nuclear technology was conceived for the purpose of manufacture of nuclear weapons, and it was clear to FoE that no absolute barrier could ever be erected to separate civil nuclear activities from their military counterpart.

There was another aspect, however, which must be considered. "The sorry record of electricity demand forecasting for the past two decades underlines an important corollary: policy influences forecasts, has long done so and—if present plans are fulfilled—will in the future do so definitively. . . . Electronuclear advocates may be correct. It may be possible to move toward an energy supply predominantly generated by base-load nuclear stations and delivered as grid electricity. It may be possible to do so without exposing the population to insidious injury from radioactivity in the environment, or to the consequences of disastrous nuclear accidents. It may be possible: but is it worth attempting? The technological demands of nuclear power make the electronuclear route a perversely difficult, expensive and potentially dangerous way to reach a destination we may deeply regret reaching. If we insist on doing it the hard way we may find ourselves where we have no desire to be—and there may be no way back." In his presentation, Mr. Patterson concluded: "In the nuclear field prematurity has been the order of the day from the inception of the technology. I think it is about time for us to adopt a different model: in nuclear matters, 'Don't just do something, stand there'."

F. P. Jenkin, CEGB System Planning Engineer, noted from the floor that the CEGB was a commercial organisation; on the whole its batting record had been better than had been suggested. "It is true that we made forecasts which were not borne out," he said. "We may very well have had demand which got much closer to the forecast and plant may have been needed if the country had had better economic growth, and we had had less competition from gas. We have had over-capacity for the last three years because of a major oil crisis—although that might have been foreseen, the timing could not be foreseen."

A paper by Dr. T. N. Marsham, managing director of the Northern Division of the UKAEA, on the fast reactor and the plutonium fuel cycle, was reproduced in the last issue of ATOM. Sir Brian Flowers, FRS, Rector of Imperial College and a past-chairman of the Royal Commission on Environmental Pollution, argued in his paper on this topic that nuclear power is at present the only thing on which we can rely with any certainty for massive contributions to meet our energy needs for the next quarter century and beyond. "This may indeed be the case, but if so it arises from the fact that for the last quarter century we have been assuming it to be the case and have therefore failed to make any alternative available," he said. "Given the existence of geothermal energy, solar energy and possibly fusion, it is impossible to assert that mankind faces a shortage of energy in the very long term.

"It should therefore be a deliberate act of policy to ensure that by the year 2000 we are faced with a choice between genuine alternatives, so that if we then decide to expand the nuclear option we do so because it is not the only, but the best thing to do at that time."

In his presentation, Sir Brian said he accepted most of Dr. Marsham's paper; in particular, he thought it right that this country should be able to exercise the fast breeder option by the end of the century, if by then that appeared the best thing to do.

"I am optimistic that the FBR as such will be shown to be adequately safe given several years more painstaking research," he said. "In 1977, however, I do not think one can rely on there being a satisfactory outcome, because one has yet to demonstrate that the consequences of a serious accident will be acceptable. What more reason for a serious examination of alternatives?"

Dr. Marsham said the prospects for fast reactors should stir anyone seriously concerned with energy problems. "It is a wonderful opportunity for which we should be thankful, and we should concentrate on solving the problems rather than allowing them to overcome us," he said. "To put the case for solving the problems in perspective, the Royal Commission report pointed out that with fast reactors uranium becomes the largest energy resource in the world. For this country, it is an energy resource ten times more important than North Sea oil—I don't think that point really gets across to very many people.

"I agree with Sir Brian that we should aim in our energy R&D strategy to have available as many realistic options as we can for the end of the century. But we must proceed also with the fast reactor. The option I would like to see is the one where we have the option to have energy available in quite large quantities if that is what society wants to have."

It was generally believed, he said, that the safety and security issues of the plutonium cycle required new, uncertain and probably unacceptable measures to ensure safety. But this was not so. Large quantities of irradiated fuels and of plutonium had been transported safely over many years, and the techniques the Authority proposed to adopt for the fast reactor followed exactly on the existing lines. "With regard to 'police states', we have been doing this operation for a very long time; I am not conscious of any particular intrusion on my civil liberties, and I see no reason why the fast reactor programme should be any worse."

Dr. Marsham said the final subject for discussion was radioactive wastes. Those which resulted from a fast reactor programme were similar to those arising from a thermal reactor programme; he and Sir Brian shared "pretty well identical views" on what should be done about them.

Sir Brian agreed that the waste disposal problem was not particularly dependent on whether there was a fast reactor programme or not. But one did not need fast reactors unless one had a large nuclear programme, and he believed that public opinion would demand that we have an acceptable means of dealing with the wastes which such a programme gave rise to.

"I do not think the first full-scale demonstration fast reactor should be postponed until the waste disposal problem has been completely demonstrated," he said. But the Government should, as their next priority, decide to build a fully-engineered waste disposal facility—"and they should take that decision before they take the fast reactor decision."

Sir Brian said he did not believe that the issue of civil liberties arose solely from nuclear power, nor that nuclear power was necessarily the major culprit. It arose from the growth of terrorism; he believed we had to assume that terrorism was going to be with us for a very long time, and was probably going to become more extensive.

"The issue of civil liberties, then, (means) you must look at all the nasty things terrorists might wish to do . . .—possibly building illicit weapons, if you can steal the plutonium to do it with," he said. "Apart from the escalation that these possibilities give to the terrorists, I think one has to look at the totality of the nasty things terrorists might do, and then ask what to do to protect society against all of those things. This we have not done, and I am sorry that the nuclear industry is being used in a sense as a whipping boy." The security vetting of people concerned with sensitive activities had in the past been restricted to a very few people with know-how. In future, one might be concerned with people who have access to materials, not just those with know-how; the numbers involved in the whole of the industry might then be large enough to create a civil liberties problem. "I do not know, I merely ask that it should be looked at," he said.

Paul Sieghart, joint Chairman of the Executive Committee of *Justice*, asked to what extent the timescale for decisions on the future fast reactor programme was likely to be affected by problems of civil liberties. "Dr. Marsham appears to take the view that for all these things there must be somewhere a technological fix—that is to say, that it is the kind of problem which you could design out of or try to design out of your system."

Sir Brian said the proposed demonstration commercial fast reactor "requires, and will have, we are assured, a major public inquiry in which I presume these issues will be included." Dr. Marsham agreed that one of the things the Authority must demonstrate is that it could carry out the programme without infringing civil liberties.

Peter Adams, of the EETPU, said there was no reason why a decision should not be taken immediately on thermal reactors, but none had been made; there was no reason why an early decision should not be made about the need for a fast reactor programme. "We are now entering the era of public debate, and public debate is right and proper," he said. "But public debate should not be used to avoid making decisions. If we do not make some decision soon, and at the same time do all the things that are necessary, as Sir Brian has highlighted, we could still find a situation where the country will be in such a difficulty over energy that crash programmes will be needed that will not take proper regard to the things being considered."

The last of the six sessions was on the international proliferation of nuclear weapons. The paper by Sir John Hill, chairman of the UKAEA and of BNFL, on this subject was published in the last issue of ATOM. Presenting it, he said he had undertaken to speak at the forum because he believed this was a real problem which needed public debate. The nuclear industry must demonstrate that it was not significantly increasing the risk of nuclear proliferation that had existed since the first nuclear weapon was detonated, in the United States in 1945.

"The exemplary record of nuclear power is not the result of good luck or of chance," Sir John continued. "It is because our plants are designed to safety standards at least ten times higher than those in the chemical, petrochemical and natural gas industries. The same will be true of radioactive waste disposal in the future; it will cause no significant hazard to anyone.

"The reason I make these points now is that safety depends on care, supervision and surveillance. The same is true about proliferation. People frequently confuse the problems of the proliferation of nuclear weapons with nuclear power, although these are really two quite distinct and separate issues. All the nuclear weapons made to date have been made in facilities that have been built for that purpose, and which have not been part of any nuclear power programme. There is no doubt that today a government which decided to build a nuclear weapon would conclude that the easiest and cheapest way of doing so would be to build facilities specifically to do that job. The reason so many countries who would like to have nuclear weapons and have the capability to build them but have nevertheless desisted from this course of action in international political pressure. This is the only way to prevent proliferation. The nuclear power programme must ensure that it does not by carelessness make proliferation easier."

Brian Johnson, Senior Fellow, International Institute for Environment and Development, aimed in his paper to show that the "social" argument for spreading nuclear electricity in the Third World was refutable. He argued that the greatest obstacle to a potentially manageable situation with regard to the geographic spread in the use of nuclear power reactors was pressure for premature fuel reprocessing and commitment to the breeder reactor; that the international system for safeguarding "peaceful" nuclear technology is dangerously inadequate; and that a number of "essential prerequisites" must be fulfilled before there is any further spread of nuclear power. These accorded closely with President Carter's proposed policy of April 1977 in offering an alternative path to a reprocessing commitment and the closing of the fuel cycle.



In his presentation he said he had been more sanguine about the distribution of nuclear technology around the world about a year ago. He was less sanguine now and more worried. There was the problem of warning time—the time within which a safeguarding authority would be able to act in advance of a non-nuclear weapon state acquiring a weapons capability. It had been assumed until now that the route to weapons production would involve an elaborate, separate facility open to surveillance. "But it is by no means inconceivable that a country desiring to get the bomb will develop facilities secretly, and if it wishes it could marry the (special nuclear) material with an explosive device, and have a nuclear explosive device in a matter of hours. Time is a critical element in international relations. . . . If you do not have time you do not have any safeguard at all. The IAEA, Euratom and the Nuclear Suppliers' Group are extremely worried."

Sir John said in the discussion which followed that the nuclear industry wanted to prevent the spread of nuclear weapons. "But the technology exists in the world in any case, and the thing we are considering is whether the nuclear industries are going to make any significant worsening of the situation which already exists. I believe it is only international pressure which can stop proliferation taking place." The problems of designing a bomb within the nuclear world made it a long and difficult job, which he did not think was any easier than building the facilities to get the necessary fissile material. Materials such as plutonium ought to be restricted to, for example, international reprocessing centres under strict international surveillance.

Sir John argued that the developing countries should concentrate, in seeking to meet their energy requirements, on coal, oil and biomass—"and we should leave them enough oil to develop their economies, and not burn it in such a profligate manner ourselves. . . . I do not think it is in the interests of the developed countries to push nuclear power into the under-developed countries at this time."

Mr. Johnson asked Sir John why, in his opinion, developing countries wanted nuclear power. Sir John said he thought the developing countries saw in the West standards of living and of industrial strength that they wished to copy; the industrialised countries had gone for nuclear power, and the developing countries wished to follow. "I think it is very clear that small nuclear power stations are not competitive with coal and oil," he added. "The developing countries cannot use the baseload stations we build, so I don't see an economic advantage to them in starting too early."

## Conclusion

The two-day debate ended with a brief consideration of the next policy steps to be taken in the UK, in which two speakers—Czech Conroy, of Friends of the Earth, and Francis Tombs, chairman of the Electricity Council, made short statements.

Mr. Conroy said he thought the most important energy policy decision facing us at present was that in relation to the expansion of Windscale. Sir Brian Flowers had said that in order to keep the reprocessing option open somebody had to show that a full-scale oxide reprocessing plant could be built and operated to acceptable standards of safety. But this was a quite different question to whether, having built it, we should use it to encourage international traffic in nuclear materials. Six months ago President Carter had announced his intention that the US should ban reprocessing, and had sought a global moratorium on this technology. This announcement had received a puzzled and sometimes angry response from the nuclear industry; many people did not really believe that the United States was asking other countries to forego reprocessing solely because it had a moral sense and was trying to restrict the spread of weapons technology.

In Britain, he said, we had not previously bothered to construct an oxide plant as such. What would happen next year if Mr. Benn and his Cabinet colleagues decided Britain should adopt a compromise position and build an oxide plant solely for domestic purposes? "I am sure the response of other countries throughout the world would be one of extreme scepticism," said Mr. Conroy. "They would argue that all Britain was doing was trying to maintain and expand oxide fuel reprocessing and the result would be that . . . in France and West Germany oxide reprocessing would go ahead; any remaining hopes of stopping the sales of reprocessing plant to Pakistan or Brazil would evaporate, and although this did not directly result in a flood of nuclear materials, it would certainly do so indirectly."

On the fast reactor, there were other options which were preferable and should be pursued; £600 million spent on it could turn it into a cuckoo which threw other energy alternatives out of the nest.

Mr. Tombs said a factor underlying all the discussions had been a somewhat belated recognition of the finite nature of the fossil fuel reserves—in particular, those of oil and gas. There was an urgent need to conserve resources by more efficient conservation and reduction of loss; and we needed to supplement the fossil reserves by developing alternative forms of energy at a sufficiently rapid rate to avoid an energy future in which access to energy became so expensive as to jeopardise our way of life and the aspirations of less-developed countries.

"It might appear tempting to postpone major energy decisions in the vague hope that something new will turn up, or that unproved energy resources will pay off," he said. "Such an attitude would fail to take account of two very important factors:

(1) the plenitude of energy is likely to be short-lived;

(2) we have to import food and other raw materials, and so have to export manufactured goods to pay for them. A country such as the UK must have energy supplies at a competitive price.

"The development of alternatives, sometimes called benign resources, is a seductive concept. . . . Unfortunately, however, although the energy itself may be free the cost of collecting it and converting it is high. . . . It does seem to me that most such energy sources are likely to cost more than an equivalent amount of energy from developed sources, including nuclear energy."

He hoped the two days of discussions had done something to dispell the concern expressed by some groups about the acceptability of nuclear power. "The shadow of the bomb understandably if mistakenly leads to apprehension; but one must distinguish the problems and advantages of the civil programmes from those of the military programme, which creates surprisingly little public concern.

"There is no doubt that a great deal more work needs to be done on waste disposal, and we should support the work being done by the EEC in this area. I think there is little concern today about the safety of nuclear power stations, but there is concern about the processing of irradiated fuels. . . . It seems to me that future strategy requires several things: to maintain falling oil and gas reserves we shall need to increase coal output and the nuclear power programme; (and) . . . we must preserve the option of the fast reactor, because the improved conversion efficiency is an attractive proposition. But the contribution of the fast reactor to energy is really a matter for the next century. We must pursue and develop the alternative energy sources, recognising that their contribution will be slow; and we must seek to conserve fossil resources by the vigorous promotion of conservation measures as they are economically justified."

Summing-up, Sir George Porter said he though it fair to conclude that there had been pretty general agreement on one policy point: that we needed to keep our options open. "If this debate has reached something of a consensus it has also arrived at something of an impasse", he said. "There is a strong case that we need nuclear energy, and there is a strong case that there may be dangers. Some might even say we cannot have an acceptable standard of living in the next century without it, but because of weapons proliferation nuclear energy is unacceptable, in which case the conflict is not between us but within each one of us. We can agree that it is of supreme importance to work towards international agreements which will make the world a fit place for nuclear reactors to work in, whether we have them eventually or not. We all of us I think have the greatest admiration for the skill of the scientists who have provided us with this wonderful new source of energy. It has arrived just at the time when fossil fuels are beginning to run out. The dangers of this source which many of us fear are no fault of the nuclear scientists, but mainly attributable to the stupidity and susceptibility of mankind as a whole. This shows little sign of improving. We all share the disappointment of the nuclear engineers, and I think most of them share our fears. I hope this forum has done something to improve understanding between us."

At the end, Mr. Conroy proposed a vote of thanks to Sir George and to the Royal Institution, for their part in organising the forum, which was warmly applauded.

## London contamination survey

The Environmental Safety Group at Harwell has been awarded the first stage of a major contract for determining contamination levels at London building sites.

The total contract, which is subject to confirmation by the Greater London Council, is estimated to be worth about £250 000.

The Harwell team will be contracted to the GLC to investigate at least 15 sites which are known to be or expected to be contaminated by noxious and toxic chemicals.

The work will involve collecting samples, analysing them using Harwell's extensive analytical facilities, and interpreting the results.



# THE RADIOCHEMICAL CENTRE LIMITED ANNUAL REPORT

The Sixth Annual Report of The Radiochemical Centre Limited was published on 4th August 1977. It included the following statement by Sir John Hill, Chairman.

The year just passed has been an exceptionally progressive one not only on account of the very good trading results which were achieved but because during its course the operational and financial foundations of TRC have been considerably strengthened. The long term advances that were made towards developing the enterprise as a Group with substantial subsidiaries overseas, co-ordinated through the parent Company at home, were of primary importance for the future.

### Trading results

Group sales increased to £21·5m from £15·4m in 1975/76. Total reported turnover was enhanced this year by consolidation of the American company's sales for the first time as a subsidiary, a change of status which is referred to later in my Statement. Excluding this factor sales would have shown an increase of 31 per cent to £20·2m. The parent Company's turnover grew by 29 per cent from £13·1m to £16·9m with a record 73 per cent exported, amounting in sterling to £12·3m.

Nett profit for the Group was nearly doubled at almost £5m. This result represents a real improvement in business efficiency, even after allowing for the considerable effect of exchange rate movements on earnings from overseas. In the year just ended a 37 per cent return was obtained although on the basis of the ED.18 recommendations on current cost accounting profits would have been reduced by approximately £1·0m after adjusting for increased depreciation and cost of sales. In line with current guidelines of national dividend policy the directors are recommending a distribution from profit in 1976/77 equivalent to an annual rate of 8·22 per cent nett on the share capital contributed by the United Kingdom Atomic Energy Authority as sole shareholder.

### Overseas subsidaries

From 1968 TRC worked in the United States through the Amersham/Searle Corporation, a 50/50 joint venture with G. D. Searle & Co. By 1976 it had become clear to the owners that, notwithstanding the considerable growth that had been achieved, continuing operation in this mode was not to their best advantage in the longer term nor in the main interest of the enterprise itself. Accordingly agreement was amicably reached for The Radiochemical Centre Ltd. to acquire the Searle share in January 1977. Later the name of the company was changed to Amersham Corporation. The unified ownership has simplified the management of the business, and significant progress has been achieved in the US market and in Canada.

Growth in Germany, though less spectacular this year than last, has been uninterrupted since 1971 when Amersham Buchler was set up and in 1976/77 the German subsidiary improved its profitability in a difficult market environment. The new laboratories at Wenden were brought into full production and the extension and improvement of the facilities was continued with the construction of a new office block.

### Operations in the United Kingdom

Construction work on the new site at Cardiff, to which I referred last year, is now in progress and the early stages have gone well with the contractors keeping close to their schedule. Although the contract for the major production buildings is not due to be placed until mid 1977 and completion is still some time away the planning and preparation for commissioning is already being given close attention; so too are the manning arrangements for the new site in conjunction with staff representatives.

In the meantime virtually all the Group's production is still from Amersham although both the American and German subsidiaries have some manufacturing capacity. At Amersham considerable progress has been made with scaling up plant and equipment and with other steps to improve productivity and utilisation of existing facilities. Notably rapid extension of production of alpha foil strip was achieved to match the unusually fast growth in the market for domestic smoke detectors, particularly in America. The successful setting up of a unit at Gloucester for large scale freeze drying of sera for our diagnostic products has provided added assurance to the supply of these important but radiologically inactive requisites.

### Product development

Emphasis in product development has continued to be mainly on increasing the range of medical diagnostic products. Amongst these were an improved kit for technetium-99m bone scanning and the indium-111 calcium DTPA injection for cisternography. Clinical chemistry kits for the determination of serum levels of folate, thyroxine and follicle stimulating hormone (FSH) were put on the market. The last of these, with our HPL and oestriol kits, helped to consolidate the Company's strong position in obstetrics and gynaecology. Other developments have included the preparation of machine-compatible protocols for the complete range of thyroid kits to which was added a further kit, for total serum T-4 (thyroxine) assay.

Changing requirements for labelled compounds, which reflect current research trends particularly in life sciences, are met by the creation of some 60 to 70 new compounds each year. This year these have mainly been concerned with providing compounds for use in neurochemistry and neuropharmacology—for example, labelled enkephalin—the extension of a range of labelled nucleotides used in molecular sequencing work and the development of new reagents for protein iodination.

### Personnel

The range of products and utilisation of resources have thus been significantly improved, thanks largely to the enterprise and dedication of the staff. This has produced results which bear comparison with the best achievements of industry anywhere, and which demonstrate the effect of having a clear purpose and a staff devoted to carrying it out.

In the context of this record of continued success and growth it is good to be able to note that the revised staff structure which was designed and put into effect in 1974 has stood up well to the strains imposed upon it by the subsequent period of pay restraint in the UK, although distortions have inevitably been caused by the strict application of the succeeding phases of the national pay policy. These effects have been especially severe on those executives who are also directors of the Company who since 1972 have received only very modest improvements in their emoluments, with virtually no increase since 1974. Besides being unreasonable in its effect on the individuals concerned this moratorium on directors' pay is delaying the reinforcement of the board by the addition of new directors. This essential objective of the present board membership has now been frustrated for some time and is becoming increasingly urgent.

### Financial and general status

During the year the board completed its arrangements to finance the programme of expansion which is in hand both in the UK and overseas. The new share issue of £5m to the United Kingdom Atomic Energy Authority was sanctioned and loan facilities of comparable size were set up in the commercial market including arrangements for funding the transaction for the complete acquisition of Amersham Corporation. The enhanced financial status of the Group is clearly demonstrated by the increase in its total assets during the year from £9·6m to £16·9m. The picture shown in the Accounts is thus fully in accord with the financial planning of the board in relation to future commitments.

It has been my aim this year to convey my satisfaction, and that of my board, at the impressive record of expansion in total sales, exports and profits, the successful development of new products and the progress of the subsidiaries in Germany and the US. These have all combined to bring about a major enlargement of the scale of operations thus providing convincing evidence that the international Group which is now in being has, whilst retaining and further exploiting its scientific characteristic, built up an increasingly powerful commercial impetus over the six years since the parent Company was incorporated. I therefore feel able to say with every confidence that The Radiochemical Centre Limited, and the Group of which it is the focus, is well placed for further development in the years ahead.

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## Reliability course

The Systems Reliability Service (SRS) of the UKAEA Safety and Reliability Directorate is particularly pleased with the continued national and international interest being expressed in their course entitled "An Introduction to Reliability—Theory and Practice".

The two 1978 courses (3rd-14th April and 4th-15th September) will be the 18th and 19th in the series. There are still a few places available. Details may be obtained from Miss Mary Sutton, Systems Reliability Service, UKAEA, Wigshaw Lane, Culcheth, Warrington WA3 4NE. Telephone Warrington (0925) 31244, Ext. 318.



## ICRP recommendations

The National Radiological Protection Board has prepared a summary of the main recommendations of the International Commission on Radiological Protection (ICRP). Prepared in response to requests from many quarters, including government departments, the summary has been published as a Board report*.

The recommendations of the International Commission on Radiological Protection were published in July 1977 (Oxford, Pergamon Press, ICRP Publication 26); the previous major review of the Commission's basic recommendations took place in 1966.

Meanwhile, the Board has received the following Directions from the Secretary of State for Social Services, acting on behalf of the Government:

"1. On every occasion when in relation to radiological protection
(*a*) the International Commission on Radiological Protection recommends the adoption of a standard;
(*b*) the Commission of the European Communities proposes the adoption of a standard to the Council of Ministers or to Member States;
(*c*) an Agency of the United Nations recommends the adoption of a standard;
(*d*) the Organisation for Economic Co-operation and Development or its Nuclear Energy Agency proposes a decision on or recommends the adoption of a standard

the Board shall advise the appropriate government departments and statutory bodies on the acceptability of the recommendations or proposals to, and on their application in, the United Kingdom.

"2. For the purpose of this Direction
(*a*) standards shall include the principles of applying standards; and
(*b*) the Board shall take into consideration such advice that it may obtain from the Medical Research Council in relation to the biological bases on which standards rest."

The second Direction states:

"'Emergency reference levels (ERLs)' means the level of radiation dose below which counter measures are unlikely to be justified.

"In the event of an accident involving or likely to involve radiation doses to members of the public in excess of the dose limits set out in Directive 76/579/EURATOM of the 1st June, 1976 laying down safety standards relating to ionizing radiation, guidance to those with responsibilities for the protection of the public as a whole shall include guidance as to applicable Emergency Reference Levels (ERLs) of dose.

"Within their function under section 1(1)(b) of the Radiological Protection Act 1970 the Board shall be responsible for specifying ERLs of dose. The Board shall also be responsible 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."

Further information is obtainable from the Information Officer, National Radiological Protection Board, Harwell, Didcot, Oxon OX11 0RQ. Telephone Rowstock (023 583) 600.

*Recommendations of the International Commission on Radiological Protection (1977), ICRP Publication 26—A summary. Harwell, National Radiological Protection Board, NRPB-R63 (HMSO, £1·00).

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## 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.

**Two Phase Flow and Heat Transfer**
*16th to 20th January, 1978*
*at AEE, Winfrith.*
An intensive course covering fundamentals and applications of two phase flow and heat transfer. The course is aimed at engineers and research workers in the process chemical, petrochemical, power generation and nuclear industries. Fee: £205 + VAT.

**Materials Science**
*16th to 20th January, 1978*
This advanced course is intended for scientists, engineers and technologists already working in this field, who require an opportunity to extend their knowledge beyond their own speciality. It will also meet the requirements of others who wish to familiarise themselves with current developments in Materials Science.

Topics will include unusual materials and their uses, ceramics, plastics, metals, composites, adhesives, physical properties, chemical interaction, compatibility, non-destructive testing and fabrication techniques. Fee: £185 + VAT.

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Sir John Hill to the US National Committee of the World Energy Conference in Washington.

**February**
*Pollution by poverty: the need for nuclear energy*
Dr. Edward Teller at the US Embassy, London.
*"The health hazards of NOT going nuclear"*
The book by Dr. Petr Beckmann summarised and reviewed by L. G. Brookes.
*The Windscale leak*
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Statement in the House of Commons.

**March**
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by Dr. D. H. Locke.
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by H. Hunt.

**April**
*Nuclear power: the world's need*
Sir John Hill to the Annual Dinner of the Institution of Electrical Engineers, London.

**May**
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Speeches by Sir John Hill and Lord Hinton at the closing down ceremony in the control room of DFR.

*Energy Research and Development in the United Kingdom*
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*The safety of the fast reactor*
R. R. Matthews, Chief Nuclear Health and Safety Officer, CEGB, to a meeting at the Imperial College of Science and Technology, London.
*WHO report on nuclear power and health*

**June**
*The energy gap and the fast reactor*
Sir John Hill to a meeting on the breeder reactor sponsored by the University of Strathclyde and the Highlands and Islands Development Board.
*Nuclear power: a social survey*
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*Nuclear non-proliferation*
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*The importance of nuclear fuel reprocessing*
C. Allday to the AIF Conference on International Commerce and Safeguards for Civil Nuclear Power, New York City.
*"The fight over nuclear power"*
Reviewed by L. G. Brookes.
*International Conference on Nuclear Power and its Fuel Cycle, Salzburg*

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