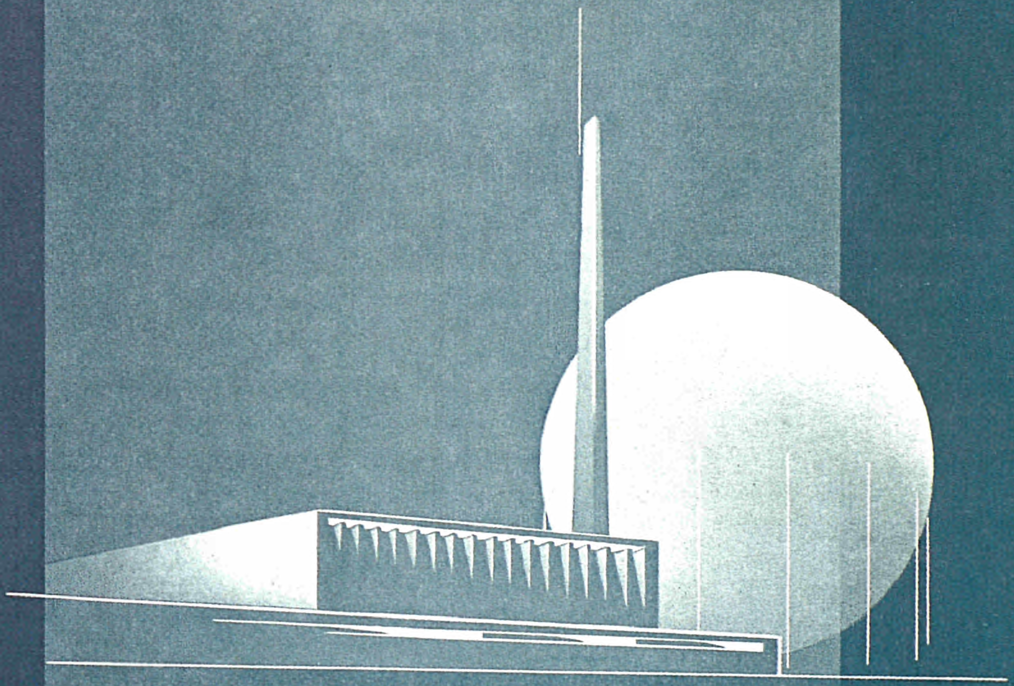
1962 No. 2



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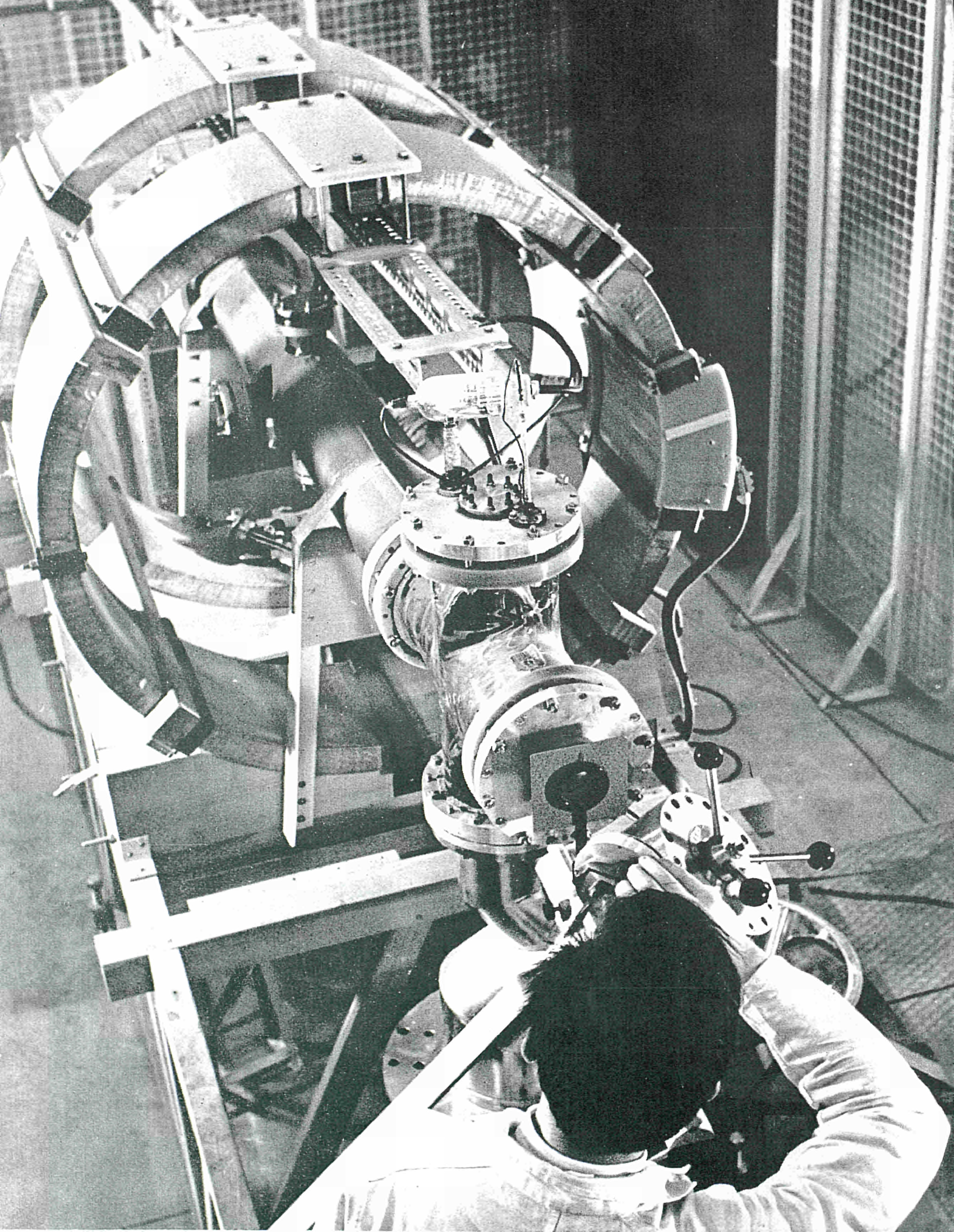
BULLETIN

EUROPEAN ATOMIC ENERGY COMMUNITY



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Information Bulletin of the European Atomic Energy Community

1962
No. 2

On the 25th March 1957 in Rome, six states, namely:

THE KINGDOM OF BELGIUM
THE GERMAN FEDERAL REPUBLIC
THE FRENCH REPUBLIC
THE ITALIAN REPUBLIC
THE DUCHY OF LUXEMBOURG
THE KINGDOM OF THE NETHERLANDS

signed the treaty which instituted the European Atomic Energy Community (Euratom).

Power reactors

Nuclear Physics

Reactor Technology

Nuclear Fusion

Radioisotopes

Mineralogy and Geochemistry

Ship Propulsion

Biology

Automatic Information Methods

Health Protection

Law

Insurance

Economics

Education and Training

When will nuclear energy truly be at the service of Man? When will nuclear energy be found everywhere, in our cities, in our factories, even in the humblest of cottages? The economist smiles and answers: "When nuclear energy can compete on equal terms with the conventional sources of energy".

"The economist may be right" said Prof. Medi, Vice-President of Euratom, in a recent comment, "but it would be unfair to confine our attention to purely commercial considerations without taking into due account the benefits of a social kind which we are entitled to expect from the utilization of this new energy. Will the miner not rejoice when his son dons the white coat of the nuclear technician"? High temperature gas-cooled reactors, thermonuclear fusion, which are discussed in this issue, are some of the instruments of this transformation.

Of course atomic energy brings new dangers as well as new benefits. We must learn to master them just as our forebears mastered all the other forces of nature which are now established as the servants of Man: there will be mention in some of the following pages of a recent victory of medicine in this field.

Doctors may still have many tasks to fulfill, but they are keeping pace with the forward surge of nuclear technology.

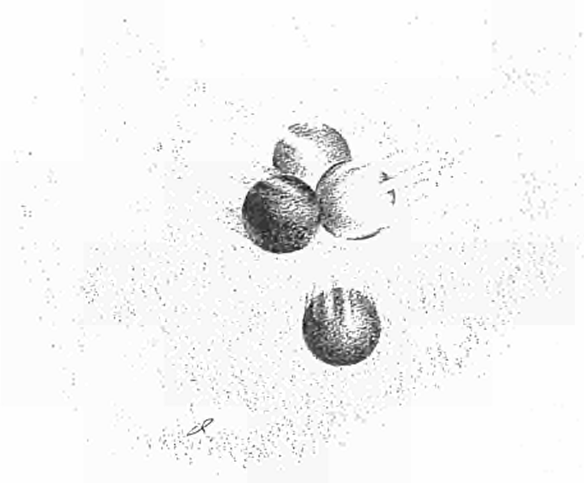
Controlled Thermonuclear Fusion

A SOURCE OF ENERGY FOR THE FUTURE

Donato Palumbo

Director of Euratom's plasma physics and controlled thermonuclear fusion research programme.

It was the release of energy through the splitting of the atom which marked the start of the nuclear age. From then on this process, the process of *fission*, has reigned supreme over most practical schemes for the production of power through nuclear energy and focused attention on heavy elements such as uranium, the raw materials essential to its realization. This supremacy should not, however, make us forget another process which has been giving the stars and the sun their energy for billions of years and which, in spite of the enormous difficulties standing in the way of its development on a laboratory, let alone an industrial scale, possesses an exciting future: controlled *fusion* reactions between the nuclei of light elements.



The reactions which seem to be of greatest interest involve two isotopes of hydrogen, namely deuterium and tritium. Deuterium is about twice as heavy as ordinary hydrogen since, instead of having a nucleus consisting of just a proton as in the case of hydrogen, it possesses one neutron in addition. As for tritium it is almost three times as heavy as hydrogen owing to the presence of yet another neutron in its nucleus.

The most useful reactions can be represented as follows:

$$D + D \rightarrow T + \text{proton} + \text{energy } (4 \text{ MeV})$$
$$D + D \rightarrow He^3 + \text{neutron} + \text{energy } (3.25 \text{ MeV})$$
$$D + T \longrightarrow He^4 + \text{neutron} + \text{energy } (17.6 \text{ MeV})$$

In all three cases the reaction can truly be described as "fusion" inasmuch as the two original nuclei merge into a heavier nucleus, but the specially interesting point about the reaction is that it involves a slight reduction in mass which is converted into energy, according to the famous law of Einstein.

In comparison with fission, which has already been harnessed in nuclear reactors, fusion has two major advantages:

First of all the fuel is, to put it mildly, in plentiful supply since it is virtually just water. Admittedly there is only one molecule of heavy water (D_2O) for every 6000 molecules of ordinary water, but it is still true to say that the energy available in the deuterium contained in one gallon of water is equivalent to the heat produced by the combustion of some 300 gallons of petrol. Tritium is much scarcer than deuterium but it is possible to produce it in the course of the fusion reaction by making the emitted neutrons react with lithium nuclei.

$$(\text{neutron} + Li^6 \longrightarrow He^4 + T)$$

Another favourable feature of fusion is the fact that it does not produce in any quantity the radioactive wastes the disposal of which is such a problem in the case of nuclear fission reactors. The only active nucleus present is the tritium nucleus, but the β-rays which it emits have low energies. As for the neutrons which are produced, they should all theoretically be consumed by the regeneration of tritium just mentioned.

In spite of these marked theoretical advantages it is still quite clear that fusion is well behind fission in terms of practical applications. We are of course not talking of *uncontrolled* reactions such as those used in the H-bomb but of the creation of *controlled* thermonuclear fusion for peaceful purposes. The special problems involved make the task of development particularly difficult, and if progress is slow, this is not for any want of trying on the part of the research teams investigating fusion; it is just that the road leading from the idea to the realization of the idea is strewn with obstacles. Let us look at some of them.

Fusion and its problems

There are two categories of forces present in a nucleus: on the one hand the short-range forces which hold the constituents of the nucleus together; on the other the electrostatic forces which are forces of repulsion and form the so-called "Coulomb barrier". Before the reactions already mentioned can occur, the two nuclei which are to fuse must collide with sufficient energy to overcome this barrier and come close enough to each other to bring into play the short-range forces, which are responsible for the reaction.

Then why not simply project beams of deuterium nuclei at the required energies against one other? This does not work because the electrostatic forces deflect the particles and prevent them from meeting. The method of bombarding deuterium or tritium targets with a deuterium beam will not work either, as most of the energy of the beam is absorbed by the electrons of the target atoms rather than by their nuclei. The method which thus seems to be richest in promise consists in confining D or T within a restricted space.

It is of course not enough to confine the D or T atoms and keep them together; their nuclei have also to be brought up to the required energies, which are of the order of 100 KeV. When we talk of energy in this context, we mean energy of motion or kinetic energy. According to the well known molecular theory of heat, if a certain amount of gas is confined in a vessel and heated, its molecules are brought into a state of greater and greater agitation. On a more practical plane this agitation means a rise in the temperature and the pressure of the gas. Thus if we were to carry out an experiment starting with a certain mass of D in, say, a steel pressure vessel, we should have to heat the gas to a temperature of hundreds of millions of degrees centigrade before the kinetic energy of the D nuclei were sufficient to bring about fusion reactions at an appreciable rate. Then obviously the experiment would be nonsensical from the very beginning as no steel vessel, in fact no vessel of any material known to us, would stand up to these conditions. It must also be pointed out that at these high energies the atoms would have gone through a certain change; initially the D atoms would consist, quite normally, of a positively charged nucleus and a negatively charged electron, but the high energies we are thinking of in order to make fusion possible are substantially higher than the energy which binds the electron to the nucleus, with the result that the atoms would be ionised, i.e. "shorn" of their electrons. Our gas having therefore become a "mixture" of ions and electrons we should be in presence of a kind of fourth state of matter, a fully ionised plasma.

A way towards a solution: Magnetic fields

It has already been shown that the use of material containers for confining the plasma is out of the question. However there is a consolation; the separation of the nuclei from their electrons means that all the particles making up the plasma are charged either positively or negatively, and hence the way is open for the use of electro-magnetic fields. The confinement effect of a magnetic field can be considered in two ways. If attention is turned first of all to the behaviour of the individual particles, it can be noted that they whirl round the lines of force of the magnetic field along what is roughly a helical path (see Fig. 1). On the other hand if a macroscopic instead of a microscopic view of the phenomenon is taken, it is observed that the magnetic field, if it is given a suitable shape, produces a pressure which is capable of balancing the pressure of the plasma.

Fusion's "energy balance"

Different shapes have been proposed for the required magnetic fields but, before showing something of the configurations which are at the moment the subjects of experiments, it is worth commenting on what might be called the "energy balance" of nuclear fusion devices in general. This "energy balance-sheet", like any balance-sheet, covers a certain space of time and shows on one side the amount of energy derived from fusion reactions and on the other side the amount of energy which it has been necessary to put into the system to make these reactions occur.

This confrontation of output with input is not of course restricted to thermonuclear fusion. It can be made in the case of familiar processes such as ordinary combustion. The combustion of a piece of coal, for instance, is in actual fact a kind of fusion process, with the difference that molecules are involved and not nuclei. It is known to all who have made attempts to light a fire, especially if their attempts have been unsuccessful, that it is not enough simply to bring the coal into contact with air, but that it is necessary to ignite it. This involves supplying a certain amount of heat for the sole purpose of bringing the coal and air up to the "ignition temperature", i.e. to the temperature where self-supporting combustion can take place. Before the ignition temperature is reached, the energy balance is very unfavourable: of the heat absorbed by the fuel and air, some is lost to the surroundings, some is used to evaporate the water in the coal etc., and what is retained, although it contributes to raising the temperature, hardly pays any dividends in the form of actual combustion. When the coal *actually starts burning* the books are exactly balanced; enough heat is being produced by the combustion reaction to make up for the losses incurred, and the reaction is therefore self-supporting.

This is not quite the complete story, as we have been talking only of the *internal* energy balance of the combustion process; if we really make a complete inventory of input and output, we have to take into account such items as the amount of fire-lighter which has been wasted, the amount of energy used in fanning the fire etc. In

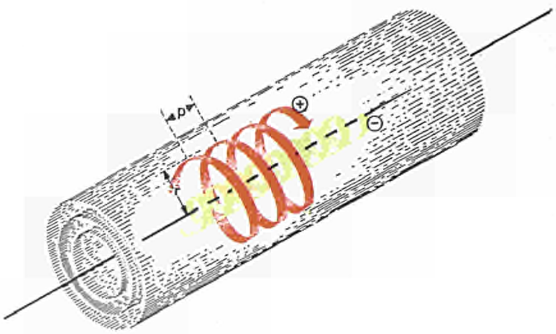


Fig. 1 Behaviour of electrons and ions in a uniform magnetic field

Both electrons and ions follow a helical path around the lines of force of the magnetic field. However, the fact that their charges are of opposite sign means that they rotate in opposite directions. At a given energy level the radius of the ions' path is much larger than that of the electrons. A particle continues to rotate around the same group of lines of force, until such time as it collides with another particle (see Fig. 2).

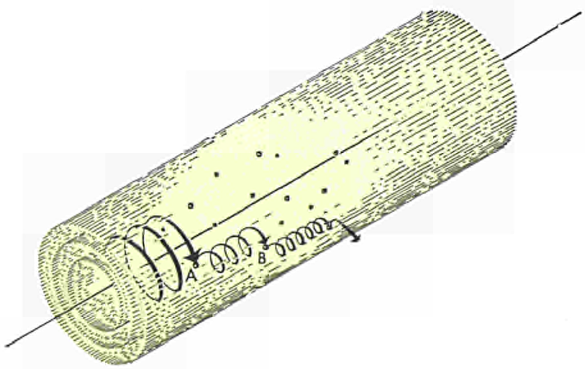


Fig. 2 Escape of particles

When a particle collides with another, say at A, it is deflected and switches over to a different helical path, having a different radius and pitch.
If the particle suffers another collision, for instance at B, a similar process occurs until, after several such collisions, it gradually leaks out towards the boundaries of the system and leaves it altogether.

actual practice, once the fire has been burning for some time, these amounts become quite negligible and hardly deserve to be shown in the *overall* energy balance. This can unfortunately not be said in the case of nuclear fusion. Research workers admittedly have succeeded in creating the conditions necessary to bring about controlled fusion reactions, but they have had to unleash such disproportionately large amounts of energy to obtain them that the process is quite uneconomic. To return to our analogy, they are rather like the novice pipe-smoker who uses up a whole box of matches to get one puff out of his pipe.

Why does this happen? A closer look at the way the energy balance is made up will help to show why: it is important in this connection to bear in mind the distinction between the plasma's *internal* balance and the *overall* energy balance.

As far as the plasma's own internal balance is concerned, the only entry which can be made on the credit side is that part of the fusion energy which is kept by the charged particles (protons, tritium nuclei and helium nuclei); the greater part of the energy produced is in fact to be found in the neutrons which, as they have no charge, are unaffected by the magnetic field and therefore immediately escape from the volume of confinement.

There are several entries on the debit side corresponding to the energy losses incurred by the plasma. At best they will include only the following:

—losses through "Bremsstrahlung", a radiation effect caused mainly by collisions between ions and electrons;

—losses through cyclotronic radiation which stem from the helical motion of electrons in the magnetic field, but whose exact magnitude is still unknown;

—losses through the escape of particles out of the plasma. We are talking here of charged particles such as ions

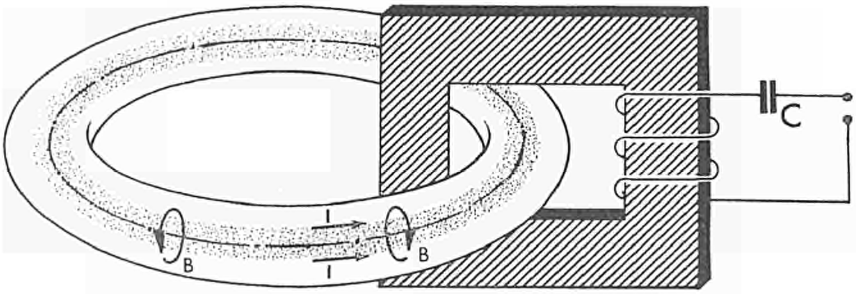


Fig. 3 Toroidal pinch

This is a schematic example of the famous toroidal "pinch" devices. Cold low-pressure gas is initially contained in the toroidal vessel. When the condenser C is discharged, as in a conventional electrical transformer, an electrical current I is induced in the gas along the torus; this current creates a magnetic field B which "pinches" the gas. The gas, having been heated both by the electric current and the pinch effect becomes a plasma which should ideally be contained by the magnetic field.

and electrons which filter out of the magnetic field either along the lines of force of the magnetic field or across them, for instance by collision, as illustrated in Fig. 2. These particles possess kinetic energy and it is the escape of this energy which constitutes the loss to the system.
The higher the temperature of the plasma becomes, the higher are the odds in favour of the occurrence of fusion reactions. At the same time there is an increase in the Bremsstrahlung-loss suffered by the system. At relatively low temperatures, the inventory of losses is much greater than the inventory of the fusion energy produced and consequently the internal energy balance of the plasma shows a deficit. As the temperature rises there comes a point however where the balance begins to show a slight profit; this corresponds to the *ignition temperature* of the plasma and marks the stage from which a self-sustaining system can be envisaged. For a mixture of D and T, this temperature is of the order of 45 million °C. and, for pure D, 400 million °C.
The *internal* energy balance has its importance for the determination of the ignition temperature, and is therefore of great interest to the physicist. On the other hand the *overall* energy balance is almost a business matter; it takes into account all the overheads, which include mainly the energy necessary to bring the gas to thermonuclear conditions and the energy necessary to create and maintain the magnetic field. The credit side, as before, shows the energy derived from fusion reactions, but can also show any energy produced by putting to good use the neutrons escaping from the plasma. Normally it is the energy involved in building up and maintaining the tremendous magnetic fields required which is the largest entry on the debit side. As part of this energy is a kind of fixed investment, independent of the confinement time (whereas the energy produced is directly proportional to it), a positive energy balance will depend on how long the plasma is kept confined.
To this day, although there are no fundamental obstacles of a theoretical nature to prevent the attainment of a positive energy balance, attempts even to come within striking distance have failed. In the case of the solutions which seemed richest in promise, such as toroidal pinch magnetic configurations (see Fig. 3), instabilities of different kinds destroyed the plasma in extraordinarily shorter times than the theoretical data at our disposal at the time might have led us to expect.

These first failures have not slowed down the research effort in this field, but have led to a certain change in approach. Although it was assumed, until quite recently, that it would be possible to arrive at a satisfactory fusion reactor by more or less empirical methods, the immediate object of research is at present to make a thorough study of plasma, this "fourth state of matter", in order to be quite sure of the possibilities it offers for the realization of a fusion reactor. From an experimental point of view, this change of outlook is not as radical as it sounds since the primary objective in the case of reactor design, as in the case of pure research, is to obtain a plasma of good quality and of appreciable duration.

Euratom's contribution

The United States of America, Great Britain and the U.S.S.R. have an advantage over the countries of the European Community mainly because they made an earlier start in controlled thermonuclear research and because they have devoted larger resources to it. However, as just hinted, they have from time to time found themselves suddenly in a blind alley and have consequently not translated this earlier start into as great an advantage as might have been expected. This means that a determined effort and a suitable deployment of resources within the Community could bring it abreast with these three countries.

Thus the United States Atomic Energy Commission alone devoted $32 million to plasma research in 1960 and employed more than 550 research scientists in this particular field. As for the European Community a sum of $ 12 million has been earmarked by Euratom within the budget of its first five-year plan (1958-1962), to which must be added a more or less equivalent amount corresponding to the expenditure of the member States' own organizations. Euratom's policy has consisted in concluding contracts of association with laboratories inside the European Community which had already started working on nuclear fusion.

The first three-year contract was concluded in July 1959 with the French Commissariat à l'Énergie Atomique (C.E.A.); a second contract, connected with the first, was concluded in 1960 with the Italian Comitato Nazionale Energia Nucleare (C.N.E.N.); a third was signed in 1961 with the new Garching laboratory founded on the initiative of the Max Planck Institute in Munich, under the auspices of the Max Planck Gesellschaft. The terms of these special contracts stipulate that both parties, Euratom and its associate, share in the management of the research work, and in the supply of both the personnel and the material resources required. The impression could be gathered that Euratom's approach to the problem is split along three completely separate lines, but this is not in fact the case. Provision has been made for constant exchanges of information between the various partner-institutions, in order to ensure that they benefit mutually from each other's achievements.

Fontenay-aux-Roses

The programme of Euratom's association with the C.E.A., which is carried out almost entirely in the Fontenay-aux-Roses laboratory, is centred on research into "magnetic

Fig. 4 Magnetic Mirrors

The figure shows a kind of double-necked "magnetic bottle". At both extremities, where the lines of force of the magnetic field come close together, the pitch of the particles' trajectories tightens. In the case of trajectory A, the pitch eventually vanishes and is then reversed. Thus the particle is in a manner of speaking "reflected" (hence the name magnetic mirrors). As this process will be repeated at the opposite "neck", the particle will move back and forth and remain confined for a long time if it is not disturbed by a collision. In the case of trajectory B the pitch is much larger initially and, although it is reduced to a certain extent near the "neck", it does not vanish. Hence the particle continues in the same direction and leaves the bottle.

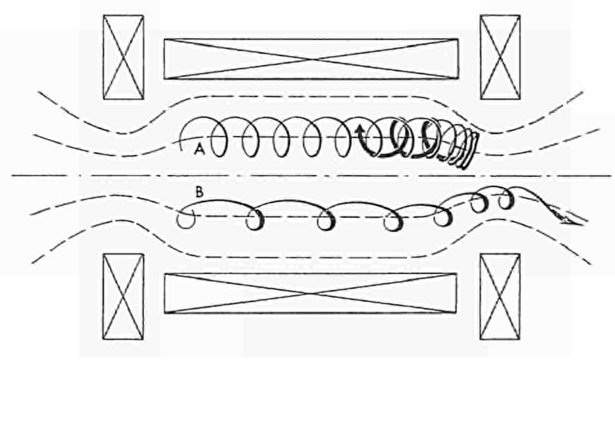
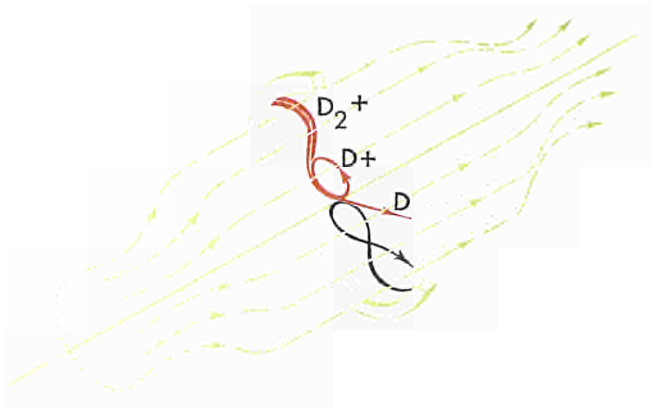


Fig. 5 High energy injection

A molecular deuterium ion (D_2+, i.e. two atoms of D, one of which is without an electron) is injected into a magnetic field which, at least near the axis, is of the magnetic mirror (double-necked "bottle") shape. After colliding with particles of an electric arc created independently along the axis, or with the residual gas (as far as possible this process occurs of course in a vacuum), the molecular ion can be split into one neutral D atom and one D+ ion. As the latter has a velocity equal to that of the molecular ion, but has only half its mass, the diameter of its trajectory in the magnetic field is smaller than the radius of the magnetic mirror "bottle", and thus the ion is trapped. The neutral atom is not affected by the magnetic field and leaves the system immediately. If the molecular ion is not dissociated it shall leave the system (bottom trajectory).



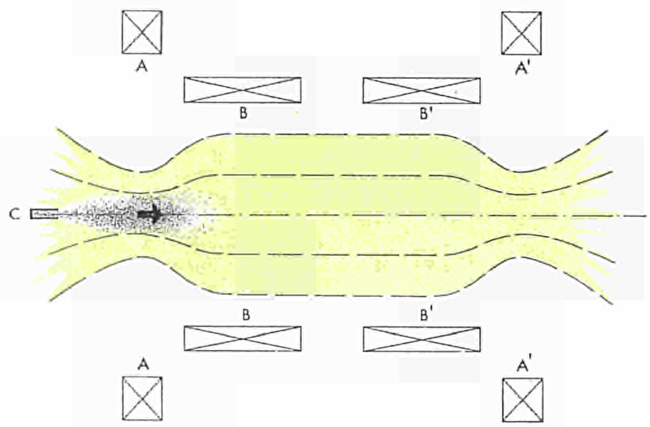


Fig. 6 DECA (Dispositif Experimental Compression Adiabatique)

A plasma "gun" (positioned at C) projects a puff of plasma into a weak "mirror"-shaped magnetic field produced by coils A and A[1]. Part of this plasma is trapped in the central region and then the main coils B and B[1] are energized, thus producing a strong magnetic field, still of the "mirror" type, which compresses the trapped plasma adiabatically. The final result should be a hot dense plasma confined by the magnetic field.

mirror" devices. Fig. 4 gives some idea of what is involved; the lines of force of the magnetic field come close together at two extremities of the machine, with the result that the pitch of the helical paths of the ions and electrons is reduced more and more as they approach these extremities; ultimately, if the initial pitch is not too large, its direction is reversed and the particles are reflected back. Hence the name "magnetic mirrors". On the other hand particles whose motion is principally axial cannot be reflected and so it is only possible to obtain partial confinement in the longitudinal direction. The loss of particles is actually continuous: ions collide against the neutral gas remaining inside the system or collide against each other and against the faster moving electrons; once deflected because of these collisions, the particles make a swift exit though either of the two extremities of the system.

Two devices are under development at the moment in Fontenay-aux-Roses.

A sketch of the first device, which in many respects resembles the DCX I and II devices in Oak Ridge (U.S.A.), is shown in fig. 5. High energy molecular ions are injected from a continuous annular source into a magnetic field so designed that the particles pass near the central axis. If no precautions were taken, these ions would tend to escape out of the magnetic field and continue along their path, back towards the outside source. Various methods, which will not be described here, are used to keep them within the system, but one of the objects of research will naturally be to develop them to a maximum

of efficiency. Heating the plasma is no problem in the case of this device since the particles can be injected with a sufficient velocity for the plasma they form to have a temperature of a thermonuclear level. The success of the device depends on obtaining a high density plasma, and this in turn depends on the intensity of the ionic stream which can be supplied from the source and on the efficiency with which the particles can be retained in the plasma.
A second way of feeding a magnetic mirror geometry consists in using "plasma guns" which produce high velocity plasma jets. Different devices, some of a novel character, are being tested in Fontenay-aux-Roses. The jet enters the magnetic mirror system from one or both extremities, and some of the particles, after colliding with each other, are retained in the magnetic field. The result is a low density and low temperature plasma. Immediately afterwards, a rapid rise in the intensity of the magnetic field and consequently of the pressure exerted in the plasma, leads to an increase in density and temperature. One of the more important devices of this type, christened DECA (Dispositif Experimental Compression Adiabatique), has been completed and is being tested at the moment in Fontenay-aux-Roses (Fig. 6).

Frascati

In Frascati, where the work of the Euratom/CNEN association is being carried out, experiments are based on a different method (so-called θ-*pinch*). The magnetic field is similar in shape to that shown in fig. 4 but the device, instead of receiving high energy particles from an outside source, contains, inside a glass tube, low-pressure preionized gas; the magnetic field is stabilized in a very short time and compresses the plasma, thereby generating shock waves which heat it and ionize it further. This principle has already been used in the "Scylla" experiments in Los Alamos (hence the Frascati experiment's name "Cariddi") and has made it possible to obtain short-lived plasmas but at high density and temperature conditions. In "Cariddi" the coil is split into six sectors and it is this feature which is responsible for the quicker build up of the magnetic field and the greater intensity and uniformity of the electric field (Fig. 7).
Finally, still in Frascati, a special group is investigating the possibility of realizing plasmas of an even higher density than in the case of "Cariddi". This increase in density is achieved at the expense of the duration of the plasma, which is even shorter-lived. The attainment of a positive energy balance depends directly both on the plasma's density and on its duration; it is therefore quite justifiable to admit the decrease of one factor as long as the other is increased correspondingly.
Fig. 8 shows the kind of arrangement envisaged: a layer of plasma, created initially near the walls of an evacuated cylindrical vessel, is driven by a magnetic field against the axis to form a thin pencil of plasma. The experiment has been given the name of MIRAPI (MInimum RAdius PInch). Concurrently another experiment is under way whose object is to produce a machine capable of producing the enormous magnetic fields (of the order of 10 million gauss) which will be needed for confining a plasma of such high density. This part of the research task has also been christened: it is called MAFIN (MAgnetic Field INtensification).
It is not our intention to describe here all the other experiments, perhaps smaller in size, but no less important, which are being carried out within the framework of the two contracts. Their object is the measurement of fundamental quantities, and the detailed study of certain fundamental phenomena, such as the interaction between a beam of particles and a plasma etc. A considerable part of the work is also devoted to the development of different observation techniques, electrical, magnetic, photographic etc., whose frequent and skilful use is essential to a full understanding of the phenomena involved. As instances we can quote the use of cine-cameras capable of making several pictures within a millionth of a second, and the development of micro-wave generators operating on wave-lengths as small as 2 mm.

Garching

As for the Munich-Garching laboratory, its work will include the study of θ-*pinch* devices, several of which are already in operation or under construction. Particular attention will be paid to mysterious shock-waves which it might be possible to put to good use, for instance for heating the plasma. As for the rest of the programme, its object is not so much the study of particular devices as systematic research into the physical properties of a plasma. Thus investigations are being made into the diffusion of plasma across the lines of force of a magnetic field, into the waves which can propagate through a plasma etc. Finally special mention must be made of the German research group's theoretical work, centred on an understanding of the various macroscopic and microscopic phenomena involved. In this field the physicists of the Garching-Munich laboratory have already made contributions of considerable importance.

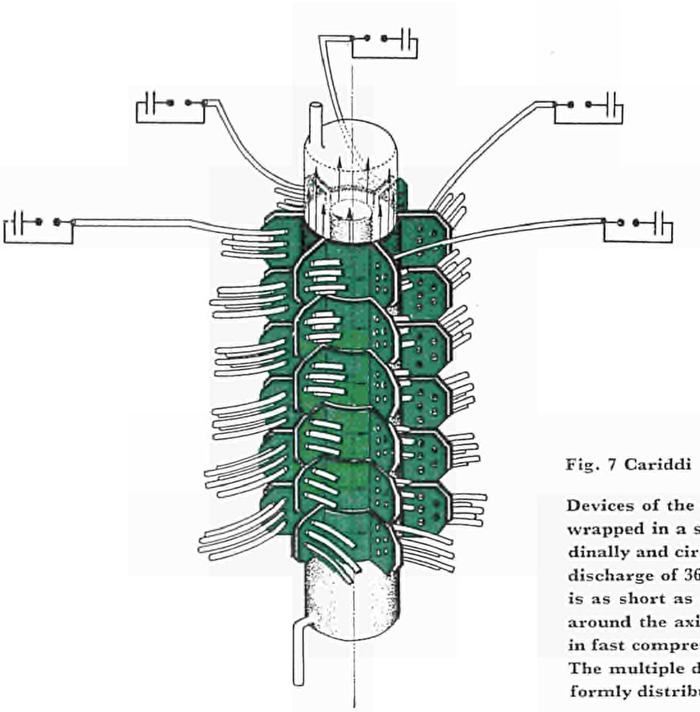
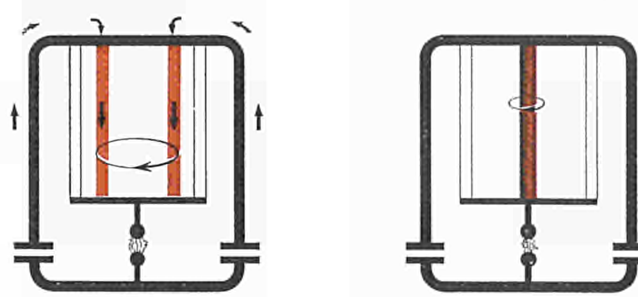


Fig. 7 Cariddi (Charybdis)

Devices of the same family, such as "Scylla", consist of a tube, containing low-pressure gas, wrapped in a single-turn coil. In the case of "Cariddi", the coil is actually split both longitudinally and circumferentially into six parts, and thus consists of 36 sectors. The simultaneous discharge of 36 condensor banks produces a short period oscillating magnetic field (rise time is as short as one microsecond). This induces an electric field and an electric current, both around the axis of the system. The interaction of the magnetic field and the current results in fast compression, ionization and heating of the gas inside.
The multiple division of the coil means that the electric field is both stronger and more uniformly distributed and that the rise time is shorter.

Fig. 8 MIRAPI (MInimum RAdius PInch)

In an evacuated cylindrical vessel a thin layer of plasma is created near the walls. Through this layer a condensor bank is discharged. The magnetic field thus produced squeezes the layer towards the axis. Even in ordinary "pinch" devices the discharge begins in the outer layers, which, as they contract, ionize, compress and heat the gas which is inside. On the contrary in the case of "Mirapi" the collapse of the initial layer meets no obstacles because it occurs in a vacuum. It is thus hoped to succeed in obtaining a "pencil" of plasma thinner and denser than in the case of ordinary pinch.



It is very probable that in the years to come the Community's overall programme will expand until it reaches proportions comparable if not equal to that of the United States. I should like, in conclusion, to make two remarks.
As far as the scientific programme is concerned, it is our opinion that the basic knowledge which we have at our disposal is not sufficient to warrant the construction of large machines, an exercise which among other things would involve us in the risk of becoming the prisoners of projects absorbing a volume of human and material resources quite out of proportion with their usefulness. If on the other hand the deployment of large resources is demanded by particular lines of research it is desirable that expansion should take place in easy stages, in such a way that each step gives time not only for reflection on the advisability of widening the project further, but also for the gathering of scientific and technical data, for which there is a pressing need at the moment.
My second remark concerns distribution of tasks; in the United States most of the tasks in the field of controlled thermonuclear research are distributed under the authority of the Atomic Energy Commission. In the European Community it is desirable, if an efficient use is to be made of money and brains, to make it possible for the different laboratories to distribute the tasks among themselves and fulfil together the aims which they share. One of Euratom's ambitions is precisely to facilitate effective collaboration by all the means at its disposal.

Jules Guéron

The Administration of Research

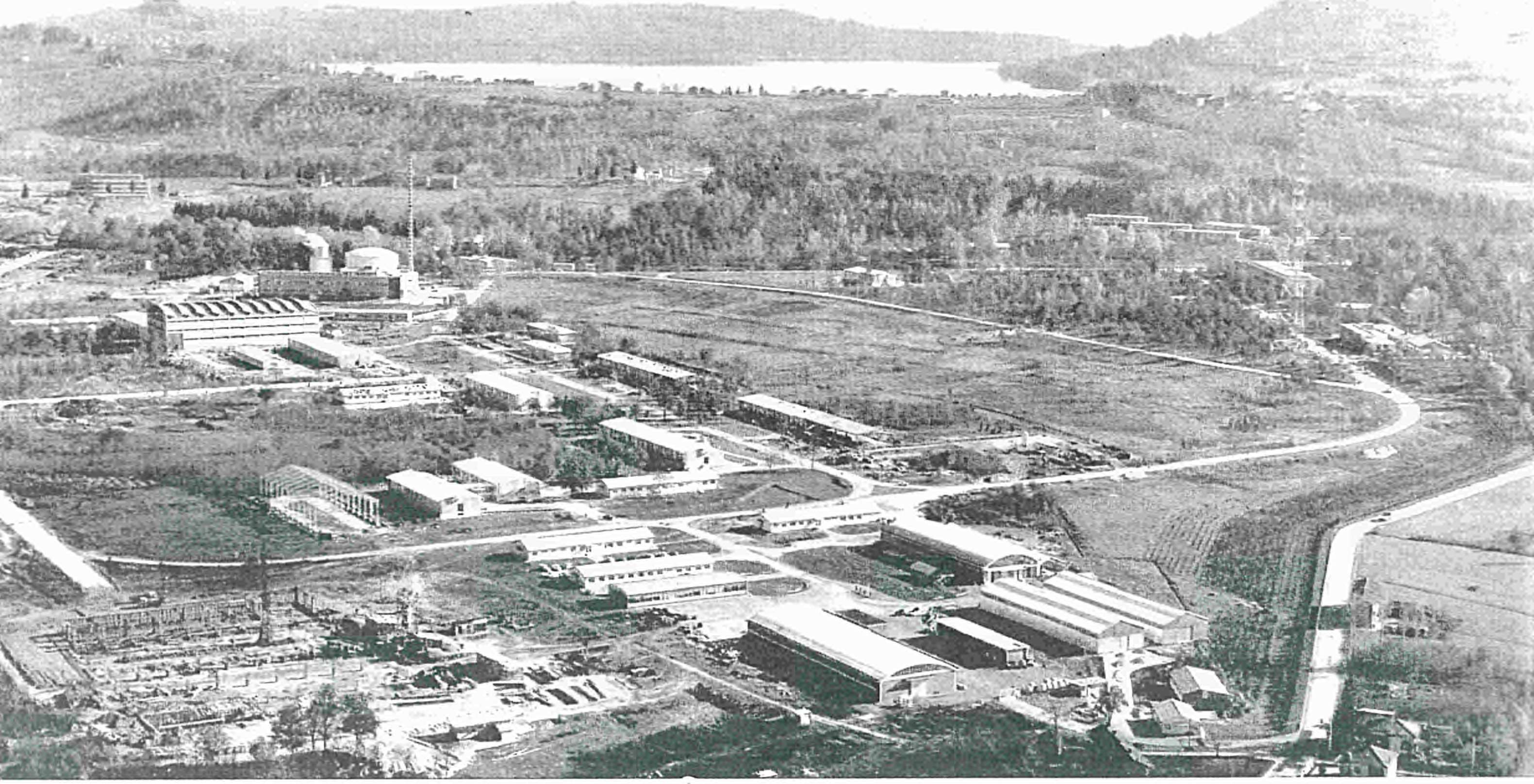
Research is one thing; organizing research is another.
If these two arts have nevertheless something in common, then it is perhaps because they make the same demands on their exponents' ingenuity and imperturbability.
On the occasion of the international O.E.C.E. symposium on the Administration of Research, held in Ménars (France) from 25 to 29 April 1960 Dr. Jules Guéron, Director General of Research and Training at Euratom, presented the following note, the scheme of which conforms with the headings of the circular introducing the symposium.

Introduction

The large research establishments of our day, private or public, are a product of the last war and in particular of the needs it created in the fields of communications and atomic energy. The technical rhythm of our age has stabilized their characteristics. Some important laboratories, mostly industrial, were certainly in existence before the war but there were relatively few of them and, although they were recognized as efficient instruments of systematic investigation, their standing as centres of thoroughgoing research was disputed.
It was by no means unusual, in the past, for eminent men to state that a group of research-workers of more than 15 to 20, with a small staff of assistants, is no longer manageable or efficient. Nowadays we reckon in terms of thousands, not in dozens, of employees. In fact the need for a technical and administrative framework (workshops, stores etc.) entails a minimum size for the establishment if it is not to be weighed down by absurd overheads and if its productive staff is not to be smothered by the mass of ancillary departments.

Growth is essentially an amoeboid process which is particularly noticeable in nuclear centres, where practically all disciplines and many specialized skills must be strongly represented. A "convergent" organization and the co-ordination under "projects" of operations requiring the services of many different specialists are the logical result of this natural state of affairs. This does not necessarily mean that they are naturally accepted and put into effect. On the contrary this is often not the case, and there follows a confusion of functions, a feeling of uneasiness and a long series of reorganizations which have a serious effect on the morale and efficiency of the establishment.

Since the classical "Social Function of Science" by Bernal in 1938, and especially since 1945, much has been written on the questions contained in the Ménars symposium programme. The "Bulletin of the Atomic Scientists"



1. Bull. At. Sc. June-July 1949, p. 186

2. cf. Tarkowski and Turnbull, Public Administration—Fall Number 1959; N. Hilberry "Elements of Basic Management Philosophy" Argonne National Laboratory 1953 etc.

3. cf. the recent (and remarkable) book by A. Dujarric de la Rivière and M. Chabrier "La vie et l'oeuvre de Lavoisier".

4. It is clear that physical environment has some influence on the critical size: this must not be forgotten when decentralisation is envisaged.

collection should be mentioned in its entirety. In particular the pathology of research centres has been discussed with both wit and penetration by Kowarski[1]. Many British and American books and articles should also be mentioned. Ingenious *Kriegsspiel* themes have even been proposed on the subject with which we are dealing[2].
It is no less instructive to delve deeper into the past; not to mention Pasteur, we can find in Lavoisier's writings an echo to our preoccupations[3].
There is therefore no purpose in saying more about the diagnosis which, at least in general terms, is clear. Without claiming to write a treatise, or even the outline of one, I shall try, bearing in mind some results gained from experience, to marshal a few thoughts and to propose methods (and not rules) of action.

I. Structure and Administration

The minimum size of a research establishment is determined on the one hand by the efficiency of its administrative departments, and on the other by the personnel required for the carrying out of the prescribed tasks *in the allotted time*[4].

The maximum size of a centre is that of its director. . .

The director must be—or at least have been—a respectable scientist[5]. He must be a respectable person[6].

In a centre which specializes in one field of enquiry, or where one field of inquiry is dominant, the director can have overall authority. In establishments combining several different disciplines, the director must

A general view of one of the four establishments of Euratom's Joint Research Centre: ISPRA

5. At the very least he must have to his credit a notable achievement as a technician or engineer.

6. To take purely classical instances, see Stendhal (Henri Brulard) or Gerhardt (Correspondence with Laurent) where comments of quite a disillusioned nature can be found on the character of certain scientists of undoubted standing...complete with examples!

exercise an influence over every department, but his authority is confined to "projects", which are horizontal operations cutting across the specialized vertical activities. This applies when the organization comprises only one research centre, in which case the director of research is also the director of the centre. When there are several establishments it is the central director who controls the projects.

The local director has in any case complete authority over the administrative departments, which must be limited, and put at the disposal of the active departments. The latter will then feel they are being helped and supported and the centre will enjoy a harmonious balance. It is far too often the case that the administrative departments direct the director. The establishment is then in a permanent state of guerilla warfare and subsists only through clandestine administrative circuits. It is ruled by a true organizational black market.

In large establishments there is an inevitable tendency on the part of functional units toward isolation. Beating down partitions as fast as they form is a task which makes a Sisyphus of the director, but it is an essential part of his work. He can only succeed in this by knowing what is going on in his establishment, a necessary condition of which is his skill in making himself into a familiar and welcome figure in all departments, including those whose activities are scientifically foreign to him.

At the same time he will be able to exercise his influence in order to maintain a certain balance between the tasks which are strictly within the programme and the flights of fancy which are essential to the intellectual health of the establishment.

II. Programmes and financial control

In our countries most large research establishments are not in a state of stability; they have not even, in general, reached their cruising speed. They are in rapid expansion and hence require a special kind of management.

At any rate they are not suited to the old-established methods of yesterday, firmly upheld by tradition. This is particularly true of state organizations which supervisory bodies endeavour to maintain or squeeze into moulds which would burst but for the iron hoops of regulations. The United States solve the problem by farming out to private companies the management of national centres. This method sometimes fills me with nostalgia, but its importation seems to be prohibited in Europe (except perhaps in Germany).

An *a priori* control by an authority devoid of executive responsibility is illusory. The only sort of effective control is that which results from a wise distribution of authority

. . . beating down partitions as fast as they form is a task which makes a Sisyphus of the director . . .

and initiative, combined with an *a posteriori* analysis—both technical and financial. The Acheson-Lilienthal report[7] contains the best discussion I know on the subject. Drawn up in 1946 by a team of politicians, scientists and industrialists, it brings out clearly the simple idea that effective surveillance means that you must have competent and intelligent overseers. Intelligent people refuse to tackle negative tasks, and only productive activity makes competent people. Therefore cooperation and joint management constitute the only reasonable control there is, as soon as the problem is no longer one of caste[8].
Detailed forecasts are founded on good analytical accounting methods. Hence they are only possible after long experience. Attempts, however premature, should nevertheless be made, if only for practice. Rough overall estimates are useful during the early life of an establishment; average values of initial investment and of annual running costs per head are surprisingly uniform.[9] In any case financial estimates can only be a point of departure and should not be binding toward external authorities, except for the total amount involved and the financial and technical honesty with which it is used. An attitude at variance with this way of thinking derives from administrative sadism, a complete lack of understanding, or both. If he cannot make his superiors realize this, a director anxious at the same time to succeed in his task and not to die before his time, should resign.

Management analysis[10] is indistinguishable from intelligent accounting.
Although the movement of funds must be recorded with absolute accuracy, a margin of uncertainty must however be allowed, which entails a slightly higher overheads percentage than in the case of industrial organizations. Nothing is worse than spurious accuracy and nothing more vital than correct orders of magnitude. It is only with the latter that management analysis of research centres should be concerned. It is sublimely ridiculous to try and force an engineer or a research scientist to use a stop-watch for the purpose of charging his activity to this or that heading of the budget as he passes, in the course of the day, from one task to another. He is capable of making a perfectly acceptable estimate on a weekly or monthly basis. When he is coerced into adopting a procedure which is idiotic he is perfectly justified in attempting to prove that such is indeed the case: this sparks off a new conflict.

Quite special problems occur also in connection with purchasing, storage, maintenance, etc. In general, economy results from a good compromise between flexibility in procedure, abundance of stocks, swift maintenance, and the preservation of a certain degree of discomfort, which fosters ingenuity. The main difficulty consists in trying to put one's finger on something which bears all the hallmarks of an economy measure but which in fact is concealing a waste of resources. Here are some examples:
The fact that there is no bus scheduled to leave half an hour after normal finishing-time entails enormous losses because the last working-hour is not utilized to the full. Who would care to assess the real expenditure caused by the closing of libraries at week-ends; or by the rule against buying more than *n* copies of the same book (whereas anyone is free to make photo-copies on the premises); or by narrowly interpreted regulations concerning purchasing procedure etc.?
This seems to me to be a subject of such obvious interest for a management analyst that I consider it a failure of my administrative career in that I have been unable to persuade anybody to take up a systematic study of the matter, which, I admit, is a difficult one.

The best link between programmes and budget is the concept of unit operations, which must possess technical individuality and which must not be too weak financially. It is preferable to devise them in such a way that their size in terms of money does not vary to any extent from one project to another. The adoption, on a broad basis, of this idea, and its implementation by means of standardized punched cards: that is the distant ideal we can set as our aim, the culmination of the idea expressed in Dautry's oft repeated adage, which would be relevant to many of the topics of this note:
"to administer well means having well-designed forms".
As for the technical definition and constant adaptation

7. "A report on the international control of atomic energy". Department of State Publication 2498, March 1946, US Government Printing Office, Washington.

8. A structure well symbolized by the notice which suddenly appeared in the laboratory of an irreverent assistant of mine whenever "personalities" were visiting the centre; the notice read: "It's smart to be incompetent".

9. In nuclear energy, assuming 4 ± 1 auxiliaries per research-scientist or qualified engineer, one can allow $ 4.000 initial investment + 30 m^2 of building, and $ 10.000 per year running costs (salary included) per head. A margin of 30% around these figures covers the difference between austerity and luxury. To this one must add large apparatus and the buildings to house them.

10. I prefer this term to the more current "management supervision": it is a better description of what is actually done by those who indulge in this exercise and does not offend those who are subjected to it.

of the programme it is of primary importance to arrive, both rapidly and circumspectly, at a collective judgment. This means "integrating" the judgments of all the individuals within the organization. This method can only work if the organization possesses a sufficient number of men of high quality (including the director), and if ideas are allowed to move about quickly, so that a strong back-wash of opinion can be made to flow from the executive grades back towards the policy-making grades. We have already mentioned, at the end of section I, an essential condition for success: the integration of the director into his establishment. This implies that the administrative departments are under the control of a man of high calibre, so that the director can focus all his energies on three things: the programme, personnel and exceptional cases (including accidents, and therefore safety and health protection).[11]

. . . meetings should be held on an informal basis . . .

III. **Day-to-day organization of work**

The propagation of instructions and, in the opposite direction, of results presents many problems, especially in large centres. A certain amount of intellectual ventilation must also be provided for, as a centre soon becomes big enough to tend to lead an isolated existence.

Instructions are issued in written form or verbally at meetings. Documents must be circulated as widely as possible. The trust which is thus quite clearly put in the staff makes it possible in exchange to insist on discretion and to punish breaches of discipline.

Although there must be plenty of meetings, their number should not become excessive (see Parkinson); they should be held on an informal and regular basis. It is essential that the results of each meeting be recorded in the form of a document, which serves as a reminder to those responsible for carrying out the decisions. Official minutes drafted merely as potential exhibits in the event of disputes are to be outlawed.

Regularly held meetings are a great asset, but cliques tend to spring up if there are too many of them.

The question of whether executive staff should be present at high level meetings and, generally speaking, whether they should play a part in the policy-making process deserves careful consideration. Although their participation is desirable in principle, as a means of short-circuiting more lengthy procedures, putting it into effect is a deli-

. . . this discomfort should be organized . . .

cate matter. Without going into detail let us mention in passing the "Comité d'entreprise" which is a well-established institution in French companies. Experiments have also been made in this direction by having staff members attend board meetings.

It is, incidentally, useful to adapt to research centres the military but nevertheless reasonable practice of switching personnel at intervals from "regimental" to "staff" duties.

To a great extent, the propagation of results follows the same channels, only in the opposite direction. Other channels are however available.

First of all, it is effected by direct contacts between the director and the departments—it is impossible to exaggerate the importance of this channel.

Then comes the routine report which, although a formality, is indispensable. Indeed, it not only gives information on progress made, but it is an efficient instrument of internal discipline for each department. The routine reports must be frequent enough to give a kind of cinematographical impression of the establishment's life. Written with simplicity, to make both the writer's and the reader's task easier, they must circulate quickly (it is actually the director's responsibility to make sure that this in fact happens; an obsolete report is of no use to the reader and is a source of annoyance to its authors). They should be monthly, if possible, and never more than two-monthly. Hence there can be no objection to the phrase "nothing to report" under a good number of headings.

The organization of work in a laboratory is still best summed up by the maxim attributed, I think, to Faraday:

"begin, finish, publish".

Frequent meditation on this formula should be recommended to all those it concerns, from the isolated research-worker to the head of a centre 6,000-strong.

I mentioned above the stimulating virtues of a certain measure of discomfort. This discomfort should be organized:

Materially: by refraining from treating research workers as spoilt children; they should not have too many gadgets, which merely become useless toys, nor too many opportunities for building them (this only delays the start of actual research in the sense of Faraday's dictum).

Intellectually: each unit in the establishment must have two tasks. The first should be of a routine character and should thus foster assiduity while affording the comfort of a productive activity; it justifies the individual's salary, or the existence of the group. The other task should be ambitious and add the spice of daring (technical or intellectual) and the apprehension of failure.

Since the programme of the symposium mentions the incidents of professional life, I should like to stress the salutary effects of the unexpected incident and especially its exploitation. During a difficult period in the life of the Montreal atomic laboratory in 1943, 15 litres of heavy water (10% of the total stock) were accidentally spilt and quickly absorbed by granulated mica (which was kept for the purpose of smothering any fires that might break out). I organized on the spot a round-the-clock effort to recover the water by distilling it from the sodden mica. This could perfectly well have waited, but for a staff anxious to get down to work, waiting impatiently for a programme, this break in the routine acted as a tonic.

IV. **The research-worker's selection and his career**

"The need was for a calculator,
A dancer was appointed",
says a French classic. Speaking from "inside" the profession, Bradley is said to have advised Queen Elizabeth the First, for the same reason, against filling the post of Astronomer Royal.

The coming into being of large institutes of research has forced the research worker out of the kind of monastic existence which was his lot before. Auto-selection, once founded on the certainty of living in modest circumstances but in freedom, supplied to research, in acceptable numbers, both efficient enthusiasts[12] and timorous eccentrics.[13] This does not satisfy modern needs any longer. The need for auxiliaries at all levels and the increasingly important part played by research in every-day life have made the unworldliness of the research-worker out of date. Furthermore the very name "research-worker" is tending to convey a different meaning, particularly because of the ever-growing importance of team-work as opposed to isolated action. These changed requirements, coupled with the sheer increase in numbers, make spontaneous selection out of the question and raise specific problems of personnel administration in research.

One of these problems frequently finds a convenient but pernicious solution and consists in the failure to distinguish between the research-scientist as such and the engineer. Indeed both are to be found in research centres and they normally work together, so that the superficial administrator tends not to be clearly aware of this distinction. This gives rise to a certain amount of friction between individuals, but it especially creates the risk of fundamental mistakes in the allotment of tasks. These mistakes could easily sterilize a research centre by seriously upsetting the above- mentioned balance between, on the one hand what might, even in the scientific field, be called production tasks, inasmuch as they lead with almost complete certainty to results, and on the other the bolder and more risky ventures. To use what is by now well-established terminology, the equilibrium between research and development would be upset to the advantage of the latter.

It is therefore necessary: to distinguish the inventive research-scientist from the efficient engineer and from the good technician; to recognize the complementary nature of their functions and to bring it home to the persons concerned; to trace out well-defined careers for them, in such a way that their essential equivalence is made clear.

It is useful to refer to the report by Hilberry, mentioned earlier, for the description of a system of personnel management in large research establishments.

 Personnel selection and administration in large research establishments would be better understood if a few establishments of this type consented, with the cooperation of their staff, to carry out a continuous study over an

11. This is a particularly sensitive point in atomic energy.

12. There will always be people like Bernard Palissy, ready to burn their furniture (G. Urbain, "Les disciplines d'une science, la chimie", foreword 1924).

13. A late acquaintance of mine, a chemist turned astronomer, stated that it was the study of secondary school staff promotion lists which drove him into the latter profession.

14. Besides, any establishment of more than 100 people should put at the disposal of its staff ***outside working hours*** **a good psychologist or psychiatrist, with all necessary guarantees as far as the management is concerned. This visible expense would certainly, I think, produce large invisible savings.**

appreciable period of time (five to ten years). This study should include systematic psychotechnical tests on candidates as well as on the existing members of the staff.[14] In conjunction with management analysis, with the assessments of departmental heads, such a study seems to me to hold out the promise of being extremely fruitful.
Would it not be possible to organize an international conference of heads of large establishments which could discuss this problem and the others I have mentioned? The conference could suggest the appointment of an executive committee responsible for preparing investigations; it could choose the men to lead them and the organizations to be used as guinea-pigs. Once intellectually accepted, such a scheme would probably not remain long without financial backing (UNESCO, OECD, Euratom, NATO, large private foundations).

The best method of showing students what research means as a profession is to make them live in a research establishment and to attach them to someone working alone or to a team. The well-established stages of a medical student's career, involving some years of practical experience in hospitals, can be transposed quite easily, here again as long as the temptation to form castes even before professional life has begun is avoided.
The acceleration of science and technology makes it necessary to establish the sabbatical year as a firm rule in the management of scientific staff. This means, every five to ten years, one year of *activity* outside the normal environment. Even without any change in specialization, there is no better way to rejuvenation nor a better method of maintaining intellectual resilience. If this practice is generalized and administered with intelligence it should not interfere with the smooth running of establishments. Research and teaching should be dissociated only in exceptional cases of confirmed inability to teach. Admittedly outside a university career, teaching should only take up a moderate amount of time, but it should never be absent for long.

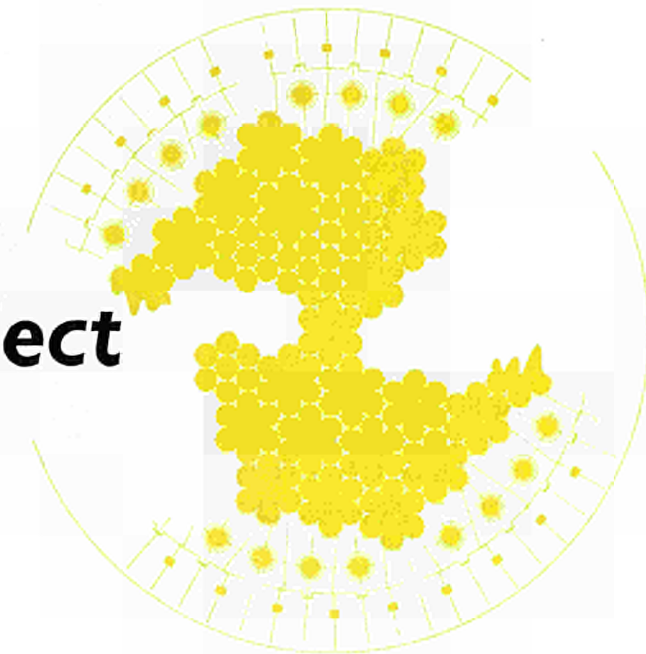
Switches between actual research, management of contracts, planning and administration should occur early in the career of those of whom it is thought that:

they are easily adaptable;
their strong point must be discovered;
they must be trained for management posts.

This will be the best way of preparing for the changes which are inevitable in any organization, and which are determined by staff turnover, whether it be because of changes of interest, family considerations or simply old age.

... the spice of daring ...

The Dragon Project



The name which this project has received is not, for once, a clever arrangement of syllables or initials: DRAGON is in fact a symbol of what the scheme aims to achieve, a nuclear reactor working at very high temperature. Dr. Franco, who is Chief Engineer of the project, outlines the main features of the reactor and discusses the special problems which will have to be solved before the final aim can be fulfilled.

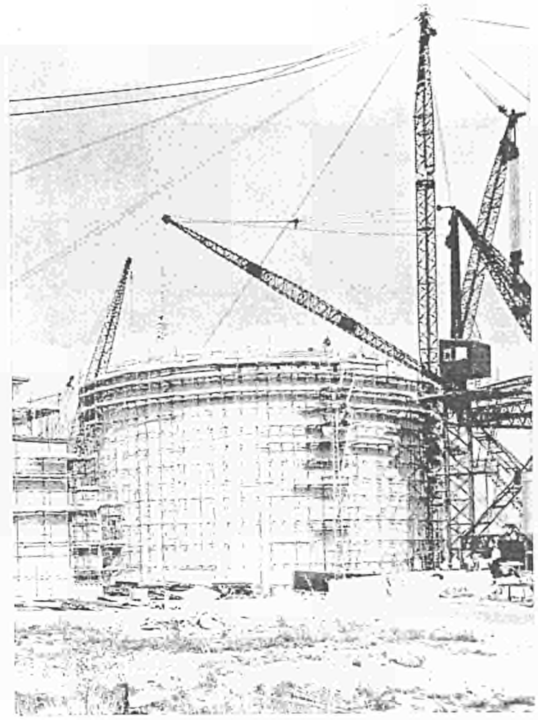
Dr. Franco is a member of an international team of more than 200 scientists and engineers, not counting their supporting staff, which has gradually been built up since 1959; it was in that year that the agreement launching the project was signed by Austria, Denmark, Norway, Sweden, Switzerland, Great Britain and the six Euratom countries. The cost of the project was initially estimated at £ 13.6 million, Euratom and Great Britain each paying 43.4% of the first £ 10 million. Great Britain has agreed to pay up to £ 3.6 million in addition, as the project's reactor experiment is being built in the United Kingdom at the U.K.A.E.A.'s Winfrith Heath establishment. Negotiations are however at the moment under way for renewal of the agreement and it is possible that they should lead to some modifications to these arrangements.

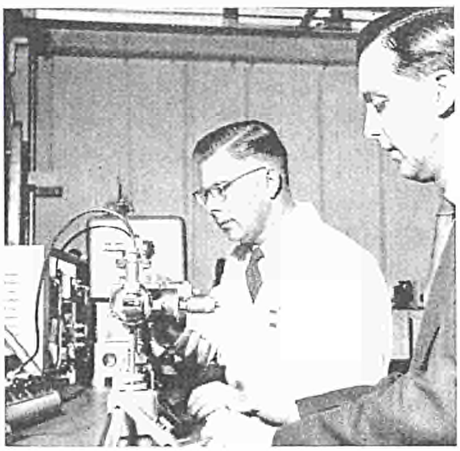
Construction of the plant is proceeding and is due to be completed early in 1963; already the reactor facility buildings have become a landmark in the middle of the bracken-covered Dorset countryside.

Dr. Gianfranco Franco, Chief Engineer of the Dragon project and author of this article

A view of the Dragon site

A British scientist and a German scientist working together in one of the Winfrith Heath laboratories.





The Aim

Modern thermal power stations of the *conventional* type have become increasingly efficient in the past ten years, mainly because of the adoption of high temperature steam conditions in boilers and turbines; temperatures of something over 550° C are now quite normal. On the other hand it is a striking fact that all the *nuclear* power plants at present in operation or nearing completion are operated at temperatures reaching a maximum of about 400° C, which means that it is not possible to produce steam at much above 350° C.

Yet there are no fundamental differences between a conventional power station and a nuclear power station as far as the boiler/turbine/alternator system is concerned. The difference lies only in the source of heat: hot gases resulting from the combustion of a fuel such as coal or oil on the one hand, and on the other a coolant, such as carbon dioxide gas, which circulates over uranium fuel-elements heated by the nuclear fissions taking place within them. However a number of factors, for instance the compatibility problems between the different materials used in the reactor, impose limitations on the outlet temperature of the coolant and hence prevent the most modern steam conditions from being adopted.

The aim of the DRAGON experiment is precisely to overcome these limitations and to produce a reactor where the coolant will be heated to a temperature of the order of 750° C. This will make it possible to use not only a modern steam cycle, but also gas turbine systems. No attempt will be made in the DRAGON reactor to transform heat into electricity; the heat will merely be rejected to the atmosphere. This is because the main scope of the reactor facility is to study the specific problems of design and construction arising from the use of high temperatures, and to examine the behaviour of materials and in particular of fuel-elements during the operation of the reactor. It is considered that the generation of electricity would not present any particular difficulties as use could be made of the most modern conventional steam or gas turbine systems.

A reactor project similar to DRAGON is under way in the United States, namely the General Atomics-Philadelphia Electric project, also known as the Peach Bottom project. This plant will generate about 100 MW of heat and 40 MW of electricity and is planned to come into operation early in 1964. Between the two projects an agreement for exchanges of information and personnel has been made in order to coordinate the common efforts and therefore save time and money.

I think it worth while to mention that all the information on research and development and on the engineering of the DRAGON Project is disseminated to the Signatories by means of reports, memoranda and symposia. In addition all main contracts for reactor components and for research are distributed in the different countries. It can thus really be said that all the Signatories participate actively both in the realization of this particular plant and in the development of high temperature reactors in general.

The Problems

What are the new problems presented by this type of reactor? They are manifold, but can be grouped under two main headings:

High temperature is the first one: materials have to be used which not only can withstand the high levels of temperature involved, but are compatible with each other.

Disposal of fission products is the second heading, the difficulties which it creates being a direct consequence of the nearly ubiquitous presence in the reactor core of graphite, an essentially porous substance.

The DRAGON reactor is indeed basically of the graphite-moderated gas-cooled type which is familiar to many, but once this has been said the recital of its similarities with the current generation of gas-cooled reactors is almost at an end. As we shall see, the coolant is not to be carbon dioxide, and the design of the fuel elements will be entirely different.

The Solutions

1. *Helium*

In order to secure an outlet temperature of 750° C for the reactor coolant, the surface temperature of the fuel elements will have to exceed 1000° C. At this level of temperature most of the gases which could be used as coolants, such as carbon dioxide, would react with graphite, and it has therefore been necessary to decide in favour of a compatible gas, namely helium. There still remains the possibility of attacks on the different materials used in the system by the chemical impurities present in the helium coolant. In order to reduce this effect to a minimum, a small part of the total gas circulating is to be continuously by-passed through each fuel-element and cleansed in a purification plant. At the same time the helium will be purified of the highly radioactive fission products in order to control the contamination of the primary circuit of the reactor.

In order to prevent the escape of any radioactive gas from the primary circuit a high standard of leak-tightness has been adopted; the maximum allowable total leakage has been fixed at 0.1% per day of the amount of gas contained in the system. This exacting requirement has led to a substantial amount of research and development work over the design of the primary circuit components as a whole, and in particular of the pressure vessels, valves, heat exchangers, helium circulators, flange joints, penetrations of cables and wires for power supply, etc. The experimental information already available actually confirms that it will be possible to remain within the limits imposed for leaks.

2. *Graphite*

It is normal in the gas-cooled reactors at the moment under intense development, in such countries as the United Kingdom and France for instance, to use fuel-elements consisting of natural uranium rods contained in metal cans, one of the purposes of these cans being to prevent fission products from escaping. In the case of DRAGON, metals are ruled out from the hottest region of the core for the simple reason that they would either melt or be very near to melting at the high temperature levels involved. The design of this type of reactor is therefore based on the idea of having a core made of ceramic or refractory materials such as graphite without using metallic canning. As the few metals which would have been eligible have high neutron absorption cross-sections in comparison with graphite, this solution has the additional advantage of making for neutron economy. The

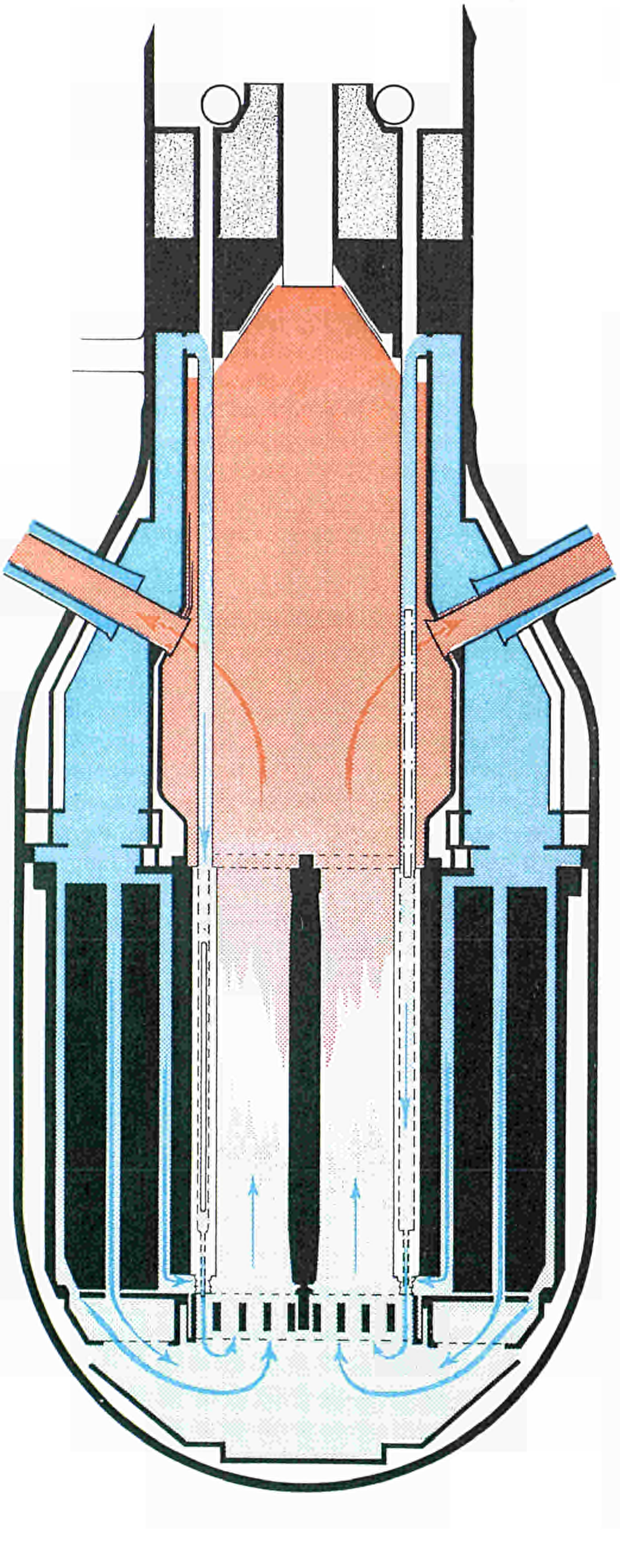


Fig. 1 Diagram of the reactor vessel showing the path of the helium coolant.

fuel-elements, whose design is being completed, will be composed essentially of graphite boxes. The active part in each box consists of fuel particles dispersed in a tubular shaped graphite insert which fits round a bar of the same material. These boxes will be stacked inside graphite tubes which will be grouped in bundles of seven to form a fuel-element (see figure 2).

Thus in this type of reactor graphite has a multitude of functions: it is slowing down neutrons to the energies required for efficient fission of the fuel, i.e. it acts as a *moderator*. It is at the same time the main *structural material* of the fuel elements, a role to which it is suited in view of its good behaviour under high temperature conditions. It also acts as *canning material* inasmuch as the outer casing of the boxes is primarily intended to act as a barrier to the escape of fission products.

3. *Keeping the fission-products in check*

Graphite suffers under the handicap of being porous, which would imply the diffusion of the emitted fission products into the main gas stream. In order to reduce this diffusion and to control more easily the contamination of the primary circuit of the reactor by these very radioactive products, a number of systems will be adopted.

The first is the coating of the fuel particles with a suitable material like, for instance, carbon, which could be pyrolitically deposited on their surface.

The second is to increase the impermeability of the graphite used for the fuel elements in order to slow down the escape of the fission products.

Thirdly, as already mentioned, a flow of clean helium will continously purge the space between the fuel tubes and the fuel boxes, carrying the fission products to a plant where they will be trapped along with normal chemical impurities.

In this way the primary circuit of the reactor will not be too radioactive and hence maintenance-work and repairs should be possible without any great difficulty. The problems related to this type of reactor and in particular to the treatment of the fission products are numerous and

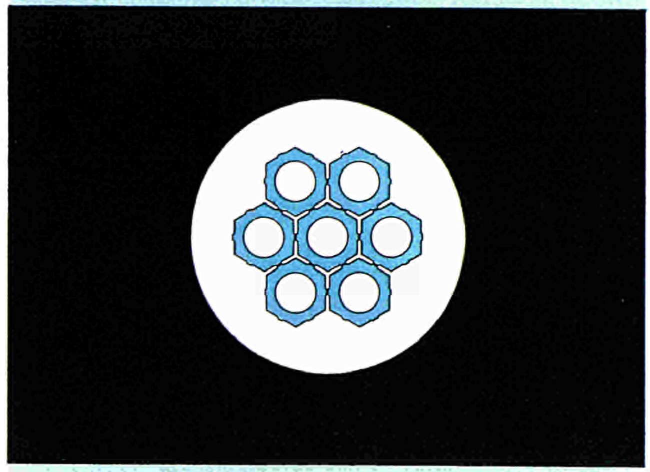
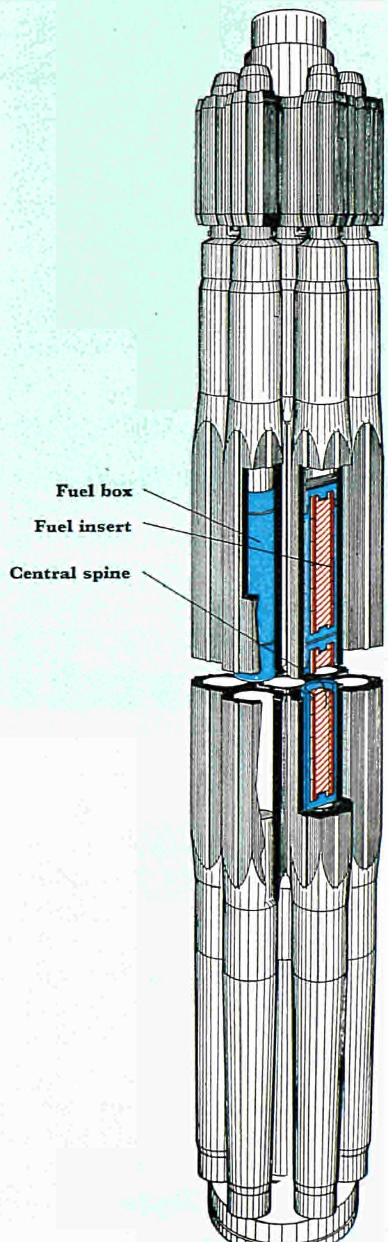


Fig. 2 *Above:* A cross-section of a fuel element, emptied of its fuel boxes. The narrow spaces between the rods are swept by the helium coolant.

Below: A view in perspective of an element, showing its division into seven rods. The fuel boxes are stacked inside each of the rods.

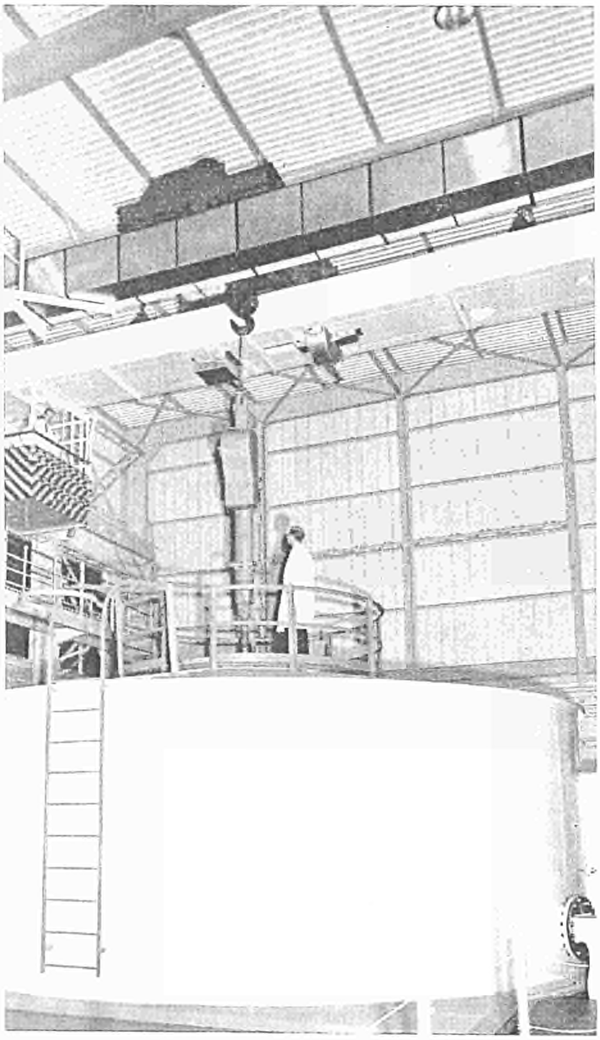


often complicated; hence a massive research and development programme has been necessary in the physicall chemical and engineering fields in order to overcome al, the difficulties, but there is every justification for these efforts in view of the advantages offered by the high temperature reactor concept.

4. *Thorium*

In the gas-cooled reactors operating or under construction at the moment in Europe, the fuel is natural uranium, i.e. a mixture of U-235 (0.7%) and U-238 (99.3%). U-235 is the essentially fissile isotope which is responsible for the maintenance of the energy-producing chain-reaction; thus when an atom of U-235 is split by a neutron, several fresh neutrons are produced (2.5 on an average), of which one is needed to fission a further atom and keep the reaction working, while the others are captured or escape out of the system. Capture normally means that the neutron is lost and serves no useful purpose, but this is not the case if it is captured by a U-238 atom, for this will lead to the production of plutonium-239, another fissile material. It is clear that if, for every atom of fissile material fissioned, one atom of U-238 were converted into Pu-239, the "conversion ratio" would be unity, and the amount of fissile material present in the core would remain constant. Under these ideal circumstances, the whole mass of U-238 present in the fuel elements would gradually become Pu-239 and therefore be eventually all used up; the "burn-up" would be complete.

Unfortunately this extremely convenient situation does not occur in the reactors I have mentioned: the conversion ratio is well below unity and, although new fissile material is constantly being produced, the overall stock is gradually whittled down until it is insufficient to sustain the chain-reaction. There is in any case another factor which militates against a high burn-up, and that is the creation of fission-products which "poison" the reaction. In the case of DRAGON, this latter disadvantage will be reduced by the continuous removal of the fission products from the core. As for the fuel itself it will consist of a



mixture of U-235 and thorium-232 carbides. Much as U-238 is converted to Pu-239, thorium-232 becomes uranium-233, yet another fissile material, but this combination offers the marked advantage that the conversion ratio is substantially higher, so that the stock of active material is depleted much more slowly.

This choice of constituents for the fuel makes it possible to look forward to a high burn-up. Of course another major condition for a high burn-up is a design which will limit damages, for instance the distortion of the fuel-elements as the various transformations entailed proceed within them: indeed a fuel-element which is distorted has to be removed before the end of its useful life. In the case of DRAGON, it is expected that this condition will be fulfilled by the fact, already mentioned, that the fuel will be dispersed within a graphite matrix. Experiments carried out to date have confirmed that radiation damage effects should not be serious.

In conclusion, it can be said that our work is proceeding satisfactorily and warrants confidence in the high temperature reactor concept, of which DRAGON is the first stage, as a well grounded attempt to create a nuclear reactor which can be married to the most modern steam generating or gas turbine systems, with a consequent reduction in the cost of electricity.

It is not in the scope of this article to examine thoroughly the numerous problems faced by the project's scientists and engineers and the results obtained, but I hope that a sufficient general view of our work has been given. I would also like to emphasize that the substantial efforts involved are not only supported by the project staff but also, to a large extent, by all the Signatories' scientific and industrial organizations, which share our difficulties as well as our hopes.

These fingers were doomed to amputation, but thanks to a new kind of treatment, they have healed almost completely.

A new step forward in the development of radionecrosis therapeutics?

Radiopathy: A Serious Problem

The development since the turn of the century of techniques involving the use of ionizing radiations for various purposes, in the laboratory, in industry and in medicine, has been accompanied by the appearance of novel forms of sickness. Several decades had in fact elapsed before it was realized that special precautions would have to be adopted in the handling of X-rays or radioactive substances if specialists were to be spared serious injuries.

The general public has learned of the existence of mysterious disorders which afflicted persons who had been subjected to irradiation. At one time there was a great deal of talk about *radiologist's disease*, with its sometimes terrifyingly vivid effects. Marie Curie herself was destined to be the classic example of the research worker who fell victim to Science. If to-day these ills have begun to be shorn of their mystery, it is nevertheless a well-established medical fact that we are left with an extremely difficult problem on our hands. What the doctors have to contend with is, in fact, *radiopathy*—a general term which has been coined to denote the varied range of ailments which may be contracted by careless or inadequately protected scientific personnel: burns, necroses, benign or malignant alterations in the blood, etc.

Somatic and Genetic Lesions

Before going any further, it must be made clear that the injury sustained by living organisms as a result of ionizing

radiations is of two fundamentally different types. These are *somatic lesions* and *genetic lesions*.
It is mainly the first type—to be more precise, a rather special case of it—with which we shall be dealing here. Before doing so, however, let us briefly explain what is meant by a *genetic lesion*.
Biologists to-day admit that ionizing radiations are capable of attacking, at one point or another, one of the forty-six chromosomes contained by each of our cell nuclei. When a chromosome is thus affected within the nucleus of a reproductive cell a local change takes place in the structure of the substance of which it is composed—basically, *deoxyribonucleic acid* (DNA). Now the structure of this DNA is, as it were, the *code* used by nature to *record* the *information* showing the way in which the descendants of the subject will develop: in short, the *heredity* of his line. If this structure is altered, the result is a *mutation*, i.e. a sharp change in the morphological features of his issue.
Unfortunately, experience shows that the vast majority of such mutations are unfavourable: a mutant is, statistically speaking, handicapped—tainted—in relation to normal persons.

Crime against Future Generations

Numerous laboratory experiments and observations carried out on the children of irradiated human beings—in particular at Hiroshima and Nagasaki—have shown that various malformations, of varying degrees of seriousness, liable even to cause death and mental debilities were to be feared in cases in which the parents had been exposed to intense irradiation.
There are too many gaps in the factual material available at the present time for us to be able to determine quantitatively the laws which govern these phenomena—(ionizing radiations are far from being the only known mutagenic agents)—but most biologists and geneticists agree as to the major importance of the process. Jean Rostand has gone so far as to employ the expression "crime against future generations". He maintains that man has to-day achieved the dismal feat of making it possible to injure generations yet unborn.

Structural Destruction and Functional Modifications

But, as said above, we are mainly concerned here with *somatic lesions*, i.e. alterations which may occur in various locations but the effects of which are felt by the actual organism irradiated. These effects may range from a specific cell to the entire organism. The somatic consequences of irradiation may be divided into two main classes, namely *structural destruction*, i.e. alteration of the very matter of the part affected, and *functional modification*, i.e. change, generally harmful, in the "physiological behaviour" of the organ in question. Thus it has been possible to bring to light the effect of irradiation on the growth and reproduction of the cellular lineages, the embryonic development, the functioning of glandular or nervous centres of certain organs, or even of the organism itself.
Let it be added that, although such effects are invariably deleterious, they can nevertheless in some cases be repaired or offset, living matter being sometimes capable of a certain "radioadaptation".
The location on which the ionizing radiations impinge and the seriousness of the lesion induced depend on a variety of factors: the *intensity*, *energy* (technologists say "hardness") of radiation, *duration* of irradiation, internal or external *situation* and *physical state* of the emitting source. Not all tissues, indeed, are equally *radiosensitive:* if the genital organs seem to suffer particularly, the liver, on the other hand, appears to be remarkably "radioresistant". The liver tissue, in fact, shows a marked capacity for recovery.

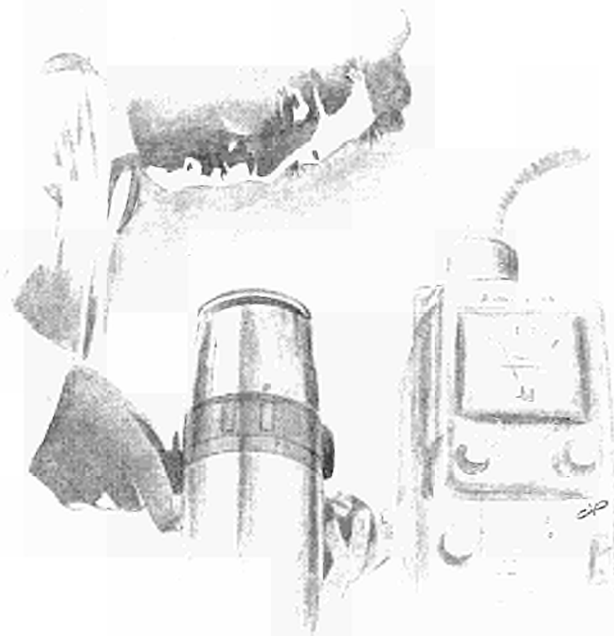
Total Irradiation—Cause of Various Cancers

When it is not any particular organ but the entire organism which has been irradiated, the term *total irradiation* is used. In such cases, specialists look for three symptoms, i.e.:

1° *disturbances in the blood:* the haematopoiesis (production of blood corpuscles in the marrow of certain bones) has been altered and a red corpuscle count will show the extent of the damage.

2° *intestinal disturbances:* the intestine is affected by an infection due to the more or less complete destruction of the *phagocytes* (white corpuscles capable of destroying agents of infection).

3° decrease in the production of *specific antibodies*.
The consequences of such total irradiations may be serious, giving rise to various cancers. Total irradiations with X-rays or gamma rays, or again with neutrons, have induced cancers of the skin, kidney, liver, intestine, thyroid, superrenals, etc.



Strontium 90: Danger of Leukaemia

It should be made clear that irradiation of the marrow of flat bones, particularly the *sternum*, in which haematopoiesis occurs, may be the cause of certain forms of *leukaemia*. This is the severe charge levelled against strontium 90, a radioactive isotope of ordinary strontium, a by-product of certain types of nuclear fission and an element which appears in atmospheric fall-out resulting from atomic explosions.

Strontium 90, which is "mistaken" for calcium in the process of metabolism (the two elements have virtually identical chemical properties), therefore takes the place of calcium in the bones. The life of strontium 90 is long in comparison with that of a human being: the half-life is around 30 years, which is quite sufficient to render the accumulation of this radioactive isotope in the bone tissues terribly dangerous for the nascent blood corpuscles, the lesion of which may induce leukaemia.

Hope for Radionecroses

Thanks to recent studies carried out by the Belgian physicians A. Massart (Euratom) and J. Henry (Institut Jules Bordet) a certain degree of optimism may now be permitted in the specific case of a cutaneous lesion caused by accidental exposure to X-rays.

Here are the facts:

The patient, a man of 33, a spectrometry technician, in a good state of general health, and without any remarkable hereditary or personal case-history, was subjected to accidental irradiation of the index finger and second finger of the right hand while handling an X-ray diffraction apparatus.

Four days after the accident the skin of the irradiated area showed congestion and inflammation which disappeared temporarily under finger pressure. This is known to dermatologists as *erythema*. (Erythema is generally caused by vaso-motor disorders in the skin, i.e., circulation disturbances in the blood-vessels of the affected area).

On the ninth day, the two affected fingers became swollen and painful, a symptom accompanied by loss of tactile sensitivity; the 11th day was marked by the appearance of what the specialists call *phlyctaenae* and to which we shall give the more common name of blisters.

These systems are classical. Furthermore, they require the conventional treatment applied for cases of acute radiodermitis: the application of a *cortisone*-based ointment for a period of three weeks.

Two months after the accident, the nail of the index finger scales off and a new nail is formed; the finger remains scarred and does not recover its original flexibility, but remains slightly swollen and readily becomes numb. Four months later, the burn gradually reappears, no improvement being effected by the conventional treatment. After two weeks the index finger is swollen, purplish, painful and an ulceration forms near the nail extending right to the bone. A callus painful to the touch was observed on the second joint of the second finger.

Similar to Acute Frostbite

It was at this stage that Dr. Massart was visited by the patient, who was apprehensive as to the future development of his affliction and its threatened remedy: amputation. The doctor, resolved to make a final effort to save the fingers, resorted to the application, by means of intramuscular injections, of a pancreas-extract hormone used in cases of acute frostbite, since it dilates the blood-vessels and thus promotes and speeds up the blood circulation in the affected areas. The lesions observed did, in fact, show a strong resemblance to frostbite and thus suggested the use of this vessel dilating agent.

During the first three weeks of treatment, the patient was in such violent pain after the injections that sedatives had to be administered. No improvement, however, was perceptible. But in the course of the fourth week the swelling was dramatically reduced and the ulcerated tissue healed.

The tissues were completely restored six weeks after the beginning of the treatment, no change being observed several months afterwards.[1]

Useful Theoretical Details

The case is interesting not only from a clinical standpoint; it yields some useful data on the theoretical plane. As the characteristics of the apparatus which had produced the irradiation were known and the subject had been able to state more or less exactly the duration and circumstances of the exposure, it had been possible to calculate to a more satisfactory degree of accuracy than in other cases the radiation dose received by the injured tissue[2]. This is a particularly important item of information, since it helps us to establish a quantitatively more exact cause-and-effect relationship between the irradiation and the lesions induced. There is, of course, still very little known on this subject at the present time.

Furthermore, the above case-history constitutes a by no means negligible argument in favour of the hypothesis which attributes radionecroses to vascular lesions which develop more or less slowly. Such lesions are believed to be caused by dry gangrene brought about by the obliteration of certain vessels. In the above case the authors used a vasodilator to treat this affection, several of the symptoms of which seemed to be connected with vasomotor disorders. Those engaged on research in this field hope, moreover, that early vasodilator treatment can serve to prevent the occurence of radionecroses in cases of exposure to irradiation.

International Cooperation

This effort marks, of course, only an initial step in the vast field of therapy for "atomic diseases"[3]. As was shown at the beginning of this text, the range of sicknesses which ionizing radiations may induce is wide—too wide. But the facts which we have set out are extremely encouraging. Finally, there is another aspect—a minor one, according to some people—, but one which we consider as being of capital importance. This research—and these results—are the fruits of cooperation at international level.

For the pharmacological study of the substance employed, Belgian doctors have called upon a French biochemist and the German firm manufacturing the drug. There can be no doubt in the mind of anybody having any experience of the practical side of scientific work today that it is only by team-work transcending national boundaries that we shall be able to solve the thousand and one problems which confront research workers today and which they will have to face up to in the future.

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1. We should point out that Dr. Massart, in collaboration with Professor Suzanne Simon of the Jules Bordet Institute, Brussels, has since adopted the same method again in curing a radionecrosis appearing subsequent to treatment for a brain tumor. The patient is responding favourably and a cure seems to be in sight.
2. Irradation on the skin surface had been around 70,000 röntgen and the dose at 0.5 cm below the surface had been of the order of 3,000 röntgen.
3. In spite of the fact that it is on a different basis, a passing mention may be made of the recent work carried out by Professor Zénon Bacq of the University of Liège on the development of a substance designed to reinforce the radioresistance of the tissues.
As Professor Bacq himself acknowledges, the results of this work have still to be corroborated.

Chemistry and Nuclear Energy

VI[e] Salon International de la Chimie

Palais de la Défense

PARIS

25 April-4 May

Euratom stand: No. 41

Chemistry and Nuclear Energy

The Use of Radiations in Chemistry

The task with which we are now faced consists in turning the part played by radiation in chemical reactions to industrial advantage: a large number of research projects directed to this end are already under way. Some of the possibilities thus open are:

the initiation of reactions;

catalysis under radiation;

synthesis under radiation;

vulcanization of rubber;

sterilization of surgical equipment;

grafting of one plastic on to another;

preservation of food-stuffs;

Radioactive Waste

All nuclear plants produce radioactive effluents. The problem is to get rid of them safely.

Here, too, chemistry is playing its part in the solution of this problem. There are several possible methods, but the first stage almost always involves concentrating effluents by precipitation or evaporation.

The aim therefore is to obtain as small a volume of effluent as possible. The next consideration is to "contain" the waste so that it can be stored or disposed of without danger. One of the most current methods consists in incorporating it with glass or bitumen. This can then be buried in the earth or sunk in deep water. Experience has shown that site contamination is negligible.

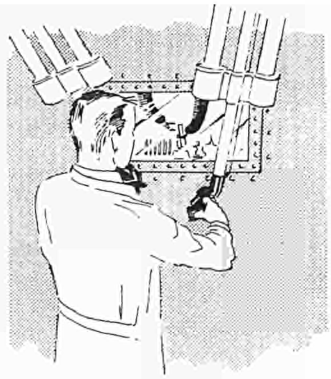
Reprocessing of Irradiated Fuels

The life of a fuel element is limited. After a certain period of time, which varies depending on the particular reactor involved, the fission products which dampen reactivity must be extracted. At the same time, the fissile matter is recovered and can be used again.

There are two ways of doing this:

by the aqueos method, in which the element is dissolved by acid;

by pyrometallurgy, in which the fuel is first melted and then subjected to separation processing.

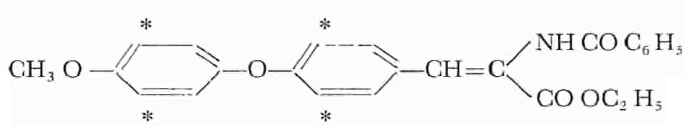


Separation of Fission Products

During the processing of effluents and the reprocessing of the fuels referred to above, the fission products were assumed to be wastes. This is not always the case, for some of them can be used as radiation sources on recovery. This can lower the very high cost of fuel reprocessing and waste disposal.
Examples of this are prometheum 147 and especially caesium 137 which is tending to supersede cobalt 60.

Production of Isotopes and Marked Molecules

Scientific research, medicine, industry and agriculture are turning more and more to radioisotopes, which explains the efforts now being made to increase the range and quantity of isotopes.
At the separation stage, their production consists of numerous chemical operations carried out in special laboratories equipped for the handling of very high activities.
They are used as tracers, frequently in the form of complex organic compounds known as "marked molecules" which make it possible, especially in the field of biology, to observe the mechanisms of life at the molecular level. In medicine, tumours can be treated with heavy doses of irradiation by means of marked molecules.



This formula represents a hormone marked with tritium (hydrogen 3). The asterisks show the location of the "marked atoms" in the molecular system.

Organic Coolants

Certain reactors now being developed, such as those of the ORGEL type, are to be cooled by organic substances.
How will the various liquids used for these purposes behave under irradiation?
What new liquids can be produced by synthesis?
These two questions form the mainspring of the research being carried out by chemists and radiochemists in this field.

EURATOM NEWS

Mr. Chatenet, President of Euratom, addresses the European Parliamentary Assembly:

$ 480 MILLION

the minimum required for the second five-year research programme

Mr. Chatenet, President of the Euratom Commission, addressed the European Parliamentary Assembly on 20 February 1962. He saw the year 1962 as decisive for European integration; and for Euratom, since during this year a decision would be taken on the second five year research programme (1963-67). He said that this programme would continue along the lines of the first five-years (1958-62). It would, however, pave the way for the change-over to large-scale nuclear activities and to atomic industrialization.
Mr. Chatenet said that the first five-year programme had been 95% achieved with the establishment of the Joint Research Centre, the conclusion of a series of contracts of association for research and international agreements. For the second five-year programme, around $480 million would be required and the Commission hoped that this 'minimal effort' would be sufficient. This estimated figure he considered reasonable since the physical capacity of the Community's installations will be more than adequate to absorb this level of expenditure. He pointed out that 90% of this research expenditure would be made in Community countries, and that Euratom is now studying the industrial impact of the second research programme. Already Euratom research provides an important contribution to the activities of Community nuclear industry and a large part of the expenditure under the programme will result in an increase in their business in the future.
Reviewing the main items of the second five-year programme, Mr. Chatenet mentioned the 'Orgel' type of reactor, which had been chosen in view of the advantages of heavy water and the results of studies already carried out in certain member countries, fast reactors, and advanced gas reactors: for the latter the Commission hoped that the Dragon experiment would be continued and, in this connection, laid emphasis on the development of the Petten (Holland) establishment. Mr. Chatenet said that the Commission would strive to encourage the manufacture in Europe of fuel elements and to develop succeeding generations of reactor types already in operation. Other activities would include the development of the most advanced types of test reactors, neutron physics, the study of radiation, neutron measurements, irradiated fuels, radioisotopes, nuclear ship propulsion, fusion, the training of technicians, biology and health protection.

Britain and Denmark request Euratom membership

Applications for membership of the European Atomic Energy Community have been made by the United Kingdom and the Kingdom of Denmark. On 5 March, Sir Arthur Tandy, Head of the British Mission to the European Communities, presented to Mr. Calmes, Secretary-General of the Council of Ministers, the British request. On 19 March Mr. Hans Tabor, Head of the Danish Mission to the European Communities, presented the Danish request. On both occasions the Euratom Commission registered its strong satisfaction that the principle of membership of all three communities had been confirmed.

Co-ordination of nuclear shipping projects in which Euratom is participating

The Liaison Committee for Nuclear Ship Projects met on 22 February for the first time. The committee consists of representatives of the four development projects for nuclear-powered merchant vessels as well as of Euratom representatives.
The Community is participating in four development projects, namely those of:

- —the Gesellschaft für Kernenergieverwertung in Schiffbau und Schiffahrt (GKSS), Hamburg, in collaboration with Interatom (development of an OMR-type marine reactor);
- —a group consisting of the Italian Nuclear Commission (CNEN), the Fiat Company, Turin, and the Ansaldo shipbuilding company, Genoa (draft design of a nuclear powered tanker);
- —the Reactor Centrum Nederland (RCN) in collaboration with a number of Dutch concerns (adaptation of the PWR reactor for use in marine propulsion);
- —the GKSS project covering a programme of general experiments, especially shielding and vibration tests, which are of fundamental importance for all reactor-powered vessels.

Euratom is contributing over $ 6 million to these projects. Euratom's rôle is to effect a degree of co-ordination between the various projects and thus avoid duplication. The Liaison Committee is an important instrument for the furthering of this aim.

Plans for a 250 MW ORGEL Power Reactor

A contract was signed on January 17, 1962, with Belgonucléaire, Indatom and Siemens-Schuckert-Werke, for the establishment of the characteristics and plans of a 250 MWe Orgel nuclear power plant. This study is primarily aimed at obtaining an optimum arrangement of the components used in an Orgel power plant. It is also intended to show in detail the effect of certain variants on the price of such a plant.

European Parliamentary Assembly

Question No 73 by Mr. Pedini:

In its Bulletin of December 15, 1961, the "Europe" Agency, summing up the preliminary studies on energy policy submitted to the Economic and Social Committee, stressed that the specialised nuclear section of this Committee had demonstrated "...the possibility of nuclear energy becoming competitive within a very short space of time, the present divergence between the cost of this energy and conventional energy being of the order of 10-30%..."

The author of the question considers that this information, if justified, is particularly important and will doubtless have repercussions on the direction taken by the European Community's power policy.

He therefore asks on what information the statement issued by the agency in question and reproduced above is based.

Reply by the Euratom Commission to Mr. Pedini's question:

1) The Commission deems it desirable to draw the attention of the Honourable Member to the original text of an extract from the "Opinion of the Economic and Social Committee concerning the Proposals for Initial Steps To Be Taken Towards a Co-ordination of Power Policies":

"Although the production cost of the nuclear kWh in 200-300 MWe plants operating for 7,000 hours a year with fixed charges of 7 to 13% is evaluated on the basis of recent calculations as being 10-30% higher than a conventional thermo-electric kWh in plants using coal at $/13.50 ton, a rapid and continual drop in the cost of a nuclear kWh can nonetheless be expected. Contributory factors to this will be both general developments in the scientific, technical and industrial fields, and particular causes affecting various items of the cost. Although the number of factors involved is very high and in spite of the difficulty entailed in assessing them, it may reasonably be supposed, on the basis of a cautious estimate, that in comparison with new electric power stations, a balance will be struck during the course of the present decade between the economic competitiveness of the nuclear and conventional kWh, obtained from high-quality coal and oil, albeit at different times and in various parts of the Community.

In the thermo-electric field, nuclear energy will therefore assume a rôle of ever-increasing importance in proportion to the rapid increase in demand. In this sector, where a balance will be maintained between the competitiveness of the various sources of energy, it will be the destiny of nuclear power to play a part which will ultimately be no less vital than that of coal, oil and natural gas, so that the competition will certainly be more active and more diversified".

2) The Economic and Social Committee issues notices representing its own opinions independent of those of the Commission and based on information which it amasses and deems valid.

3) The Commission, however, on its part, is devoting part of its activities to systematic and thorough investigations of the competitive possibilities of nuclear power on the basis of published data, information with which it is supplied or which stems from contacts with the interested parties.

In the light of these investigations, the Commission has come to the conclusion that the thesis put forward in the extract from the above notice is valid with regard to the present state of the energy market and nuclear technology.

4) Moreover, the cost price estimates for the most recent nuclear power plants projects in Germany, France, Italy, Great Britain, and the United States available to the Commission confirm that the envisaged cost of nuclear electric power is 10-30% higher than that of conventional energy.

On the other hand, thorough analyses carried out in various countries and based on considerable industrial experience in this sphere—in France, Great Britain and the United States—indicate that by 1970 large nuclear power plants will be in a position to compete with conventional power plants having the same characteristics, facilities and operating conditions.

By way of example, at the Tokyo Forum, the USAEC authorities announced that certain nuclear power plants put into operation in 1968 will be competitive in those parts of the country where fossil fuels are equal to or exceed the price of approximately $ 10 per ton of equivalent coal delivered to the plant.

Marked Molecules

Euratom recently signed a series of contracts with the Institut Interuniversitaire des Sciences Nucléaires, Brussels, the University of Heidelberg, the University of Göttingen, TNO (The Hague) and the University of Freiburg, concerning the manufacture of certain products "marked" with carbon-14 and tritium. All of these products are complex organic compounds intended for use in biological research; in certain cases the research is centred on their therapeutic applications.

Transplutonium elements

Euratom has concluded with the Reactor Centrum Nederland a two-year contract for research on transplutonium elements. The research will be conducted into six fields, the most important of which are: methods used for the separation of transplutonium elements such as americium and curium from reator fission products, procedures for the identification of these elements, the nuclear properties of certain transplutonium elements and their technical and scientific applications. The RCN will be assisted by the Nuclear Physics Research Institute (Instituut voor Kernphysisch Onderzoek) which will give technical advice.

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