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A scientist of the Ispra Biology Department.

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1969 - 1

Today "Euratom Review" appears under a new title. Our choice of the name "euro-spectra" is intended to reflect the widening of the journal's scope to keep pace with the expanded field of activity of the Commission of the European Communities. However, even though its name has changed, the aims of the journal will remain the same.

The activities of the European Atomic Energy Community are now combined under one authority with those of the European Economic Community and the European Coal and Steel Community. Consequently, the former "Euratom Review" must now set its sights beyond the purview of the European Atomic Energy Community, particularly since in the two other Communities as well the problems of research and technology are visibly increasing in importance.

Naturally, the journal will continue to cover the nuclear field which is the province of Euratom. In addition, it will deal with research in the coal and steel sector, in which the ECSC has for many years been able to initiate and promote noteworthy projects thanks to the possibilities opened up by the Paris Treaty. Finally, as regards the EEC's sphere of activity, mention must be made of the resolution adopted by the Council of Ministers on 31 October 1967, which virtually gave the green light to the development of all-round co-operation between the six Member States in research and technology. Operations on this front are only just starting but it is already clear that the Community can no longer escape giving constant and active attention to all the various aspects of research and technology. By keeping the public informed, "euro-spectra" can and will help the Community to look beyond the nuclear energy, coal and steel sectors and to reach the political decisions which are essential to the technological future of Europe.

I wish the journal good luck and every success.

Fritz Hellwig,
Vice-President,
Commission of the European Communities

The present status of international technological co-operation

International co-operation in research and technology is at once a fact, a source of concern and a necessity. How can we ensure that it is effective?

PIERRE MAILLET, *Director for scientific and technological policy*

AT THE PRESENT time, towards the beginning of 1969, international co-operation in research and technology is at once a fact, a source of concern and a necessity. The main subjects touched on below are the magnitude and variety of such co-operation, the deep-seated causes of the dissatisfaction shown with the inadequacy of some of the results, the need for such co-operation between countries of the size of those in Europe, a survey of further fields for possible joint action and a brief recapitulation of the requirements to be met to ensure that it is effective.

International co-operation in technology is a fact

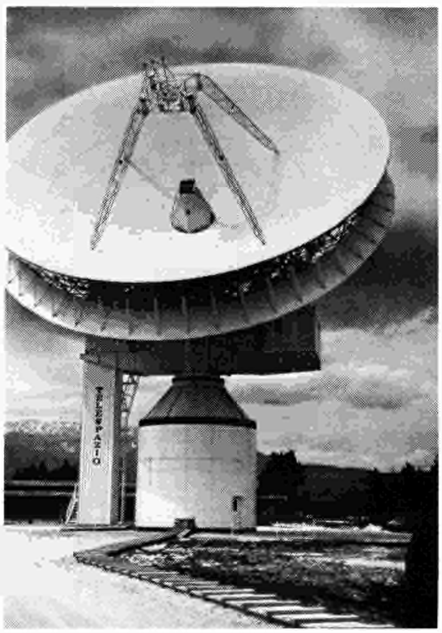
Over the last ten years or so a number of agreements have been signed instituting co-operation between two or more countries in the field of research and technological development. The distinctive features of present co-operation are the appreciable expenditure involved, the wide variety of fields covered and the organisational or administrative arrangements employed.

At a reasonable estimate, this co-operation can be said to involve an annual expenditure of the order of 400 million dollars for the Community countries, which represents almost 10% of the Community's overall research effort. This proportion is considered high by some and low by others, according to each one's opinion of the usefulness of international co-operation.

The fields covered by these activities are remarkable for their diversity. Admittedly, the major recipients are the nuclear, space and aircraft fields, as is the case with the national research programmes also. Nevertheless other very different fields are also included, ranging from basic research activities, as at *CERN (European Nuclear Research Centre)* and *EMBO (European Molecular Biology Organisation)*, to co-operation for fairly immediate industrial purposes, and taking in co-operation by certain public services such as weather-forecasting.

There is no less variety of participation and structures. At one end of the scale we have only two countries involved in certain bilateral projects, and at the other approximately 100 in the organisations set up by the *United Nations*. Even if attention is confined to European multinational organisations, the number and identity of the partners is found to vary from project to project, so that Euratom is made up of the six European Community countries, while there are seven countries in *ELDO* and nine in *ESRO* (Table 1). This disparity in the number of countries taking part is matched by a variety of administrative set-ups, a notable feature of which is the difference in the powers conferred on the central secretariat and the methods of drawing up programmes and budgets.

In short, then, the present situation is characterised by a wide range of experience from which material lessons can be drawn now that such co-operation has been under way for several years.



Satellite earth station at Fùcino, Italy.

International co-operation as a source of concern

Over the last few months the main international co-operation projects have been discussed frequently by the participating countries, most of which have displayed a certain amount of dissatisfaction with the results achieved. This is true both of Euratom, where there are serious difficulties in securing approval for a third five-year programme, and of space activities, to which the responsible ministers have devoted several meetings without yet arriving at a wholly satisfactory solution. Even a basic research organisation, such as the *CERN*, long

It can enable research to be carried out at *lower cost* by reducing duplication of effort. Thus, co-ordination of research into the measurement of the harmful effects of pollution and methods of combating it and the adoption of a common programme should yield the same knowledge for a smaller total effort.

It can enable research to be carried *under better conditions*, either by bringing together the best brains from several countries, or through the joint construction of a particularly large piece of apparatus: the formation of the *CERN*, with its large accelerator, has made it possible for European high-energy physicists to catch up with the scientific standards set by the United States and the USSR.

International co-operation can also *raise the economic efficiency* of the projects undertaken by widening the market and therefore opening the way to longer production runs. It may be said that the main reason for two countries building the *Concorde* was to avoid the construction of two competing aircraft and thereby to secure both countries' markets for this aircraft and thus facilitate the capturing of other markets.

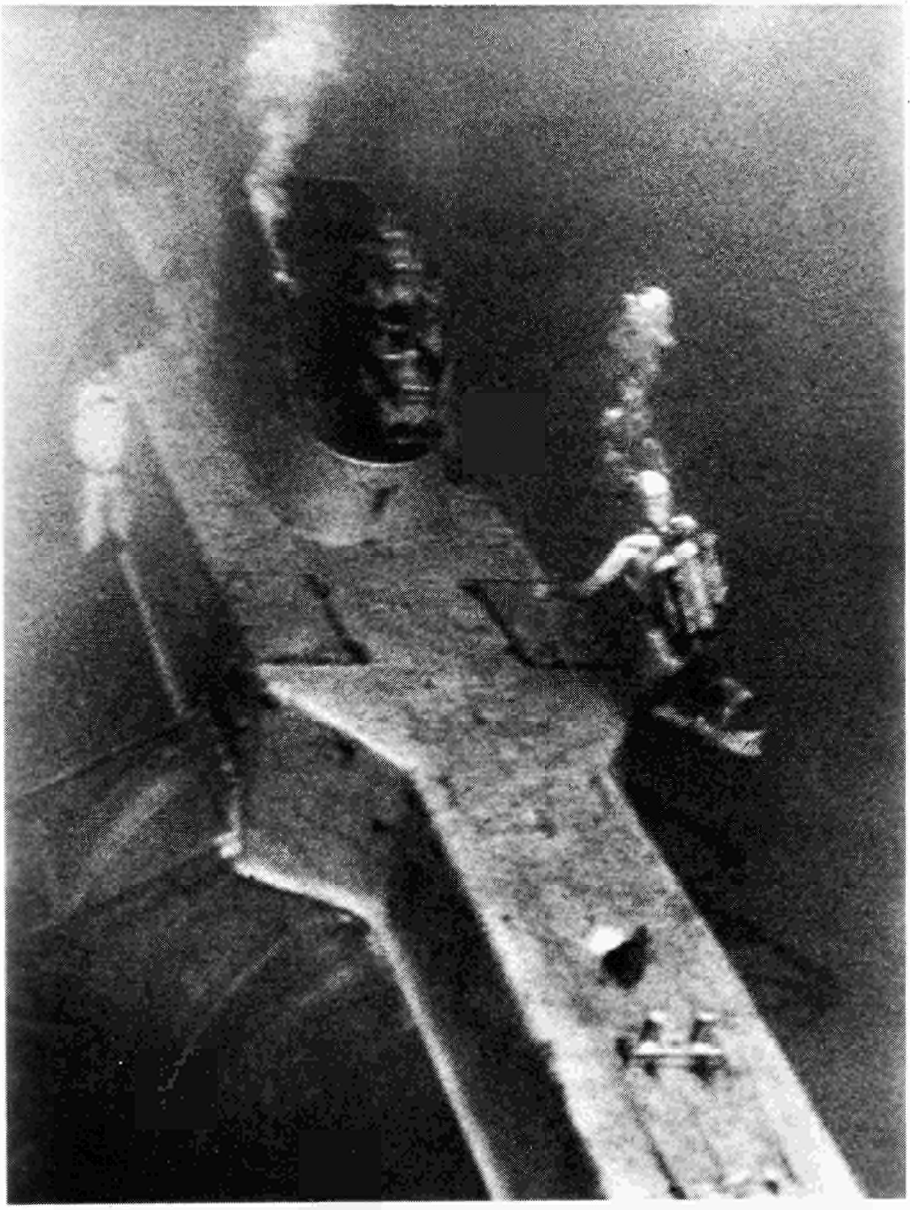
Lastly, *for certain countries* international co-operation may be *the only way* of having a hand in advanced-technology projects which are beyond the scope of any of their individual economies, but from which they can hope for beneficial spin-off. In certain cases it can form the starting point for a later, national programme, as is the case with space research.

In short, international co-operation can be expected to provide knowledge that can be put to subsequent use, or to widen the market.

The latter point warrants further comment. It might be thought at first sight that the setting-up of an economic area within which there are no customs duties or technical barriers to exchanges would afford a solution to the problem and that free competition would ensure that "the best man wins". In practice, the operation of this ideal mechanism is greatly hampered by two factors.

Firstly, competition may prove to be very expensive when it results in there being two production units, both operating below the level giving the lowest cost. The construction of two plants entails additional investments and the smaller market for each makes it impossible to reap the benefit of the cost reductions provided by big production runs. (It is generally felt that in the aircraft industry, for instance, doubling the size of the production run results in a reduction of the mean unit cost by as much as 20% or even more.)

Secondly, technically sophisticated equipment is often sold in very special markets where free competition is subject to certain limitations, there being a "built-in" tendency to support the home industry—a tendency that may be part of the system or spontaneous. This applies to the markets for nuclear power plants, for aircraft and related equipment, for large computers and certain telecommunications equipment. The main customer is the State, or undertakings financed by it to a greater or



A view of the French bathyscaphe FNRS III *used for oceanographic research. The vessel has just submerged.*

lesser degree, and it is a well-known fact that where the placing of government orders is concerned, the criteria of price for a given quality are not the only ones to operate[2]. This results in a certain fragmentation of the market and a tendency for countries to specialise.

Each country's economy thus loses on several scores:

—it wastes productive effort, notably research workers, who are frequently considered to be in short supply;

—the equipment sold to its user industries is more expensive and less well-tried;

—it cuts itself off from export markets.

Thus there are probably a fair number of cases in which international co-operation can be a profitable undertaking for all the partners.

Admittedly, allowance must be made for the fact that international co-operation costs money to organise and run, so it must be ensured that the savings expected outweigh the additional expenditure involved. In certain cases experience has been disappointing, precisely because no such check was made at the start. If, however, the project can bring a net gain to all the partners, there is no reason why the rules should not be laid down in such a way that each one shows some gain and therefore has an interest in the project.

Possibilities for co-operation in Europe

The benefit that can accrue from international co-operation in technological research and development is sufficiently acknowledged for the Council of Ministers of the Six to have passed a resolution in Luxemburg on 31 October 1967 emphasising the importance of research for economic development and calling for a review to be made within a fairly short time of the possibilities of co-operation between the member countries, both in certain fields specified in the resolution and in other fields that might be suggested to the Council. This resolu-

2. "Each country regards its own public purchasing as an instrument of its national policy for industry. The result is that, at present, the European market for major equipment is non-existent". *National Council for Science Policy* No. 2, Research and Economic Growth. Brussels 1967, page 139.

tion derived from preparatory work, notably that carried out by the Medium-Term Economic Policy Committee's Working Party on Scientific and Technical Research Policy, better known by the name of its chairman, Mr. Maréchal. In July 1967 it submitted a lengthy report to the Council on the benefits of and conditions for international co-operation and, in particular, put forward for initial consideration the fields that were finally agreed on by the Council.

These seven fields are of a widely differing nature and in fact accord with the various motivations outlined above as underlying international co-operation.

The field of *nuisances*, i.e. the fight against air and water pollution and against noise, affords a notable example of the desire to reduce duplication of effort and, therefore, the cost of research and development for the Community as a whole. The importance of this is increasingly being recognised; the growing rate of urbanisation is tending to step up the harmful effects of air and water pollution on man, and the greater use of chemicals, e.g. pesticides and insecticides in agriculture, may also push a number of pollutants over the danger level.

Some of the studies required in this field relate to public health, and the rest to economics. The aim is to seek a better understanding of the overall effects on man of the pollutants to which he is subjected and to estimate the cost of the fight against pollution, with the ultimate purpose of implementing the most suitable regulations and developing the least expensive methods.

There is a twofold justification for this research being carried out jointly by the Community countries:

—firstly, they all have the same kinds of problems;

—secondly, this fight demands common provisions, either because pollutants can move from one country to another (notably in the case of the pollution of a whole river basin) or because the working of the industrial common market would be disrupted if the regulations to which firms are subjected differed greatly between countries.

The same considerations apply to *meteorology*. This is a public service whose techniques are at present being revolutionised, for the use of weather satellites enables data to be gathered and transmitted rapidly and in far greater quantities than hitherto, and computers can be used to process a very large amount of such data very quickly. Meteorology is therefore being transformed and the coming years will see the advent of a discipline which will be very different from that which has gradually developed over the past century. Co-operation between Community countries is not only warranted by the large amount of equipment required but is made all the more essential by the fact that, after all, these countries cover only a small part of the globe.

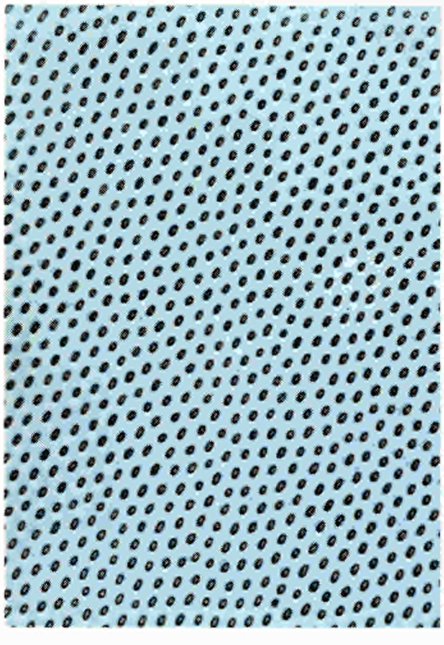
Even the setting-up of a single computer centre for the Community countries can be contemplated; equipped with major facilities, this would provide an example of the second type of co-operation—that centring on a machine which would be too large and expensive for any of the member countries alone.

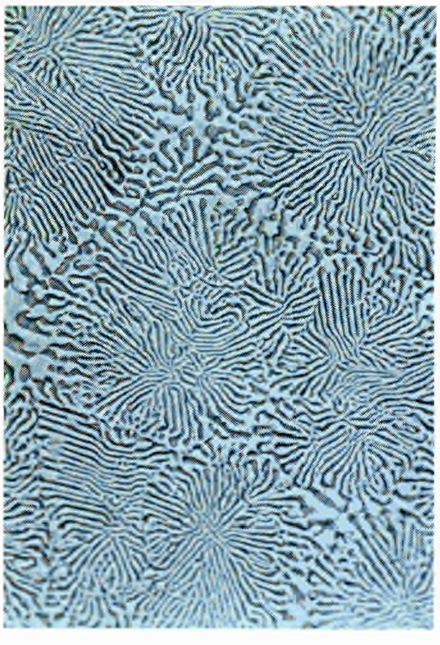
Marketing aspects are of primary importance in the following three fields: the science of information, telecommunications and new means of transport.

There is hardly any need to restate either the importance of the *science of information* for the economic development of industrially advanced nations or the low productive capacity of Community firms other than the subsidiaries of American firms. There are therefore two underlying reasons for the idea of co-operating in this field: consideration can be given to the question whether it would be beneficial, firstly, to promote the development of a genuinely European computer industry, and, secondly, to speed up the use of electronic data processing systems both by firms and by the public authorities, for a campaign to publicise these techniques, to train personnel and to develop jointly-owned software could improve the working of the Common Market.

The growth of the science of information presupposes the availability of a much more sophisticated *telecommunications* network than is the case today. It would, however, be a mistake to think that telecommunications will serve as an ancillary to this science. While the development of remote data processing will probably be one of the leading preoccupations of the next few years, we must nevertheless already be looking

The metallurgy of tomorrow. Composite structures consisting of a spread of fibres aligned in a single direction possess particular mechanical properties, combining plasticity of the matrix and good fibre strength. (Metallurgy Department, Ispra.)



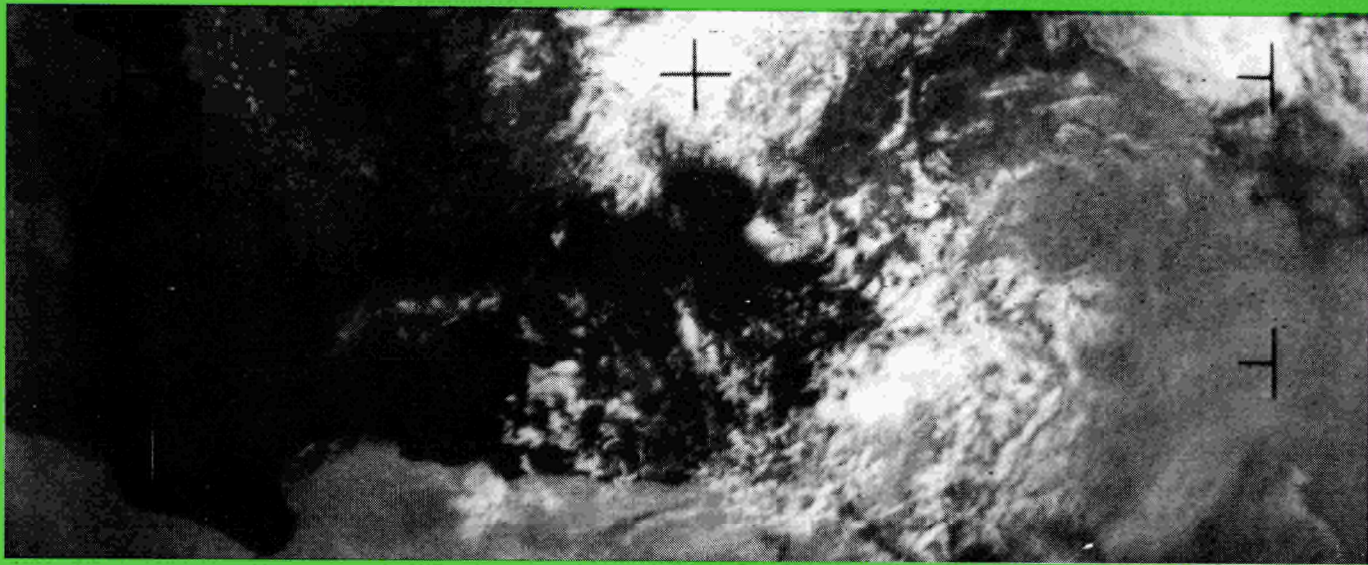


further ahead, and thinking methodically and imaginatively of the enormous communications requirements which may arise somewhat later, say around 1980, and may only be able to be met with the aid of techniques stemming from research initiated right now. These requirements will spring, in particular, from the increasingly dense urbanisation already alluded to and from the hoped for advent of multinational firms for which new methods of communication will be necessary in order to facilitate operation across frontiers. Lastly, telecommunications equipment is primarily sold to public authorities, so that the removal of national barriers is essential.

Similar remarks can be made about *new means of transport*. Here too, it is increasing urbanisation and the rise in trade between the Community countries, often involving distances of 200 to 400 miles, that creates the need for new means of transport. It might be worth while to develop them on a Community basis, thus immediately securing for them a sufficiently large market, on which the public authorities would frequently be a customer of prime importance.

Oceanography differs considerably from the previous fields. Emphasis may be placed either on the search for scientific knowledge, with an attendant concern for reducing duplication of effort, or, on the other hand, a special importance may be attached to future possibilities for exploiting the oceans, efforts being concentrated on the manufacture of the equipment required, with sufficiently long production runs. Also, this is a relatively new field in which even until quite recently countries spent only very modest amounts. However, many countries have been displaying increasing interest in it for some time now. In the United States, for example, interest is being shown both by the Government and by private firms, which see here a possible follow-up to space activities, in which a substantial cutback is expected after the completion of the Apollo project to put a man on the moon. Moreover, the US Government has asked a number of other countries to engage jointly in a ten-year oceanographic programme. Also, France has just laid down the main lines of a programme for *CNEXO* (*Centre national pour l'exploitation des océans*) and the German Government is working out its policy on oceanography. Insofar as this

An acute problem of our day—pollution



Meteorology can no longer be conducted on a national scale—view from the satellite ESSA 6.

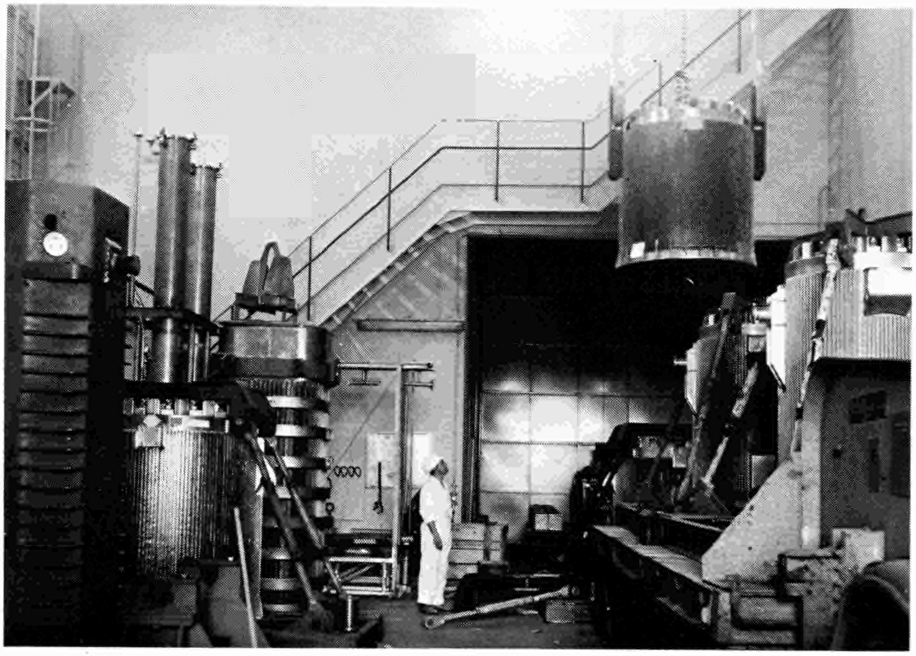
is a relatively new field, it may be considered especially suitable for launching international co-operation, since it is one in which national traditions are not yet very strongly established.

The seventh field specified in the Council's resolution, *metallurgy*, is of interest in that it throws up problems not yet encountered, or presents them in a more acute form. The point of departure for our thinking is the fact that the availability of materials having the required properties is often a prerequisite for the development of other technologies, and where costly technological research and development is needed to obtain these materials, it might well be beneficial to reduce duplication.

In this sector, however, research is hardly thought of without regard for industrial outlets in the fairly short term, and, furthermore, metal producers sell primarily to private industry. The result is that, even more than in other sectors, co-operation between countries, or between firms in different countries, raises the problem of industrial property and the possibility of granting exclusive licences. Finally, the research involved is frequently within the financial scope of large companies, so the need for co-operation is felt to be less pressing and it is hard to find subjects on which co-operation would be both worthwhile and feasible.

Conclusions

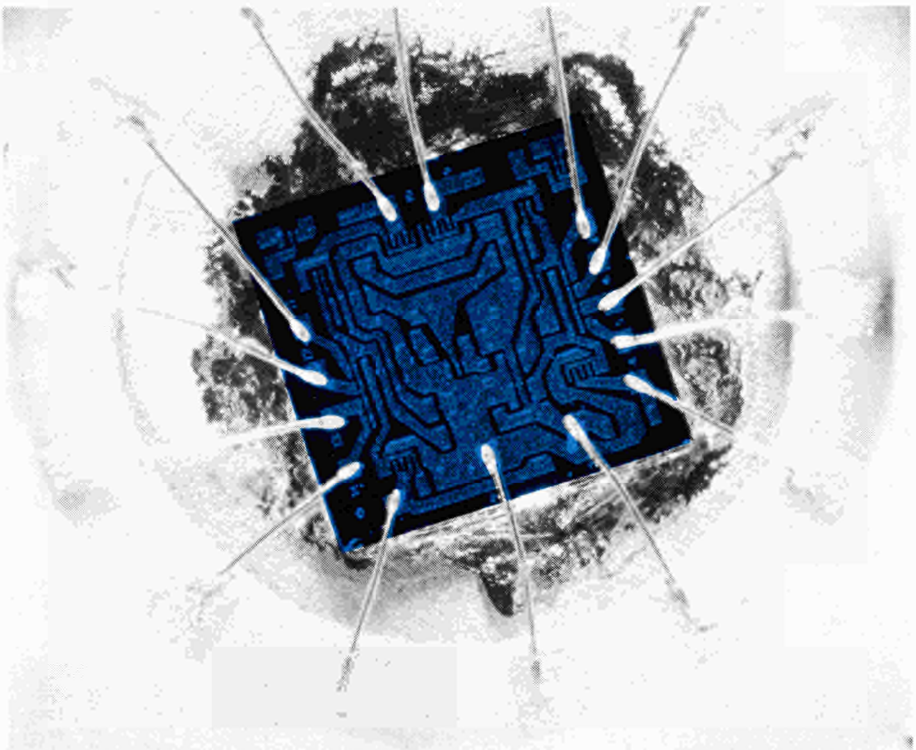
There is a marked variety not only in the subjects of but also in the reasons behind international co-operation, this applying both to fields in which it is already in progress and to those in which such possibilities are still being considered. This variety pays dividends in that it opens up a wide range of methods of co-operating, which may in certain cases be restricted to a mere comparison of national programmes, or may be more ambitious and aim at a certain degree of co-ordination between these programmes, or, finally, may go as far as the formulation of a genuine, single programme for the whole Community, with the research work carried out in national centres (laboratories or firms), or, the ultimate stage, in a joint Community research centre. However, if this variety is to lead to effective co-operation, it is important



The reception hall for the containers from Eurochemic (European Organisation for the Chemical Processing of Irradiated Fuels). On the left are containers of the types DIORIT, PEGASE *and* VAK/BR 3. *A* PEGASE-*container being loaded on to a truck joins two* MELUSINE *containers.*

to ensure that there is a modicum of consistency between the various projects. This desire for consistency must extend, in particular, to the definition of aims and the harmonisation of methods.

Regarding aims, it seems essential, if we wish to ensure truly effective international technological co-operation satisfactory to all concerned, for the projects agreed on to be fitted into an overall picture of long-term economic development. Only in this way is it possible to decide on priorities among the various possible projects and to make sure that projects carried out on a co-operative basis harmonise with the national programmes. While the definition of this overall picture of long-term development will unquestionably take quite a considerable time, this only makes it the more imperative to start work on it immediately.
In addition, it is important that the methods of implementing the various programmes should display a certain measure of uniformity. This does not mean that the practical arrangements for each programme should all be cast in exactly the same mould, but rather that similar solutions must be worked out for identical problems, so as to avoid any excessive increase in the cumbersome machinery of international co-operation. For this reason the existence of a single secretariat providing a modicum of comparability between solutions can be a most valuable factor in enhancing the efficiency of such co-operation. In this respect the Community constitutes a particularly well-equipped group of countries, since it is endowed with Community institutions which can carry out precisely this function of securing uniformity and comparability.
Lastly, it may be said that the greater the number of projects undertaken, the easier it will be to solve the problems of so-called "fair return", since compensation for the various countries' laboratories and industries will be thus facilitated.
It would be a mistake to think that, because co-operation has proved difficult over the last few years, it must now be confined to a few small-scale projects. On the contrary, by advancing towards new fields of co-operation it will be easier to modify the methods employed so far and to give them the efficacy that is the prior justification for these projects.
(EREA-A 8-1)



Monolith for a Siemens computer installation (enlarged about 45 times).
The silicon plate shown here holds 15 transistors, 13 resistance functions, and their "wiring".

Nuclear desalination 1968

The conference on "nuclear desalination" held in Madrid in 1968 has shown that desalination technology is making progress. It has also made it clear that desalination and nuclear energy are very distant relations.

JEAN-CLAUDE LENY, *ORGEL Project Director*

THE INTERNATIONAL *Atomic Energy Agency* held a colloquium on "nuclear desalination" in Madrid from 18 to 22 November 1968. A total of 68 papers were scheduled, but only 65 were actually presented because the Russians, who were to have talked about the Chevchenko desalination complex, did not come—to the general disappointment of all concerned. The harnessing of a fast reactor to a desalination plant is—at least at present—so surprising that it would have been very interesting to hear the reasons for it from the authors themselves.

This being said, here are some remarks arising from a perusal of the documents submitted and from discussions with various persons.

The title of the colloquium is deceptive. It had probably never been so clearly apparent that desalination and nuclear energy are two different things and that very special conditions are needed for the two to be brought together. The explanation lies in the fact that desalination requires very cheap, more or less medium quality steam (350°F = 185°C being the maximum at present, but I shall come back to this later), its source being of little importance. A poor reactor might be suitable, if economic, but so could a very good one.

In actual fact, with one exception (the Italian *ROVI* reactor, which is precisely a low-performance but, according to its promoters, economic reactor) nuclear steam raising plants have only been proposed for very large, dual-purpose installations. While this scheme is attractive and, if the environment is disregarded, fairly easy from the theoretical study angle, it is unfortunately very difficult to make it a realistic proposition in practice: it is generally assumed that the power plant will operate as a base-load installation throughout its amortisation period, but experience shows that over their lifetime plants inexorably creep up from base to peak-load operation. Obviously this throws the economic calculations right out.

The agro-industrial complex studied at Oak Ridge offers the only logical solution to this problem but, in the absence of an under-developed country or one in a medium stage of development which can afford it, it would appear to be beyond the means of all but the United States (or the USSR?).

There is therefore no escaping the fact that, since for the time being there is a much larger market for desalination plants supplying a few million gallons a day[1] than for those with a capacity of tens or hundreds of millions of gallons a day, the use of nuclear power for this purpose cannot be contemplated at present, except in a very large, very rich country.

Let us now turn to desalination plants. In theory several processes can be considered: distillation in its various forms, but also dialysis, reverse osmosis, freezing, etc. Distillation may not be the most "subtle" method, but by far the greatest effort is being devoted to it, particularly by the Americans, whose programme is colossal in comparison with others (although here again a reservation must perhaps be made with regard to the USSR).

1. 1 million gallons/day = 3785 m^3/day

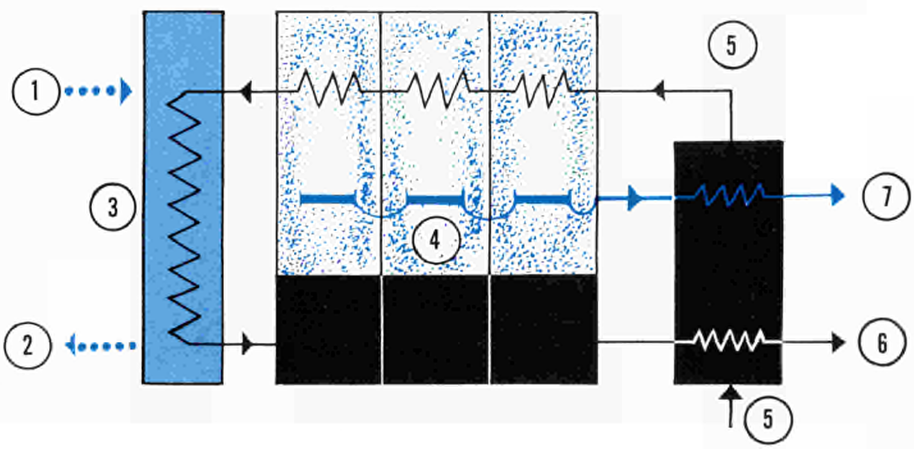


Figure 1: Multi-stage flash distillation.
1. steam in; 2. steam out; 3. brine heater; 4. evaporator; 5. seawater; 6. brine blowdown; 7. fresh water.
Seawater is heated in the brine heater (3), after which it enters the first chamber of the evaporator (4). The pressure in this chamber is such that some of the brine flashes into steam. As a result, the temperature of the remaining brine drops. It then flows into the next chamber, which is maintained at a lower pressure. Thanks to this, more steam is flashed off, in spite of the temperature drop. The process is continued through several chambers. The steam produced comes into contact with the heat-exchanger, through which flows the incoming seawater, and is condensed.

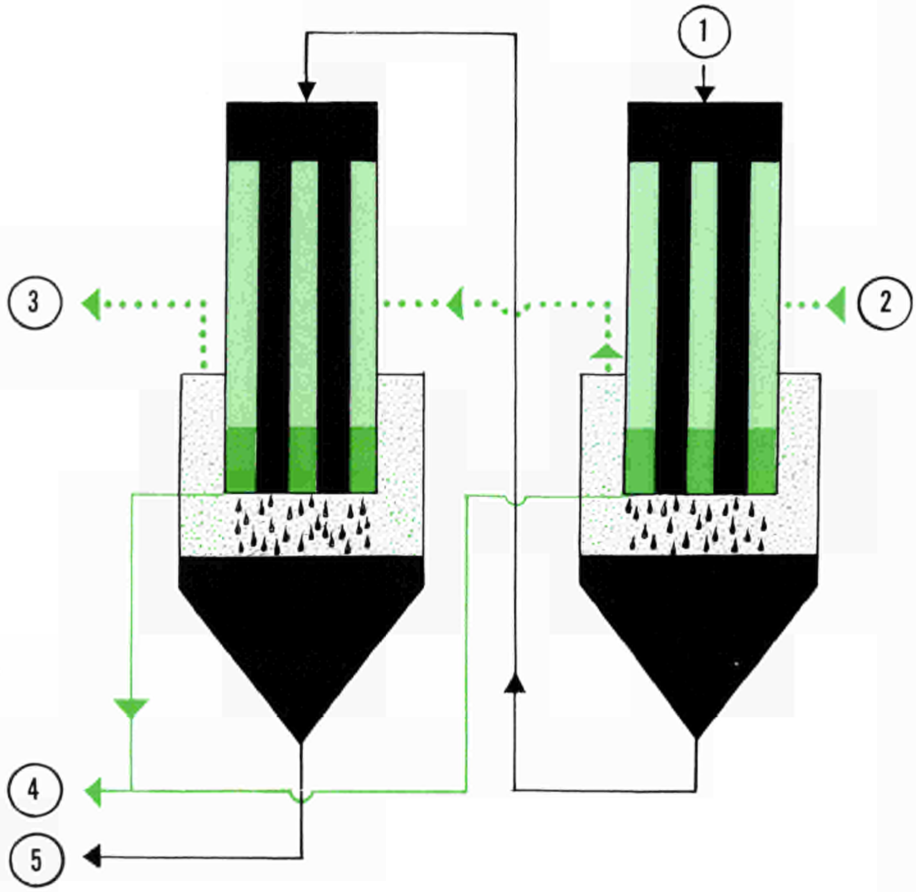


Figure 2: Long-tube vertical distillation.
1. seawater; 2. steam from boiler; 3. steam to next stage; 4. fresh water; 5. brine.
The incoming seawater (1) falls through a bundle of tubes located in a chamber to which steam (2) is supplied (e.g. from a reactor). As the seawater falls it receives heat from the steam, some of which condenses (4). The brine gives off steam which is collected and enters the next stage. The process is repeated through several stages, the pressure being reduced from stage to stage, as in the case of multi-stage flash distillation.

The results described show that a combination of ingenuity, the necessary hardware and consistent thinking pays dividends. Thus the multi-effect multistage flash process (Fig. 1), of which a prototype has been built in California (the *Clair Engel Plant*), is described as representing a genuine technological breakthrough in the field, its output of 20 tons of desalted water per ton of steam being twice what is generally counted on. The trick in multi-effect distillation lies in producing a cascade of brine temperatures, so that its representative point remains on the right side of the calcium sulphate solubility curves. This is reflected in the capital cost but the overall balance is favourable. The *Office of Saline Water (OSW)* has already initiated the study of improvements. Apart from this the only process that has been extensively used is electrodialysis, but almost always in low-capacity plants.

If large desalination plants were to be developed extensively, the single- or multi-effect flash process would have such a lead that it would stand a very good chance of ousting all others, especially as it has a potential for further development (long-tube evaporators and the vapour compression system, see Figs. 2 and 3).

Before reviewing the main sections of the conference, a few words should be said on the possible impact of desalination on the Community's programme. One thing is quite clear: nuclear power cannot be the Community's side-door into this field. As for desalination plants proper, they require a certain amount of research work: heat transfer in the evaporators must be carefully studied, which implies a good understanding of boiling phenomena; there is also the problem of the study of materials having fairly long-term resistance to salt or brackish water in the required temperature conditions; and there is the question of water treatment to prevent scaling. As regards processes other than distillation, new types of membrane might be sought (though the British claim that their attempt to find something better than cellulose acetate has been unsuccessful), or even new processes.

To do so, the example of the United Kingdom could be followed, where the *Risley*, *Harwell* and *Winfrith* nuclear research centres have been commissioned to carry out certain work on desalination; or that of the United States, where the same applies to *Oak Ridge*; or that of France, where certain tasks have been laid upon the *Commissariat à l'énergie atomique (CEA)*. It should be said that

all the work mentioned above can be undertaken by industry right away.
Finally, it must not be forgotten that desalination will have to face the same difficulty as nuclear energy, i.e. competition from the conventional sources of supply, which have not by any means been fully exploited. Water supply problems are barely out of their infancy, and certain papers have shown the extent to which a careful study could put off new requirements to later dates (e.g. simply owing to the surprising fact that there are 50% losses in old piping systems!). It cannot be denied, then, that the Community might play a part in certain fields of research but it is far from clear that desalination could ever be a major programme.
Now to discuss the main sections of the conference.
With regard to *general programmes*, only the United States, the United Kingdom, Japan and France produced methodical surveys.
The *OSW* programme (with 160 million dollars spent up to the year 1969) is based on the study of distillation, and the first plant built on this principle, located at San Diego, has a capacity of one million gallons a day, later raised to 2.1 million gallons when it was transferred to Guantanamo, while the second, the one million gallons a day *Clair Engel Plant*, has given excellent results, as already mentioned.

Long-tube vertical distillation has also been tested in a one million gallons a day pilot plant set-up at Freeport, Texas. After initial difficulties the results have been very good. The vapour compression method, which could improve performance even further, is being used in the study of an eight million gallons a day plant.
The *OSW* is also keeping an interested eye on reverse osmosis, but does not consider it to be competitive with the distillation processes at the moment, at least for large plants for processing seawater. It is, however, very satisfactory for very small units used for treating brackish water and is already being marketed.
The United Kingdom has a relatively modest Government programme (£1.3 million over three years). It is managed from the *UKAEA's Risley* centre, heat transfer being studied at *Winfrith* and materials at *Harwell*, but a preponderant role is taken by industry.
Japan has an extremely interesting and well-planned programme aimed at improving process economics by the judicious utilisation of waste-products (extraction of bromine, soda, etc.).
The French programme (five to six million francs) is managed by a committee on which sit representatives of five State organisations under the *Ministry of Scientific Research* and which relies on three industrial groupings and two companies, some studying distillation and the others reverse osmosis and electrodialysis. The *CEA* is performing certain tasks on materials and corrosion, as well as economic and dimensioning studies.

Another section of the conference was concerned with installations: a distinction must be made between the desalination section and the reactor section. Several descriptions of desalination plants using distillation methods were given, all of them very similar. When we come, on the other hand, to the reactors to be coupled to them, we again find the usual diversity, with everyone making it clear that his brainchild is particularly well suited to the job in hand. The British, for example, talked about gas-

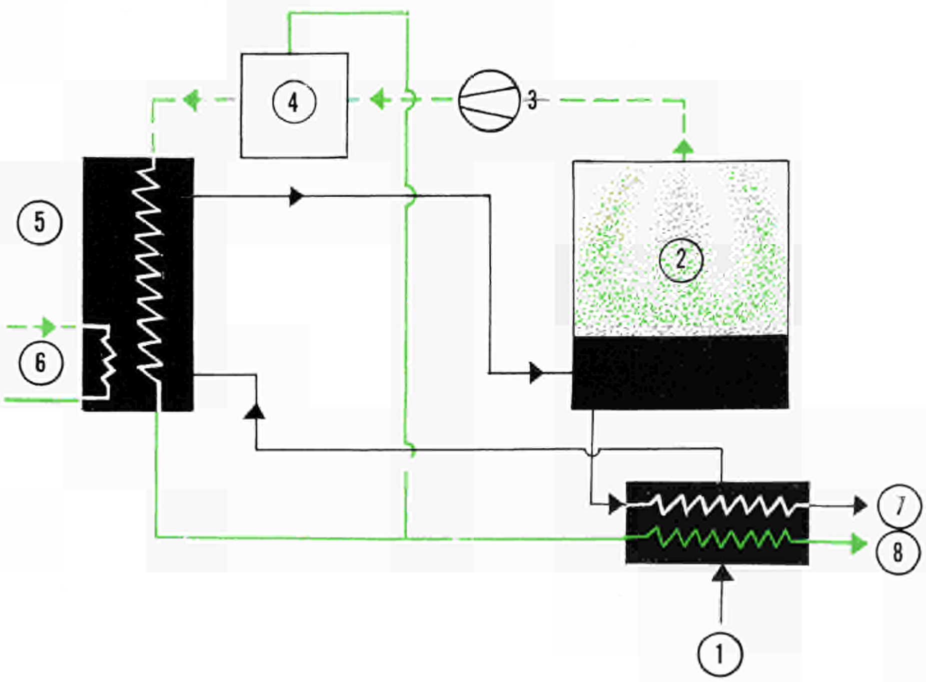


Figure 3: Vapour compression distillation. 1. seawater; 2. flash evaporator; 3. compressor; 4. de-superheater; 5. brine heater; 6. start-up heater; 7. brine blow-down; 8. fresh water.
The steam produced in a flash evaporator (2) is compressed (3), as a result of which its pressure and temperature are increased. After de-superheating (4), the steam enters the brine heater (5), where it gives off heat to the incoming seawater and is condensed. The heated brine then enters the flash evaporator. In this simplified case, the compressor alone supplies energy to the cycle.

cooled reactors, the *SGHWR*[2] and even fast reactors. The French give some quantified examples based on a graphite/gas reactor; *Siemens* proposes a pressurised light or heavy water reactor; *Inter Nuclear* sings the praises of a direct-cycle high-temperature reactor with a gas turbine; *BelgoNucléaire* suggests the *Vulcain* reactor, the *Bechtel Corporation* a sodium-cooled fast reactor and *Oak Ridge* an organic-cooled reactor *(HWOCR)*. Special mention should be made of the Italian *ROVI* project. Its promoters proceed from the fact that it is extremely difficult to find buyers for dual-purpose plants, for reasons stated above. In their view a reactor must be found which supplies cheap, low-quality steam. They feel that they have found the answer in an organic-cooled reactor operating at low pressure (10 kg) and temperature (200-240°C).

There were lively discussions of economic problems. In most cases the work is based on an assumed scheme producing equations which can then be solved. The most usual scheme is the famous "mixed plant", omitting all the troublesome constraints (position on the load curve and how this position evolves, cost structure, profitability criteria, etc.). Furthermore, in view of the fact that estimates of capital cost entail margins of error of up to 50%, the results of such studies are to be treated with some reservation, to say the least. This was pointed out in no uncertain terms by some of those attending. Gaussens, in particular, recalled that a function with maximum values can also have minimum values and an optimum point may have quite a different location, or can even be eliminated, depending on whether or not certain constraints are taken into account. It would, however, be regrettable to give the impression that the theoretical character of the mixed plant escaped everyone. Proposed solutions concerned the production of industrial products whose processing requires large quantities of electricity, e.g. phosphorus, aluminium or chlorine, and, above all, the agro-industrial complexes being studied at *Oak Ridge*. But, however interesting these studies may be, it can never be emphasised too strongly that they imply considerable installed power ratings (1,000-2,000 MWe) offerring both high load factors and low generating costs (3 mill/kWh).

The last important subject to be dealt with brought in two major technological features of desalination plants: materials and scaling. Unlike economics, these are tangible subjects and the few papers dealing with them supplied interesting and precise information.

Regarding scaling, let it merely be stated that the addition of acid to seawater and the monitoring of pH values are by now standard practice in distillation plants, so that any base scaling can be controlled. The importance of brine degassing was also emphasised. An inhibiting agent to prevent calcium sulphate scaling has not yet been found, which limits the temperature to 121°C in seawater concentration, but this difficulty has been avoided in the multi-effect distillation process mentioned above.

With regard to materials, the aim is to find something cheaper than cupro-nickel alloys for evaporator tanks and tubes. Good results have been achieved with concrete coated with epoxy resins.

It has also been confirmed that titanium has excellent properties except in the presence of teflon. The price of titanium in the United States is not prohibitive, being lower than that of inconels. Austenitic corrosion-resistant steels, however, are acknowledged to be unusable.

2. Heavy-water moderated, light-water-cooled reactor.

(EREA-A 8-2)

General aspects of the fast reactor family

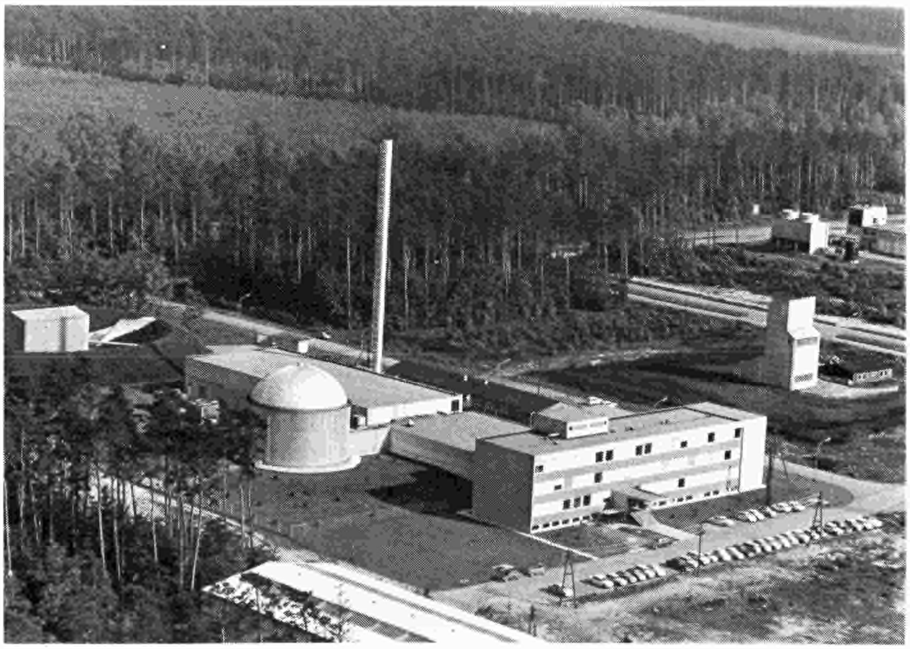
The fast reactor family, whose advantages are conspicuous, is today the object of a race for commercialisation.

JACQUES VILAIN, *Directorate-General for the Joint Nuclear Research Centre*

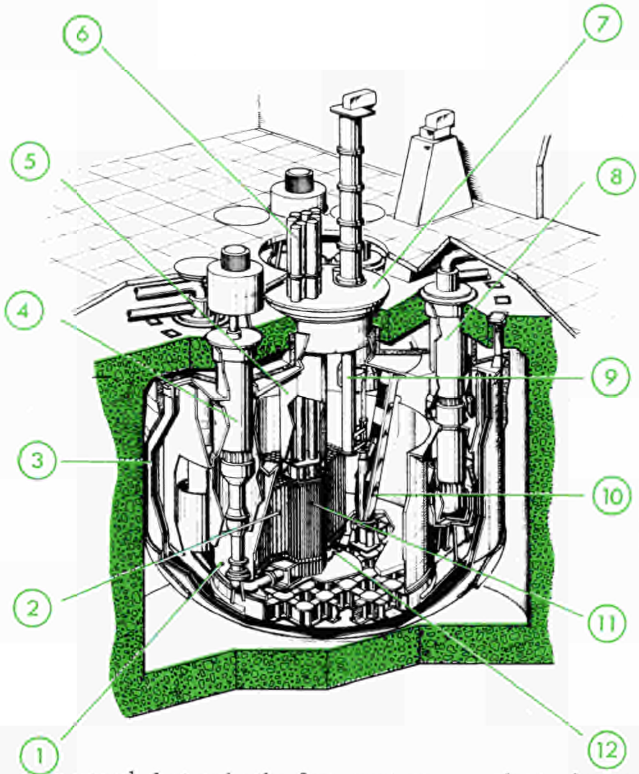
THE PRINCIPLE of the fast reactor dates back to the very beginning of the nuclear age. The concept stemmed primarily from Fermi and Zinn, who as early as 1944 drew attention to the possibility of a controlled chain reaction, without neutron moderation, which would allow effective "breeding" of the fissile material, and to the long-term interest of this breeding process as regards the optimum utilisation of natural resources.
Experimental confirmation was soon obtained in the United States; it was provided initially by *Clementine* (1946-1949), the first fast reactor to run on plutonium-containing fuel, and subsequently by the *EBR-1* (end of 1951), the first small nuclear power station to supply electricity. The Soviet and British fast reactor programmes got under way shortly afterwards (in the early fifties), those of the European Community somewhat later (in the late fifties). The first plants to be built are shown in chronological order in Table I.
As a subject of research, therefore, fast reactors are by no means junior to thermal reactors, as was indeed the case with the corresponding electricity generating stations, but their parallel development will have taken considerably longer. This is not surprising, since the fundamental problems to be solved, particularly in the engineering sector, were (and still are) far more difficult in the case of the fast reactors, which consequently remained for a long time a subject of non-priority frontier research in certain instances. Moreover, the work could hardly have begun any earlier owing to the inadequate availability of highly-enriched uranium or of plutonium.
In recent years fast reactors have entered the forefront of the major nuclear programmes. This new-found favour and, in particular, the accompanying speeding up of the timetable for the first big construction projects are not due merely to the maturation of the techniques involved or to the conspicuous advantages of this reactor family, which will be enumerated later in this article, but above all to the incentive provided by a sort of race for commercialisation in which the various programmes are competing and in which the pace is currently being set by Britain and to some extent the USSR.
Whereas with thermal reactors the competition was primarily between distinct reactor families, in the fast reactor field there is a remarkable similarity between the major choices at present under consideration throughout the world. This marked similarity of choices, which differ only in the construction methods adopted, partly explains the attention that is being paid to commercial exploitation of the work and, paradoxically, the difficulties of co-operation in this field.

General arguments in favour of fast reactors

The immediate and long-term advantages of fast reactors derive essentially from the breeding process, as a result of which they are able during operation to produce more new fissile material (from the fertile material present, which can be converted into fissile material by neutron capture) than they consume in order to maintain the chain reaction. In point of fact all the power reactors now in service or planned are in varying degrees producers of plutonium i.e.



Fast zero-energy facility at Karlsruhe (SNEAK) *with Institute for Applied Reactor Physics.*



Phenix reactor block—cutaway view.
1. primary vessel
2. neutron shielding
3. main vessel
4. pump
5. core cover
6. control rod mechanism
7. rotating plug
8. intermediate heat exchanger
9. transfer arm
10. ramp
11. core
12. diagrid

converters[1], but only the fast reactors—and above all those employing the plutonium/uranium-238 fuel cycle—can attain a conversion ratio appreciably greater than unity, as against the ratios of 0.4 to 0.8 at the most which are possible with thermal reactors, even of "advanced" types.

This advantage, the consequences of which are numerous, must, however, be paid for. In particular, with a fast spectrum and for a given core volume the critical masses are considerably greater, and the effect of the in-pile fissile material inventory on the cost of the fuel cycle is only acceptable on the assumption of substantial in-core power densities (in the MW per litre range) and consequently of an advanced coolant technology.

In principle, breeding will allow an optimum utilisation of natural resources, particularly uranium, which would be inconceivable with thermal reactors alone and which is all the more important since the known deposits of uranium which can be worked at present-day costs seem to be very limited. It is this often quoted long-term advantage which sparked off the initial interest in fast reactors and which a priori continues to confer a historic importance on them.

As stated above, a fast breeder power plant, by converting fertile material, produces more fissile material than it consumes; since the fissile material balance is always positive, a closed system would need only to be fed with fertile material. On the other hand, a converter whose conversion ratio is substantially less than unity, as is the case with all present-day thermal plants, inevitably results in inefficient utilisation of the fertile material. The fissile material burnt in it comes in any case from the 0.7% of uranium-235 contained in natural uranium. The conversion process and the recycling or in situ fission of the plutonium produced allow a certain limited utilisation of the residual uranium-238, though only to the extent of a few per cent[2], and the rest would normally be lost.

On this assumption uranium-238 (and even thorium) would have practically the same energy value as the far less abundant uranium-235; this would in principle be equivalent to a multiplication of the natural resources by a factor of about 100 and would open up the possibility of using the "expensive" uranium[3], at present unacceptable but available in unlimited quantities, extracted, for example, from certain phosphate deposits, from seawater and, at a pinch, from granites.

Attractive as these prospects are, they are still very remote, because quite apart from any question of the reliability or profitability of fast-reactor power plants, the current expansion of the energy demand will ensure that they remain a utopian dream for a long time to come.

Although it is in fact true that a fast-reactor plant produces a surplus of fissile material, the start-up of such a plant calls from the outset for a stock of fissile material, in the form of an initial inventory, both in-pile and out-of-pile. The doubling time required by a fast-reactor plant in order to breed a surplus of fissile material equal to the total inventory of an identical new plant to be started up[4] is about fifteen years or even longer in the case of the conservative concepts currently under consideration.

In the industrialised countries the overall energy demand, which continues to increase, still shows doubling times of around ten years, with no saturation point in sight. Consequently, fast reactors could not capture a growing share of the market unless their own doubling time were considerably less than the ten-year doubling time of the overall demand.

It is thought that not until after the year 2000 will fast reactor power plants—either because of saturation of the energy demand or because such plants will by then have a doubling time of well under ten years—have the field to themselves. In the meantime there will be a mixed economy of fast reactors and converters in a proportion that will be determined, inter alia, by the law of plutonium supply and demand.

This partial introduction of fast reactors will have certain beneficial effects. By supplanting an ever-growing number of converters fuelled by natural or slightly enriched uranium, the fast plutonium

1. The uranium-233/thorium cycle and the mixed cycles in which thorium is used are at present in a less advanced stage of development.

2. If C is the conversion ratio and if no account is taken of the differences in fissile value or of losses, etc., the conversion would increase the initial fissile material by

$1 + C + C^2 + \ldots = \frac{1}{1-C}$ i.e. by a factor of 3 to 5 for non-ideal converters.

3. In a nuclear economy consisting solely of fast reactor plants and provided that the losses of fissile material in recycling are strictly limited.

4. This is the *simple* doubling time obtained by storing the surplus fissile material. If, in the case of a group of breeder reactors, the surplus fissile material is reinvested by inserting it in the reactor as and when it becomes available, a lower compound doubling time is obtained.

Table 1: First plants built.

	USA				USSR			BRITAIN	FRANCE
	CLEMEN-TINE	EBR 1	EBR 2	FERMI	BR 1	BR 2	BR 5	D.F.R.	RAPSO-DIE
Power- MWth	0.025	1.2	62.5	200	0	0.1	5	72	20
-MWe	0	0.2	20	66	0	0	0	15	0
Fuel	Pu metal	U metal	U metal	U metal	Pu m.	Pu m.	PuO_2	U metal	UO_2-PuO_2
Maximum flux n/cm² sec.	$5 \cdot 10^{12}$	$1.1 \cdot 10^{14}$	$3.7 \cdot 10^{15}$	$4.7 \cdot 10^{15}$	$5 \cdot 10^{10}$	$1 \cdot 10^{14}$	$1 \cdot 10^{15}$	$2.5 \cdot 10^{15}$	$1.8 \cdot 10^{15}$
Cooling medium	Hg	Na K	Na	Na	—	Hg	Na	NaK	Na
Average power density MWth/litre	0.01	0.17	0.8	0.45	0	0.06	0.3	0.5	0.32
Outlet temperature °C	120	320	470	430	—	60	450-500	350	500-540
Critically reached:	Nov. 46	Aug. 51	Oct. 61	Aug. 63			June 58	Nov. 59	Jan. 67
Full power reached:	March 49	Dec. 51	Apr. 65	Aug. 66	1955	1956	July 59	July 63	March 67

reactors will cause a corresponding fall in the overall demand for natural uranium. The general opinion is that the introduction of fast reactors will reduce this demand—integrated over the period that must elapse before these reactors become entirely self-supporting (i.e. after the year 2000)—by a factor of 3 to 5 as compared with what it would be in the case of the same nuclear installed capacity consisting solely of thermal reactors. This is still a long way short of the previously mentioned factor of 100; nevertheless, this reduction could make all the difference between a safe transition to a nuclear economy based on fertile material, in which high-cost uranium is acceptable, and the premature exhaustion of the cheap resources, followed by scarcity and the general penalisation of the nuclear sector. The sooner the fast reactors come on the scene the greater the advantage will be, and in the hypothesis that the present breakthrough in the nuclear sector is sustained it is most urgent that they should do so before 1990; this would to some extent justify the speeding up of the work.

All the same, it is clear that this speeding up is in no way prompted in the short term by the conservationist arguments set out above and that whether or not fast-reactor plants make their appearance in the near future will depend purely on their profitability; but here, too, their prospects are particularly favourable and justify the enormous interest being taken in them. Indeed, fast reactor power plants offer a whole range of advantages which are not found all together with any other class of reactor.

Their construction costs are comparable to, or at the very most only slightly higher than those of rival nuclear power plants. The greater complexity of the installations and of the techniques to be employed is offset by the extreme compactness of the reactor and its containment. The neutron economy over the fast neutron spectrum is relatively unaffected by the presence and, above all, by the composition of the absorbers in the core; consequently, the choice of construction materials is not restricted and it is possible to use inexpensive conventional alloys (austenitic or ferritic stainless steels) for, among other things, the fuel cans, the core structures and, of course, the circuits[5].

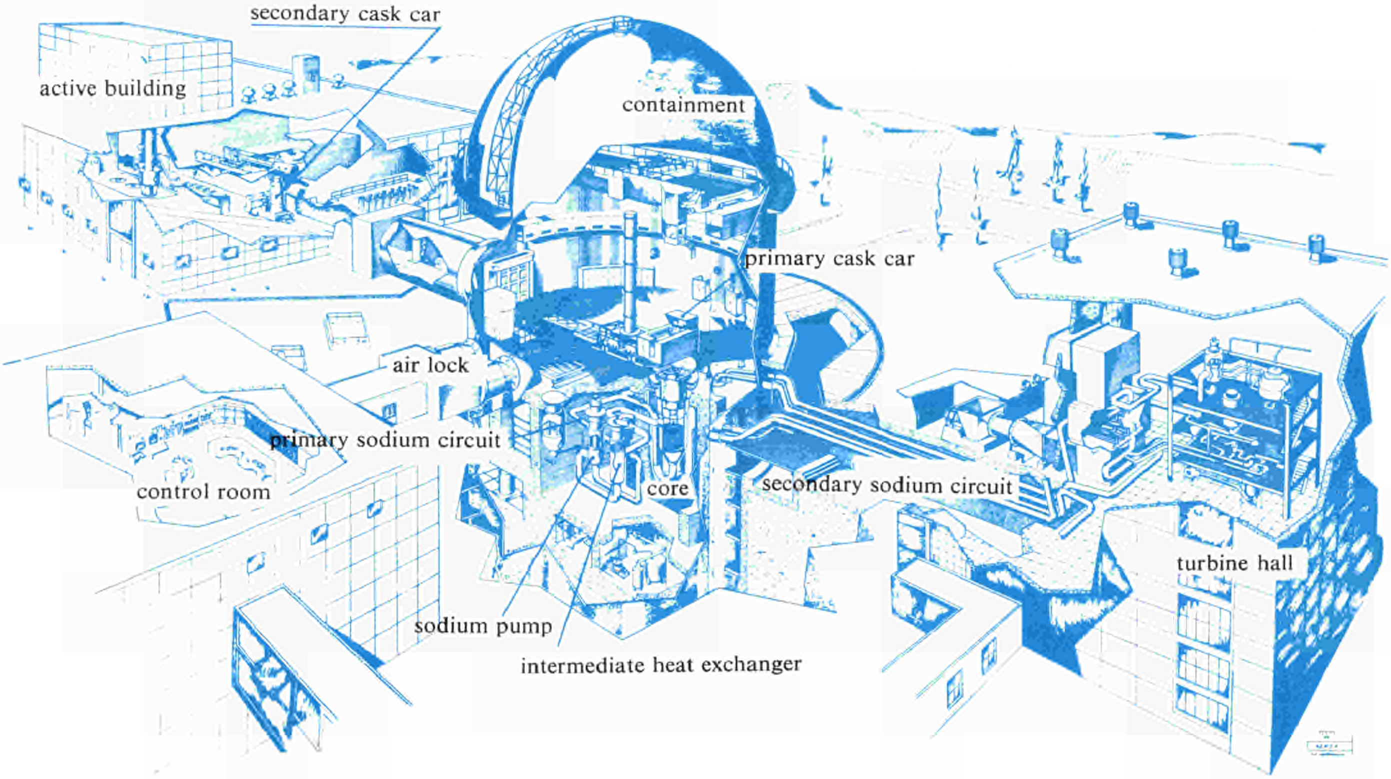
The influence of the fuel cycle cost on the electricity generating costs should be considerably lower than is the case with thermal reactors: i.e. from 0.5 to 1 mill/kWh[6] for the first fast reactor plants, falling to less than 0.5 mill/kWh for the later improved plants, as opposed to 1.5 to 2 mill/kWh for proven reactors. Here again the advantage is due to the breeding: the surplus of fissile material produced during operation of the plant constitutes a credit item on the balance sheet, whereas the consumption of fertile material has only a negligible effect. This means, moreover, that fast-reactor power plants would be practically unaffected by a rise in the prices of fissile material or natural uranium, since the interim interests to be paid on the fissile material immobilised both in-core and out-of-core are already almost offset by the breeding dividend in the case of the first fast-reactor plants and will be cancelled out entirely when the improved versions come on stream, whereas a rise in these prices would weigh heavily on proven-type and even advanced reactors.

In view of this combination of acceptable construction costs and a distinctly favourable fuel cycle cost, fastreactor power plants can be expected to show a profitability which, already marked at the outset, will be capable of a large measure of further improvement later on. This perfectability is not in itself sur-

5. At least when the coolant is sodium.

6. 1 mill = 10^{-3} US dollar.

RAPSODIE

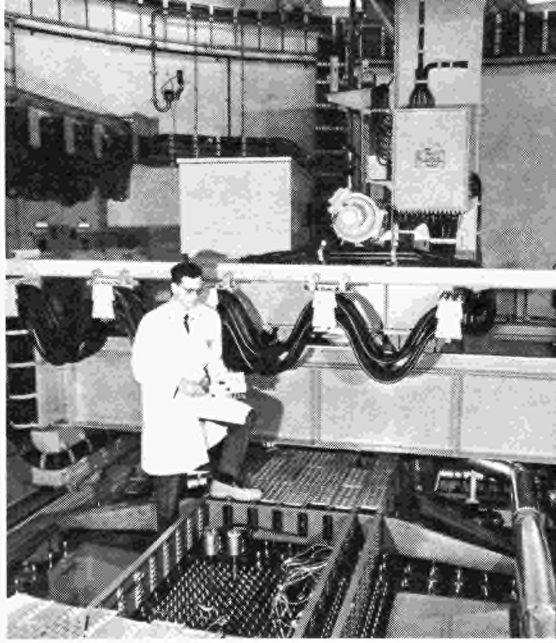


prising, for fast reactors are only in the earliest stage of their development and the concepts worked out to date are deliberately very conservative. Nevertheless, the capacity for improvement is there and it remains to ascertain the inevitable technological limits associated with the behaviour of the fuels and materials. As far as proven-type reactors are concerned, these limits are already known and have almost been reached, and the principal factors will henceforth be the effects of size, of duplicated construction and of detail simplifications. It is to be hoped that such simplifications, which lead to considerably reduced construction costs, will play a part in the case of fast reactors just as they do with thermal reactors, since the combination of high capital investment and very low operating costs is a priori not the optimum one. It would merely accentuate the effect of size, which already characterises the nuclear sector, by making it necessary to install very large units intended for base-load. For this reason the present fast-reactor reference power plants are all planned for an installed capacity of 1,000 MWe or more, and, if this proves to be the minimum competitive size, their initial commercialisation by about 1980 will by no means be facilitated.

The preferential fuel for fast reactors is still plutonium, which gives a better breeding ratio than uranium-233 or uranium-235. Since the contribution of fast-neutron fissions from fertile material (U^{238}, but also Pu^{240} or Pu^{242}) is a large one and since the poisoning effect due to the fission products has no serious consequences in the fast-neutron spectrum, there are no particular restrictions as regards isotopic composition, and it will be possible for the new fast-reactor power plants to be fed initially either with plutonium that has been bred in other fast-reactor plants, or, in the early stages, with plutonium extracted from thermal converters. In the latter case, moreover, the plutonium has a greater utilisation value than it would have if it were recycled in these converters, so that the introduction of fast reactors would also improve the profitability of thermal converters by providing an advantageous outlet for their plutonium and would thus help indirectly to keep the costs of nuclear electricity low.

There is no doubt that this latter consideration is responsible in ever-increasing measure for the interest that electricity producers are showing in the fast reactor family. To the extent that the large-scale introduction of light-water reactors could result in a rise in natural-uranium prices, fast reactors would remain the most effective counterweight for the stabilisation of these prices.

If there were nothing but fast-reactor power stations, in other words if the profitability and the doubling time of such plants enabled them to meet the demand unaided, there would be no more need for enriched uranium and it would be possible to avoid reliance on diffusion plants for isotope separation[7], with all the consequences that this entails as regards dependence on outside sources. It would merely be necessary to ensure a supply of fertile material, and the natural-uranium tonnages involved would moreover be far lower in proportion than would be



View of support plate, cable bridge and upper charging machine of SNEAK *reactor.*

required if it were necessary to supply thermal reactors, whether of the enriched-fuel type or not. Obviously, this situation is still a very long way off, but the fact remains that the introduction of fast reactors on an increasing scale to replace thermal reactors burning enriched uranium will correspondingly relieve the pressure on the existing diffusion plants or reduce the need for new isotope separation facilities.

This would be equally true if fast reactors proved so competitive that they were universally adopted in preference to thermal reactors and it were considered acceptable to start them up on highly-enriched uranium for a few cycles despite the economic handicap thereby entailed. Even then, since fast reactors are after all better converters than thermal reactors, the demand for enriched uranium would still be reduced.

Specific arguments in favour of the fast reactor family

Quite apart from these general considerations each major programme is motivated by specific arguments of varying importance.

In the United States the thinking of the *AEC* and the reactor constructors still differs appreciably. The *AEC* has so far attached a good deal of importance to the conservation of resources, and hence to the breeding factor, whilst at the same time recommending a comparatively gradual programme for the perfection of the fast reactor family—essentially of the components and fuel—before undertaking any major construction projects such as prototypes, first of the series, etc. At the moment the *AEC*'s programme for the next ten years consists primarily of a vast range of research and pre-commercial development work or of studies of general interest, and a substantial portion of its resources is being devoted to the design and construction of the *FFTR (Fast Fuel Test Reactor)* for experiments under a fast-neutron flux of 400 MWth.

The construction consortia (*General Electric*, *Westinghouse*, *Atomics International*, etc.), on the other hand, would prefer to cut short these preliminary steps and to embark on the empirical stage of prototypes in the very near future and then to launch the first commercial project before 1980. Strictly speaking, they would be doing so more from a spirit of competition than from internal necessity, since their investments in the light-water reactor types are still far from being amortised. Nevertheless, the utilisation of the plutonium produced in these light-water plants prompts the early introduction of fast reactors.

It is probable that these two trends will continue to exist side by side, especially in view of the fact that American firms are beginning to receive considerable backing from the utilities for these activities and will be only partly dependent on the *AEC* for the financing of their prototypes.

In this sense the American programme is, and will continue to be, undoubtedly the most highly diversified of all. The impression may have been gained that it has been marking time for the past few years, owing chiefly to a lack of new construction projects or of clear options. It would be presumptuous to conclude from this that America's current predominance in the nuclear market will cease with the advent of fast reactors, since even with the handicap of a slight initial lag American firms retain their advantages of size, reputation and ample financial resources.

In Britain the desire to maintain and exploit the lead already held and to evidence it as soon as possible by initial construction projects certainly outweighs all other considerations. This is confirmed by the accelerated construction of the *PFR*, by the decision to build a first 600 MWe power plant at the same time and by the reorganisations of the consortia, etc. The extent of this short-term commercial gamble is, of course, accentuated by the difficulties confronting the British consortia and by their meagre success hitherto in exporting the "national" nuclear power plants (*Magnox*, *AGR*, etc.). There is no certainty that the fact of being first in the field with fast reactors will prove to be a winning ticket in the long run, but the British are going all out for this early success—without, be it noted, any dissipation of effort or lavish spending—and are consequently compelling other national programmes to keep up a similar pace.

Naturally, the accelerated introduction of fast reactors would also be all the more justified in Britain because that country is already using nuclear energy on a considerable scale and will possess increasing stocks of plutonium from its *Magnox* and *AGR* power stations.

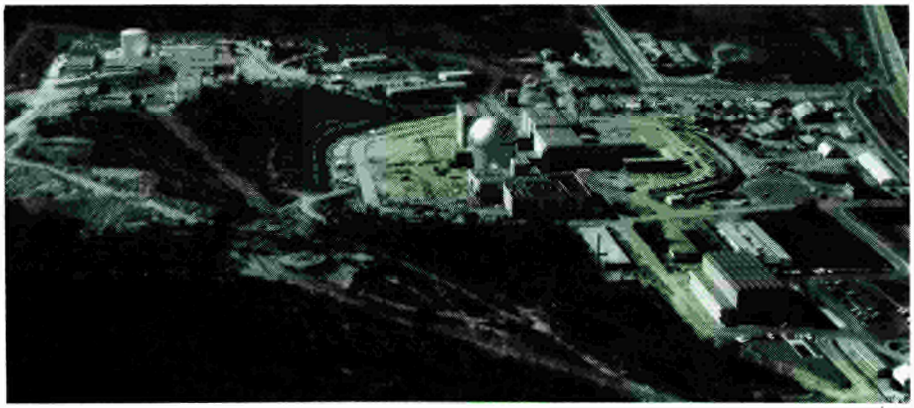
In the USSR, where, moreover, sources of fissile material and water power abound and the urgency is less, the programme shows an evolutionary pattern almost indentical to that in Britain: accelerated construction of a prototype plant with an equivalent power of 350 MWe (200 MWe being used for desalination) and simultaneous laying down of a 600 MWe plant; it is probable, however, that the Soviet programme includes more medium-term studies which are unconnected with initial commercialisation.

The priorities are not known. It would seem that the USSR is gambling almost exclusively on sodium-cooled fast reactors, even at the cost of starting them up on uranium-235, since in that country proven-type reactors have scarcely progressed beyond the demonstration plant stage and work on advanced converters has been suspended.

In the Community there is no uniformity of thinking or of ambitions in this field.

7. Such reliance is not inevitable, inasmuch as the exclusive use of converters fuelled by natural uranium for the purpose of supplying plutonium for fast reactors would allow diffusion plants to be dispensed with entirely; however, this "plutonium route" remains a deliberate choice and is not necessarily the most economic one.

Furthermore, the various programmes started later than those of other countries (which must therefore be caught up) and did not all get under way at the same time. The French and the German/Benelux programmes place the accent on the early construction of prototypes and on bringing forward the start of commercial operation. The Italians apparently intend to skip this stage and are concentrating on somewhat more advanced solutions, namely improved nuclear fuels, materials-testing reactors, etc., so that there is similarity between present Italian thinking and that of the *USAEC*.
In every case there is a manifest desire to develop home-based solutions and to be in a competitive position when commercial activity commences. That this is recognised is already reflected at the industrial level by a policy of selection and of combination on a national or multinational basis; for the moment, however, there is no sign of any all-Community solution.



Aerial view of part of Cadarache Nuclear Study Centre: *on the right the* RAPSODIE *zone, on the left the* MASURCA *zone.*

Probable evolution of the fast reactor family

The present prototypes and, after them, the "first-generation" power plants that will be constructed around 1975-80, will still have a fairly modest performance in comparison with what would theoretically be possible. They will represent a whole series of compromises necessitated by the present state of the art and of basic knowledge. The technological progress and increased knowledge that will result from the research currently in hand will undoubtedly enable the restrictions to be relaxed and more satisfactory performances to be obtained with fast reactor plants of the "second generation". Even now, however, it would be conceivable to build a first-generation power plant in the Community without entailing any major risks or unknown factors, as will be demonstrated by the 600 MWe prototype plants scheduled for construction in Britain and the USSR.

The fast-reactor power plants of the first generation will be sodium-cooled (with an outlet temperature of some 550-600°C) and will be fuelled with mixed oxides, or possibly carbides, of uranium and plutonium in ceramic form; the fuel elements will be arranged as clusters of pins, probably clad with stainless steel, and there will be no release of fission gases. The reactors will have a fairly soft neutron spectrum (the average energy of the neutrons being in the region of 100-200 KeV), a low breeding ratio and a long doubling time (15-20 years). There is reason to believe that these plants will already be more economic than those of other reactor families, chiefly because the overall cost of the fuel cycle will be low.
Later on, other cooling media such as helium or dry steam, other fuel elements and even other, less restrictive, concepts will certainly be tried out.
But on the whole, once this initial stage of demonstrating the viability of fast reactor power plants is past, it is likely that the second-generation activities will be concerned less with drastic revisions of concepts than with the steady improvement of performance: better neutron economy and higher breeding ratios, increased coolant outlet temperatures, higher specific power of the fuel or higher power density of the core, higher burn-ups, simplification of circuits, equipment, containments, etc.
At a still later stage, the full utilisation of fissile material resources will doubtless become the overriding consideration in determining the course of the activities.
There will certainly be no clearly marked frontier between "generations" of fast reactors. Such terminology serves primarily to enable a distinction to be drawn between the early commercial power plants of still modest performance which will be introduced first—no doubt on a limited scale—and the improved versions that will come into general use later on.
It is fairly obvious that fast reactors constitute a new genus of reactors rather than merely a new species and that the development work on them is still only in its infancy and will continue for a long time to come. The cost of this work, which is at present borne by the public authorities in all the countries concerned, is considerable: in the region of 200 million dollars a year in the Community, for example, and about the same elsewhere, and it will remain at this level for another ten or twenty years, if not longer. At all events it will be around the year 2000 before the savings resulting from the use of fast reactors will enable this expenditure to be recouped, and even then only if these reactors come into general use as envisaged.
That is why the fast reactor family, in particular, calls for the co-ordination of activities, credits and industrial policies and the setting up of an effective nuclear common market.
(EREA-A 1-3)

Bone marrow transplantation

Bone marrow transplantation is a promising method of treating individuals who have suffered accidental irradiation, but what can we do about the immunological conflict which follows?

HANS BALNER, *Radiobiological Institute TNO, Rijswijk, the Netherlands*

ONE OF THE hazards connected with the exploitation of nuclear energy is the risk of total body irradiation. There have, fortunately, been very few accidents since 1945, and one can only hope that there will never be many, but this is no reason to ignore the problem and the question of how to treat individuals who have been accidentally irradiated will inevitably have to be answered. Attempts to solve this problem have been made throughout the world for the last 20 years and one of the promising approaches is the transplantation of bone marrow; but even that therapy has its limitations,as we shall see. The purpose of this article is to review this method of treatment, to outline the difficulties which inevitably crop up and to indicate a number of ways in which they might be overcome. Finally, a word will be said about the experimental work on monkeys which is under way in the *Radiobiological Institute TNO, Rijswijk*, in association with Euratom.

Why bone marrow?

Amongst the living cells which are the first to suffer from total body irradiation are the rapidly proliferating cells of the hemopoietic system; they are the precursors of the red cells (erythrocytes), platelets (thrombocytes), and the white cellular elements of the blood (leukocytes). The erythrocytes are responsible for bringing oxygen to the tissues, the platelets to promote blood clotting; the white blood cells have the task of fighting against disease and, in general, against everything that is "foreign" to the body, whereby the lymphocytes (small leukocytes with a single nucleus) have the specialised role of producing specific antibodies (proteins circulating in the blood) and in general react against foreign substances. At low doses of irradiation the hemopoietic system may be only damaged, but at higher doses it will be completely wiped out, with the result that the individual is not only deprived of new supplies of erythrocytes and platelets, essential to its life, but is also stripped of its leukocytes and thereby of its "immunological" equipment. It is this breach in the body's defences which in many cases proves fatal because of overwhelming infections which take place within weeks after total body irradiation.

In man, the bone marrow occupies a central position in the production of cellular blood elements; it is in fact the only site of hemopoietic tissue (whereas in several animal species the spleen also contains significant amounts of hemopoietic tissue). In animal experiments, an intravenous injection of a suspension of bone marrow cells has proved effective in allowing otherwise fatally irradiated individuals to survive. When this type of treatment was first applied it was thought that the action of the injected cells might simply be of a chemical nature; but further animal experiments soon showed that the injection constituted a true graft: a small number of the precursor or "stem" cells settles in the appropriate places, thus repopulating the bone marrow and eventually supplying the life-saving mature red and white blood cells as well as the platelets. A man who has received a total body dose of anything from 600 to 1,000 roentgen should, on the basis of those animal experiments, be able to recover if he is given new bone marrow intravenously. Below this dose he would probably recover spontaneously, but beyond a dose of about 1,100 roentgen even bone marrow transplantation will not help. Other vital parts of the body will then have been irreparably damaged, especially the epithelial lining of the intestines. Unlike the bone marrow, this lining, once wiped out, cannot be replaced by transplantation.

Let us come back to the case of an individual having been exposed to a dose of 600-1,000 roentgen total body irradiation; if nothing were done, he would live for a few weeks at the most, since without a functioning hemopoietic tissue to produce new leukocytes, he would be prone to infections of all kinds and the lack of platelets would lead to major hemorrhages. Experiments carried out on animals have shown that this so-called "bone marrow syndrome" brings about death within 10 to 15 days in most species. Unless, of course, viable bone marrow cells are injected into the blood stream shortly after exposure.

The graft-versus-host reaction

Transplantation of bone marrow will not present major difficulties if it is the individual's own bone marrow which is reinjected (assuming, of course, that it was extracted before irradiation took place), or if an identical twin is available to provide the marrow. Under those circumstances the lymphocytes produced by the injected precursor cells will find themselves, as it were, in surroundings which are familiar, not foreign, and will therefore not react against the surrounding tissues of the new host.

However, in the case of a radiation accident, it is more likely that the bone marrow to be transplanted will have to be extracted from a non-identical individual.

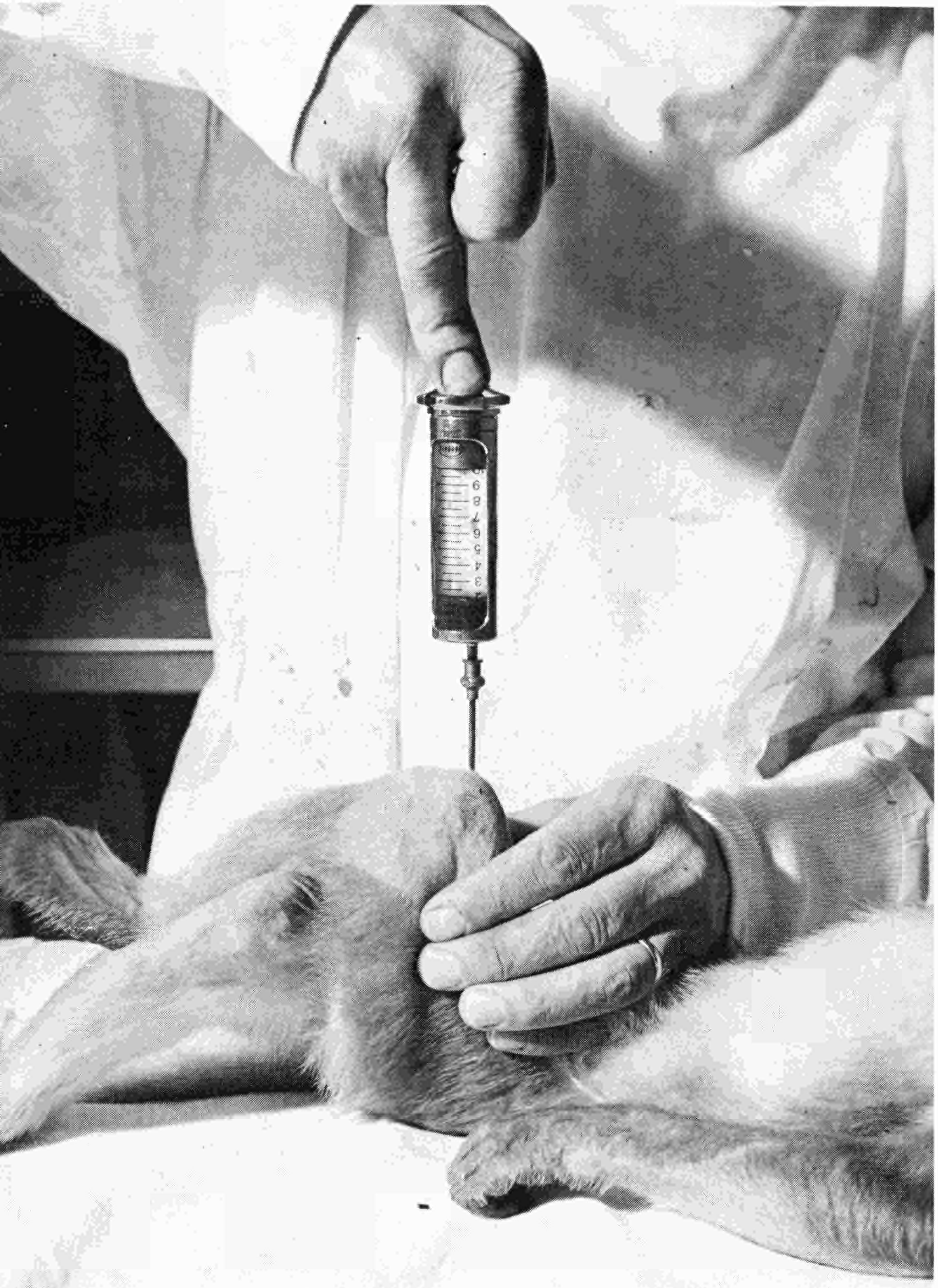


Figure 1: Extraction of bone marrow from the femur of an anaesthetised Rhesus monkey.

We can then expect certain complications of an immunological nature. After a few days, the injected cells will have settled and begun to produce lymphocytes, along with the other cellular blood elements. Within about two weeks, the new lymphocytes, as well as the mature lymphocytes already present in the injected cell suspension, will be able to recognise their environment as foreign. At this stage they will begin to perform their natural function, which is to react against anything foreign, in this case the tissues of the irradiated, defenceless host. We are then faced with a so-called "graft-versus-host" reaction.

This immunological phenomenon is in a way the reverse of the so-called homograft reaction, which is associated with transplantation in general; when a kidney, lung, heart, or practically any other foreign[1] organ or tissue is transplanted, a host-versus-graft or "homograft" reaction takes place, during which the foreign tissue is rejected, unless rigorous measures are taken to prevent such a rejection (immuno-suppression, see below). Actually, the only reason why the foreign bone marrow cells in the case mentioned above were able to settle and proliferate in the irradiated host is the total absence of host-type lymphocytes to fight against the injected donor-type cells.

It has been shown that each individual (except in the case of an identical twin) differs from another in the mosaic of his tissue antigens, the differences lying in the chemical composition of certain proteins of the membranes of the cells making up the tissues of each individual. It is these differences which the lymphocytes will detect and start reacting against, both in the graft-versus-host and the homograft reaction.

It might be argued at this stage that one method of solving the problem of "foreignness" as far as bone marrow transplantation is concerned, would be to ensure that everyone keeps an adequate supply of his own bone marrow just in case he should be accidentally irradiated. There is of course a natural reluctance of individuals to take such measures, but

1. by "foreign" we mean, in this context, tissue derived from an unrelated individual of the same species.

technically it is now possible to store bone marrow and keep it viable for future re-injection. A whole research programme, conducted by L. M. van Putten of this Institute (also under Euratom contract) was devoted to this subject. Although to our knowledge such prophylactic measures are not being taken anywhere, there could be a case for tackling the problem in this fashion, particularly in laboratories where the risk of exposure to radiation is high (although the accident rate has fortunately been very low, so far).

But what can we do to minimise the immunological conflict ensuing after the transplantation of foreign bone marrow? For one thing we can select a donor whose "foreignness" relative to the recipient is minimal. Experiments on mice and rats during the past 10 years have clearly shown that marrow grafts from donors which are rather similar to the recipient, as far as their tissue antigens are concerned, react less vigorously against the host and may indeed become "tolerant" to his tissue antigens. As we shall see later, several methods of tissue typing have been developed by which cells of different individuals can, as it were, be finger-printed and matched with each other.

Another approach is to weaken the graft-versus-host reaction after transplantation of the bone marrow, through immunosuppressive therapy, in much the same way as we can postpone or prevent the rejection of grafted tissue in a non-irradiated individual (suppression of the homograft reaction).

Yet another approach is to attempt to make the bone marrow of the donor more tolerant, that is less likely to attack the host, for instance by trying to eliminate the lymphocytes or their precursor cells from the marrow *before* it is injected. All three approaches have been adopted for experimental animals in our laboratory; we will now look at them in greater detail.

Tissue typing

The first step in tissue typing for human beings is, understandably, to carry out conventional ABO blood grouping. The principal antigens of the human red cells, the blood groups of the ABO system, have indeed been shown to be tissue antigens; but as it turned out there are many other antigens or tissue individualities which have to be taken into account. Unfortunately, most other human tissue antigens, unlike in mice and rats, are not recognisable on red blood cells. For those other antigens we have to turn to the white cells of the blood, which have been shown to be rather similar (in their antigenic make-up) to nearly all the other cells of the body. One can therefore assume that if a good match is found between donor and recipient on the basis of leukocyte typing, the fit will be valid for most of the other cells as well. The only reason why leukocytes are preferred for tissue typing is that they are readily available from the peripheral blood.

As is well-known, conventional erythrocyte typing is carried out in test tubes by means of an agglutination test, making use of specific antisera. Thus, an anti-A serum will clump only red cells carrying the A-antigen but not those without it. The methods used for "finger-printing" the white cells of the blood are basically similar to those used for ordinary blood grouping. The individuality of the cells is visualised by making them react with sera containing antibodies specifically directed against certain antigens. These antibodies are proteins contained in the blood serum of individuals that have been in contact with and have reacted against tissue antigens of other individuals. In the case of animals, it is possible to obtain such sera by deliberate immunisation with cells from another individual of the same species; antibodies against the individuality of the donor cells will then be produced. This is of course more difficult to realise for human beings. Fortunately it is possible to exploit sera taken from people having been given multiple blood transfusions or from women who have had multiple pregnancies. The usefulness of the latter sera stems from the fact that the foetus is basically a tissue graft, the mother often producing antibodies against the paternal antigens carried by the foetus.

If a sufficient number of such "typing sera" is available, it is possible, with the aid of a rather complicated computer programme (introduced by J. J. van Rood of Leiden University) to identify "single" antigens, that is, the characteristics of the leukocytes (and thus the tissues) of the individual that is being tested.

Figure 2: A bone marrow suspension can best be given by the intravenous route; the figure shows an intravenous injection given to a Rhesus monkey sitting in a chair.

Thanks to the work carried out in recent years, some 20 well-defined human leukocyte antigens can now be recognised. Many of these have been shown to be tissue antigens, in other words, antigens which are important for matching donor/recipient pairs for transplantation.

Typing leukocytes with antisera is not the only conceivable method of tissue typing. Others are being developed, such as culturing mixtures of lymphocytes in a test tube; lymphocytes from the potential donor and the recipient are made to grow together and the extent to which they "fight" against one another (which is

Figure 3: To assess the compatibility of various host/donor combinations, use is being made of skin graft survival times; the figure shows four skin grafts from various donors. The lower left graft shows rejection, the other three are still viable.

measurable) seems to determine the tissue compatibility between the two individuals. However, leukocyte typing with antisera remains the most practical and reliable method of tissue typing at the present time.

Altering the graft before transplantation

A second approach to tackle the graft-versus-host reaction is to try and modify the donor marrow before injecting it; the idea is to make it more adaptable to the foreign environment of the new host. This can be done in vivo (in the living donor) or in vitro (in the test tube) although in vivo conditioning of the donor is hardly conceivable for man, in view of the risks involved. For human bone marrow transplantation the modifications will therefore have to take place in vitro, that is after extracting the marrow from the donor. The actual extraction of bone marrow is a rather simple procedure but, because of its painfulness, must be carried out under anaesthesia.

As can be expected, the primary aim of research under this heading is to reduce the number or modify the activity of the lymphoid elements present in the bone marrow. The lymphoid precursor cells of the marrow are a mixed blessing inasmuch as they produce the mature lymphocytes which will provide the individual's defence mechanism against infections but which are also responsible for the dangerous graft-versus-host reactions, as we have seen. If the number of lymphoid elements (stem cells and mature cells) could be reduced selectively before injecting the bone marrow suspension, the overall situation might be improved, although one is then incurring the risk of making the host relatively defenceless against diseases. This is indeed a dilemma. A compromise solution could be achieved by reducing the lymphoid cell population in the marrow sufficiently to delay the onset of the graft-versus-host reaction, thereby giving the repopulating lymphoid system more time to acquire a certain "tolerance" toward the host. This type of adaptation seems to be possible: in the case of mice and rats (probably owing to the fact that fewer lymphoid elements are contained in rodent bone marrow) it takes several weeks after bone marrow transplantation before the graft-versus-host reaction sets in. During that time the donor marrow apparently adjusts to the new situation and can gradually become "tolerant" to the host tissues.

Many methods of inhibiting the lymphoid

part of the hemopoietic system have been tried. One of these is purely mechanical: the bone marrow is centrifuged in a so-called protein gradient system and a separation of the various types of cells is obtained due to the differences in their specific gravity (see below; programme of K. Dicke of this Institute). Alternatively, the marrow can be stored at different temperatures for a certain time; some aspects of the latter method have been worked out by G. Mathé and by D. W. van Bekkum, both under Euratom contract. In practice, however, the efficacy of storage at various temperatures has been somewhat disappointing.

Finally, there are methods which involve incubating the bone marrow cells with substances which have the property of killing off or selectively incapacitating lymphoid elements of the marrow. Somewhat promising in this respect, at least in rodent experiments, is antilymphocyte serum or ALS, a powerful new immunosuppressive agent.

Treatment after transplantation

In conjunction with tissue typing (to choose a relatively compatible donor) and selective elimination of lymphoid elements, something can yet be done once the transplantation has taken place. The basic purpose of such treatment of the host will once again be to incapacitate the lymphoid cell population, so that the graft-versus-host reaction can be held in check. Here too, use can be made of antilymphocyte serum and certain chemicals (cytostatic drugs). If the appropriate doses of ALS are given at the right time, it has been possible, at least in animal experiments, to subdue the immunological reaction sufficiently to keep the host alive. Unfortunately, his immunological defences are then reduced to a point where susceptibility to pathogenic bacteria and viruses is dangerously increased (see below).

The monkey programme in Rijswijk

Fortunately, there have been very few cases of accidental irradiation of human beings who had to be treated with foreign bone marrow; also the experience obtained by G. Mathé in a number of leukemic patients given foreign bone marrow after therapeutic total body irradiation is rather limited. But we did learn from all these cases that the grafting of foreign bone marrow in man gives rise to an extremely severe and usually fatal graft-versus-host reaction. For obvious reasons it will be very difficult to assess the relative merits of the mentioned approaches to mitigate this complication, by applying them to patients. A better understanding of the disease and how to fight it would depend on our being able to do actual experiments, having untreated control cases etc. This is clearly something that cannot be realised within the clinical situation and one therefore has to fall back on animal experiments and hopefully extrapolate results to man.

Mice and rats are the obvious first choice for such experimental studies. But as we have indicated above, rodents do not serve particularly well as experimental models for bone marrow transplantation in man: the graft-versus-host reaction in rodents sets in after months, not weeks, and is often of a relatively benign character, allowing many lethally irradiated animals to survive as so-called chimeras: the injected bone marrow repopulates the host's destroyed hemopoietic and lymphatic system and will become tolerant to the foreign environment. This state of "peaceful coexistence" does not readily occur in man, it seems. Thus, an experimental animal was looked for which would show the human type, acute and very severe graft-versus-host reaction. A species closely related to man was the obvious candidate for such pre-clinical experimental work; and indeed, when bone marrow transplantation was first tried in irradiated Rhesus monkeys by van Bekkum and collaborators in this Institute, it soon became clear that the monkey was an experimental animal particularly suited to solve the problems we were faced with in the clinical situation. This is what led to the joint "monkey programme" launched in this laboratory in 1960 in association with Euratom.

Figure 4: The appearance of the face of a Rhesus monkey showing some of the lesions typical for the acute graft-versus-host-reaction as described in the text (edema, skin lesions, general malaise).

Guided by prior extensive rodent research the optimal methods of bone marrow transplantation in Rhesus monkeys were soon established; pathological studies by M. J. de Vries revealed that also the histology (microscopic appearance) of the lesions produced by the acute graft-versus-host reaction in monkeys was identical to that seen in man. The monkey was thus indeed the ideal experimental subject to study this serious immunological complication which also occurs in man. All the mentioned approaches to mitigate it, namely tissue typing, the modification of the graft prior to injection as well as treatment of the host after transplantation of the marrow, have been tried in monkeys and the present state of affairs will now be briefly outlined.

Several methods of tissue typing were applied but, as in man, matching for leukocyte antigens turned out to be the most practical method. Numerous antisera were produced and tested; using a method very similar to the one applied by J. J. van Rood for human leukocyte typing (and also making use of his computer programme) we are now capable of identifying a number of leukocyte antigens of Rhesus monkeys. In the course of the last few years it was proven that such "finger-printing" and matching of Rhesus leukocytes provided a method of selecting the more compatible host/donor combinations for the transplantation of skin, for instance. A number of preliminary experiments have already indicated that this type of matching is beneficial also for the outcome of bone marrow transplantation experiments: the graft-versus-host reaction seemed to be milder in the matched combinations (see table).

Modifying the bone marrow graft before injecting it into the irradiated monkey recipient has not been very promising until recently. None of the in vitro methods mentioned above have significantly reduced the graft-versus-host reaction, with one exception: the selective elimination of lymphoid cells from the marrow with Dicke's gradient-centrifugation method. This approach has provided highly promising results in rodent experiments. The method is presently being worked out for monkeys and is already cautiously tried in cases of human bone marrow transplantation.

Although hardly applicable in man, certain kinds of in vivo treatment of the marrow donor have also been tried in monkeys. But even a method that was highly successful in rodents (pretreating the marrow donor with antilymphocyte serum) gave disappointing results in monkeys, so far. Another, not yet mentioned approach is the use of a different source of hemopoietic stem cells: fetal liver cells have hemopoietic capacity but seem to be immunologically less reactive, at least in mice. The use of fetal liver cells (instead of bone marrow) in monkeys showed few advantages and a number of serious drawbacks. And, once again, the method is hardly applicable to man.

There remains the approach whereby

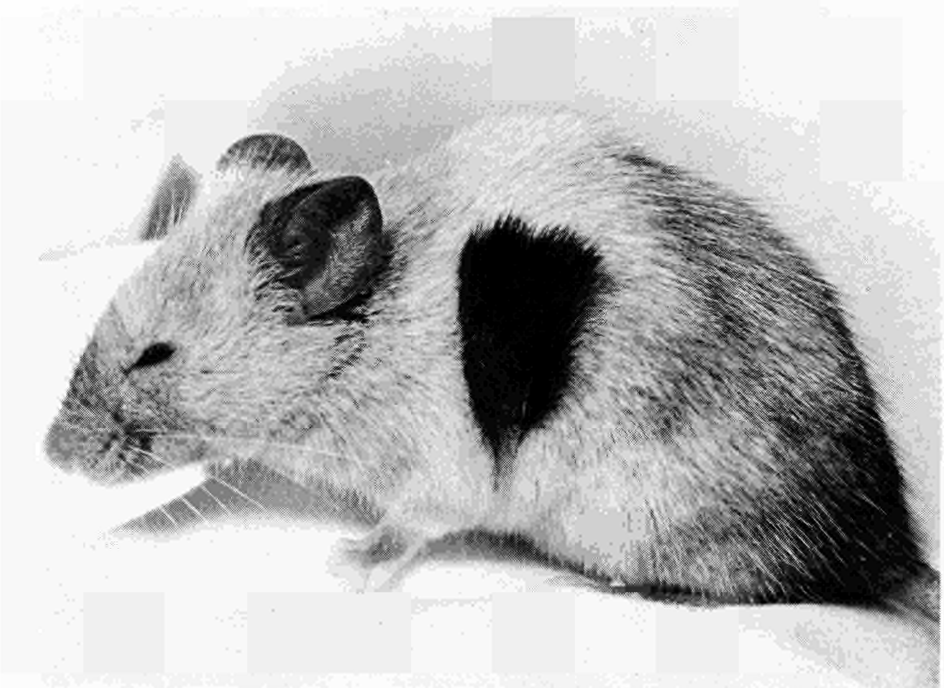


Figure 5: A "chimera" is an animal whose hemopoietic (blood forming) and lymphatic tissue (defence apparatus) is replaced by that of another animal, usually of the same species. The figure shows a grey mouse which had been lethally irradiated and kept alive by an intravenous injection of bone marrow obtained from mice of another strain (black coat); chimerism was proven by permanent survival of a skin graft obtained from a donor belonging to that second (black) strain.

Table I:

Influence of leukocyte matching on survival and on severity of the graft-versus-host reaction in irradiated, bone marrow treated rhesus monkeys.

(*from*: Histocompatibility Testing 1967, p. 267. Munksgaard, Copenhagen, 1967)

donor	host	host/donor compatibility	immuno-suppressive treatment	survival (days after irr.)	graft-versus-host reaction	probable cause of death
822	838	compatible for 1a	cycloph.-imuran	35	none	infections
	800	incompat. for 1a	cycloph.-imuran	15	severe	graft-v.-host reaction
	845	compatible for 1a	cycloph.	46	moderate	sepsis
	840	incompat. for 1a	cycloph.	46	slight	sepsis
884	870	selected for identity[1]	cycloph.	40	slight	pneumonia
872	866	random combination[2]	cycloph.	17	severe	unknown
872	874	random combination[2]	cycloph.	11	none (aplasia)	sepsis and hemorrhages
674	651	compatible for[3] 1a and 1b	cycloph.-methotrex.	160	none	endocarditis
668	643	id.	cycloph.-ALS	415	none	pneumonia

1. Reactivity pattern of the 12 sera typing for 1a and 1b, as well as of 26 out of 28 other antisera was identical for host and donor leukocytes.
2. Reactivity pattern for half of the 1a/1b sera and 7-10 of the 28 non-defined antisera was different for host and donor leukocytes.
3. Compatibility for 1a and 1b based on reactivity pattern of unabsorbed anti-1a and 1b sera (retrospective determination).
NB.: 1a and 1b were the first two major leukocyte antigens determined for Rhesus monkeys.

the host is treated *after* transplantation of the bone marrow. All the experience gained during years of rodent experiments was used to combat the graft-versus-host reaction in monkeys in this fashion. This is hardly the place to go into much detail with regard to the various treatment schedules. Let it just be said that application of the conventional immuno-suppressive drugs was insufficient to cure animals suffering from the graft-versus-host disease. Only when antilymphocyte serum was added to the therapeutic arsenal did we succeed in saving bone-marrow transplanted monkeys from the consequences of the graft-versus-host reaction. However, there was a price to be paid: in subduing the immune reactivity of the graft to such an extent, the host's susceptibility to bacteria and viruses was also greatly increased. Most of the animals died in the end of overwhelming infections.

After all we have said, the future of bone marrow transplantation in primates (man and monkeys) as a therapeutic measure seems somewhat uncertain. There is however sufficient reason to believe that a combination of better donor selection plus a perfected gradient-separation of the hemopoietic stem cells and maybe also a more judicious application of antilymphocyte serum and immuno-suppressive chemicals will soon make bone marrow transplantation in monkeys and man a less risky undertaking. Besides, progress is being made in certain other areas of transplantation research (such as inducing tolerance to tissue antigens) which have not been discussed here because of their complicated nature. Obviously a concerted research effort is necessary to solve the remaining problems of bone marrow transplantation in man and to us it seems that there is no better way of solving them than continuing the present research programme in our closest relatives, the monkeys. (EREA-A 8-4)

Blibiography: (1) D. W. VAN BEKKUM, M. J. DE VRIES: Radiation Chimaeras. *Logos/Academic Press, London* (1967). (2) H. BALNER: Bone Marrow Transplantation after Whole-body Irradiation; an Experimental Study in the Rat. *Thesis. Municipal University, Amsterdam* (1963), Euratom Report EUR 484 e (1963). (3) G. MATHÉ, J. L. AMIEL, L. SCHWARZENBERG: L'aplasie myélo-lymphoïde de l'irradiation totale. *Gauthier-Villars, Paris* (1965).

Getting European scientific and technological co-operation off the ground again

As a result of the resolution adopted by the Council of Ministers of the European Community on 10 December 1968, the "Scientific and Technical Research Policy Working Party" of the Medium-Term Economic Policy Committee (see *Euratom Review*, Vol VII (1968), No. 1, p. 30) was able to resume its work at the beginning of January 1969.

After reviewing the state of the work undertaken in 1967 and interrupted at the end of January 1968 because of differences of opinion between the Member States as to the desirability of extending co-operation to cover non-member countries, the Working Party first elected its new chairman, Mr. Pierre Aigrain, who has succeeded Mr. Maréchal at the *Délégation générale à la recherche scientifique et technique* (France), and decided on its programme.

Since then the Working Party has had to keep to an extremely tight schedule, particularly in order to be able to present to the Council by March 1969 a report on the possibilities of co-operation in seven priority sectors (information science, telecommunications, new means of transport, oceanography metallurgy, the abatement of nuisances and meteorology —see also pp. 2-9 of this issue).

At the same time the Party is carrying out a comparison of the programmes and research budgets of Member States, is studying a Community system for technical information and is examining the means of ensuring better co-ordination in the training of scientific personnel.

Finally, the Working Party is to undertake a preliminary analysis of the possibilities of co-operation with non-member countries, particularly those which are applying to join the European Communities.

Future Activities of Euratom

Meeting in Brussels on December 20th 1968. The Council of Ministers of the European Communities adopted the following resolution:

The Council

—hereby adopts a research and training programme consisting of a joint programme and of supplementary programmes for a period of one year from 1 January 1969;

—will establish, before 1 July 1969, further research and training programmes covering a period of several years;

—will examine, before 1 July 1969, the criteria and the principles necessary *to obtain a co-ordinated industrial policy in the nuclear field*;

—will, in the spirit of the resolution of 31 October 1967, supplemented by the resolution of 10 December 1968 on technological co-operation, and in the spirit of the resolution of 8 December 1967 on the future activities of Euratom, decide on *further activities capable of being undertaken in the Joint Research Centre, and will adopt the procedures for putting them into operation.*

The Council confirms that the employment of present Community staff on the supplementary programmes will not affect the Community's legal obligations in respect of such staff.

In the budget covering the 1969 programmes, the credits for expenditure for the second half of 1969 will be temporarily frozen while awaiting the result of the studies defined by the Council under item 1 above.

The joint programme, which accounts for a total of 24.03 million u.a., covers the following activities:
fast reactors (indirect action); heavy water reactors *(ESSOR)*; high temperature gas reactors (indirect action); plutonium and transplutonium; fusion—plasma physics; biology—protection of health; nuclear measurements and standards; industrial applications of isotopes (Eurisotop office); dissemination of information; education and training; co-ordinating activities.

The supplementary programmes, accounting for a total of 24.20 million u.a., will be as follows:
fast reactors (Ispra direct action); heavy water reactors (multi-purpose research, on light water and heavy water strings); high temperature gas reactors (direct action); technological problems (plant safety, determination of fissile material content); plutonium and transplutonium reactor physics; condensed state physics; nuclear materials; direct conversion of energy; biology—protection of health (application to medecine, biology and agriculture); information processing—*CETIS*; BR-2 reactor

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Power reactors in operation, under construction and planned in the Community
(Status as at 28 January 1969)

1. **The total net electric capacity of the nuclear power plants in operation, under construction or planned is 13,144 MWe, broken down as follows:**

	Country	Opera-tional	Under con-struction	Planned	Total MWe
a) *Proven-type reactors*					
Gas/graphite					
Chinon 1 (EDF 1)	F	70	—	—	70
Chinon 2 (EDF 2)	F	200	—	—	200
Chinon 3 (EDF 3)	F	480	—	—	480
St. Laurent 1 (EDF 4)	F	480	—	—	480
St. Laurent 2	F	—	515	—	515
Bugey 1 (St. Vulbas)	F	—	540	—	540
G 2 Marcoule	F	40	—	—	40
G 3 Marcoule	F	40	—	—	40
Fessenheim 1	F	—	—	650	650
Fessenheim 2	F	—	—	650	650
ENEL (Latina)	I	200	—	—	200
		1510	1055	1300	3865
Boiling-water					
KRB (Gundremmingen)	D	237	—	—	237
KWL (Lingen)[1]	D	155	—	—	155
VAK (Kahl)	D	15	—	—	15
ENEL (Garigliano)	I	150	—	—	150
GKN (Doodewaard)	N	52	—	—	52
KWW (Wurgassen, Weser)	D	—	640	—	640
		609	640	—	1249
Pressurised-water					
KWO (Obrigheim)	D	283	—	—	283
SENA (Chooz)[2]	F	266	—	—	266
ENEL (Trino Vercellese)	I	257	—	—	257
BR 3 (Mol)	B	10	—	—	10
KKS (Stadersand Elbe)	D	—	630	—	630
S.E.M.O. (Tihange s/Meuse)[3]	B	—	—	750	750
Nuclear Power Plant at Doel/Scheldt	B	—	—	750	750
		816	630	1500	2946
b) *Advanced converters*					
Heavy-water					
MZFR (Karlsruhe)	D	50	—	—	50
KKN (Niederaichbach)	D	—	100	—	100
EL 4 (Monts d'Arrée)	F	70	—	—	70
CIRENE (Latina)	I	—	—	35	35
		120	100	35	255

1. Excluding conventional superheat.
2. Franco-Belgian power plant (50/50).
3. With French participation (EDF) of 50 %.

	Country	Operational	Under construction	Planned	Total MWe
High-temperature					
HKG (Hagen/Dortmund)	D	—	—	300	300
AVR (Jülich)	D	13	—	—	13
KSH Geesthacht 2 (Schl.-Holstein)	D	—	25	—	25
Sodium/zirconium hydride					
KNK (Karlsruhe)	D	—	19	—	19
Nuclear-superheat					
HDR (Grosswelzheim)	D	—	22	—	22
		133	166	335	634
c) *Fast breeders*					
Phenix (Marcoule)	F	—	—	250	250
Na2 (German/Belgian/Dutch Group) (Aachen)	D	—	—	300	300
		—	—	550	550
d) *Type not yet decided*					
Schwaben, NeckarW, Stuttgart (Lauffen)	D	—	—	650	650
BASF (Friesenheimer Insel)	D	—	—	600	600
RWE (Biblis)	D	—	—	1000	1000
ENEL 4 (Lombardie)	I	—	—	650	650
ENEL 5 (. . .)	I	—	—	650	650
GKN 2 (Flessingue)	N	—	—	350	350
		—	—	3900	3900
TOTAL		3068	2491	7585	13144

2. Percentage breakdown of the reactors in operation and under construction, according to type

Gas/graphite	2,565 MWe	46%
Boiling-water	1,249 MWe	23%
Pressurised-water	1,446 MWe	26%
Heavy-water	220 MWe	4%
Other advanced converters	79 MWe	1%
	5.559 MWe	100%

3. Breakdown according to state of completion and by country

	Germany	France	Italy	Netherlands	Belgium	Community
Reactors in operation	753	1646	607	52	10	3068
Reactors under construction	1436	1055	—	—	—	2491
	2189	2701	607	52	10	5559
Reactors planned	2850	1550	1335	350	1500	7585
TOTAL	5039	4251	1942	402	1510	13144

Reasons for satisfaction, reasons for concern

In the introduction to the *General Report* on its activities during 1968, the Commission of the European Communities includes, among the *reasons for satisfaction*, the resumption of the meetings of the Working Party on Scientific and Technical Research Policy. Among the *reasons for concern* the Commission mentions the Euratom crisis:

"It is perfectly understandable that Member States should disagree on the programme of work to be accomplished by this Community institution, since the basic elements of nuclear research and its industrial follow-up have changed greatly since the European Atomic Energy Community was established, and their disagreement is even more understandable when it is remembered that in most of them the national programmes themselves are the subject of difficult rethinking. But the real cause of the crisis is the absence of any genuine political will for joint action. It is deeply disquieting that once again agreement has proved possible only on a provisional programme for one year—and even then half the projects are to be paid for by only five of the Member States out of six—while the 1969 research budget is still not adopted. If the Member States should get into the habit of financing only those projects which are of direct concern to them, the result would be a rapid and serious deterioration of Community action.

The interest of the Community as a whole must come first; and so it was not without a feeling of bitterness and impatience that the Commission participated in the deliberations at the end of the year when the Member States were discussing the reduction of their joint effort in the first large technological centre created by the Community. And this at the very time when American cosmonauts were flying round the moon and striving to outbid their Soviet rivals in the conquest of space!".

Extermination of the tsetse fly by sterilisation of the male

Towards the end of 1968 the Commission of the European Communities approved the financing, out of non-repayable aid from the second *European Development Fund (EDF)*, of a project concerning the Central African Republic. This project had been endorsed by the *EDF* Board at its 36th meeting, held on 15 October 1968; the sum concerned is 97,000,000 Frs CFA, or 393,000 u.a.[1]

The project consists in the application on a pilot scale of a method for the extermination of glossinae (tsetse flies), the carriers of animal trypanosomiasis, by releasing males sterilised by irradiation, with a view to adapting this technique for use on a wide scale in Africa. The experiment, which will last four years, will be conducted at Bangui, the capital of the Central African Republic, and in the surrounding jungle. It will be carried out with the aid of the biological departments of the *Joint Research Centre*. The work will be entrusted to the *Institut d'élevage et de médecine vétérinaire des pays tropicaux (IEMVT)*. This project is one of the many investments made by the *EDF* (1st and 2nd Funds) in this country with the aim of developing and improving stock breeding (see also *Euratom Bulletin*, Vol. V (1966), N° 1, p. 4).

1. one unit of account = 1 US$.

Testing of a Vortex twisted-tape element in the Kahl reactor

Under a research contract with Euratom the German firm of *AEG-Telefunken* and the French firm of *SNECMA (Société nationale d'étude et de construction de moteurs d'aviation)* are developing a high power density boiling-water reactor based on the twisted-tape or *Vortex* principle. Fuel assemblies of this type are fitted with helical metal strips between the rods of which they are made up, so that a twisting motion is imparted to the water/steam mixture. Centrifugal force projects the water in the mixture onto the heat-producing rods, which results in a considerable improvement in the heat transfer properties.

A fuel assembly of this design was first inserted in the nuclear reactor at Kahl, Germany, on 5 November 1966. The purpose of this irradiation experiment was to demonstrate that the presence of twisted tapes does not entail any unusual corrosion or scaling problems.

After six months' exposure the assembly was subjected to its first visual inspection in the plant's decontamination pool by means of an underwater television camera. The mechanical properties of the assembly were found to be excellent and no signs of corrosion or unusual deposits were observed.

Irradiation was then continued up to the beginning of September 1968, when

the assembly was visually inspected for the second time. As on the first occasion, this inspection confirmed the assembly's excellent corrosion resistance. It was therefore decided to continue the irradiation experiment in the Kahl reactor for an additional period of about 12 months.

In January 1969 the assembly had built up a burn-up of over 6,000 MWd/t. The maximum rod power attained by then was 354 W/cm.

In order to complete the experiment carried out in the Kahl reactor, which is of the natural convection type, preparations are being made for tests in a forced-convection loop in the *AEG* laboratories at Grosswelzheim, in the course of which rod and tape vibration and relative motion will be measured.

Visual examination of an irradiated Vortex *assembly on TV screen.*

A recent economic study comparing the Würgassen nuclear plant (640 MWe) with a plant of the same rating but equipped with an optimised twisted tape reactor showed that the latter opens the way to very considerable savings—of the order of 5-6%—in generating costs.

Stresa symposium on nuclear electronics

The contribution of electronics to the study of nuclear phenomena will be the subject of a symposium to be held at Stresa, on the banks of Lake Maggiore, from 6 to 8 May 1969, under the sponsorship of the American *Institute of Electrical and Electronics Engineers* and several Italian organisations and with the co-operation of the Commission of the European Communities.

The Congress will be in seven sessions, devoted respectively to preamplifiers and amplifiers, timing problems, nuclear spectrometry, miscellaneous techniques, the use of on-line computers and data processing in nuclear experiments, the theory and applications of statistics and standardisation of equipment.

There will also be a comprehensive exhibition of equipment used in this sector.

Technical Novelties

In its "Technical Notes" series the Commission of the European Communities recently published information on the following six devices and processes, which were developed under the Euratom research programme:

—*Thermal insulation for LPG tanks:*
At a distance of a few millimetres from the inside surface of the tank a porous, elastic lining is installed which surrounds the liquid. The interspace between the tank wall and the lining becomes filled with the liquid's own vapour and thus forms an insulating layer (see also *Euratom Bulletin*, Vol. VI (1967), N° 3, p. 96).

—*Servo-control device for travelling gantries and cranes:*
This device was designed with the aim of providing extremely accurate control of a travelling gantry or crane by an operator standing in the immediate vicinity of the load. The load is surrounded by a frame equipped with a handle which the operator holds in his hand; inside the frame are a number of movable rollers. When the operator wants to displace the load horizontally he moves the frame in the desired direction. The reaction of the load to this displacement repulses the appropriate rollers in such a way that, via microcontacts, the gantry is set in motion in the right direction.

—*Pneumatic level-gauge for liquids*:
The liquid level can be determined accurately (to within 0.1 mm) from the vertical displacement of a measuring head equipped with a pneumatic system which enables it to follow closely the movements of a float.

—*Electromagnetic flow-type viscosimeter:*
The liquid whose viscosity is to be measured is caused to rotate in an annular channel by means of electromagnetic fields which act on the entire mass of the liquid. The viscosity is determined by measuring the speed of rotation of the liquid and the total force acting on it. With this method it

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is possible to measure viscosities of the order of one centipoise.

—*Experimental and control rod for nuclear reactors:*
This rod, consisting of two rotating parts, each of which has an eccentric bore, extends the range of applications for reactor control elements; it can be used in particular as: a) a shim rod, b) a fine-control rod with directional effect, c) a measuring tube, and d) an irradiation channel.

—*Control box for travelling gantries or cranes:*
The box is equipped with three tumblers which are actuated by the operator's thumb; each tumbler has several positions, giving operational control in both directions at two different speeds.

Enquiries for further details on these devices and processes, with a view to their application, should be addressed to the Commission of the European Communities, DG XIII, Direction A, 29, rue Aldringer, Luxembourg.

Ispra 1961-1967

The Ispra Establishment of the *Joint Research Centre* takes stock of seven years of work in a book recently published by the *CID*. The book is in three volumes.

Volume I ("Physics") deals with reactor physics, physics of matter and automatic information processing, Volume II ("Nuclear Materials") with the chemistry of nuclear materials and nuclear materials research and development, and Volume III ("Engineering") with mechanical engineering and heat transfer, electronics and automatic control, and direct conversion by means of thermionics.

The book (which bears number EUR 3940 e I-III) is available at the price of $ 6 per volume from *CID*, 29, rue Aldringer, Luxembourg.

Behaviour of granular material

The proceedings of a conference held in Jülich (Germany) in March 1968 are now available, under the title "Problems of the pebble bed and granular material". The book includes 20 papers, followed by discussions, on the flow and storage of bulk solids, the flow of a pebble-bed, the pressure distribution in bins and hoppers, pebble-bed models for the molecular theory of simple fluids, and several other related topics (see also *Euratom Review* Vol. VII (1968) n° 4, pp. 118-123, "Does a pebble-bed behave like a fluid?" by D. Bedenig).

The book (which bears number EUR 4190 d/e) is available at the price of $ 10 from *CID*, 29, rue Aldringer, Luxembourg.

Addendum

The following sentence should be added to Chapter II, 2, of the special issue of *Euratom Review*, which appeared as a supplement to Vol. VII (1968) under the title "Survey of the Nuclear Policy of the European Community": "Since February 1967 *Brown Boveri et Cie* has been in a position to tender for nuclear power stations equipped with *AGR* reactors in West Germany, under the terms of a licensing and technical collaboration agreement concluded with British firms".

The IAEA asks the Commission to help prepare its International Nuclear Documentation System

The *International Atomic Energy Agency* recently contacted the Commission of the European Communities concerning the preparation of its *INIS (International Nuclear Documentation System)*. The *IAEA* proposes an arrangement whereby it could—under terms which are still to be negotiated—benefit from the experience accumulated by the Commission's *Centre for Information and Documentation (CID)* which has been running an automatic documentation system for several years.

This question, which also concerns the six Member States, still has to be discussed through the usual channels.

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