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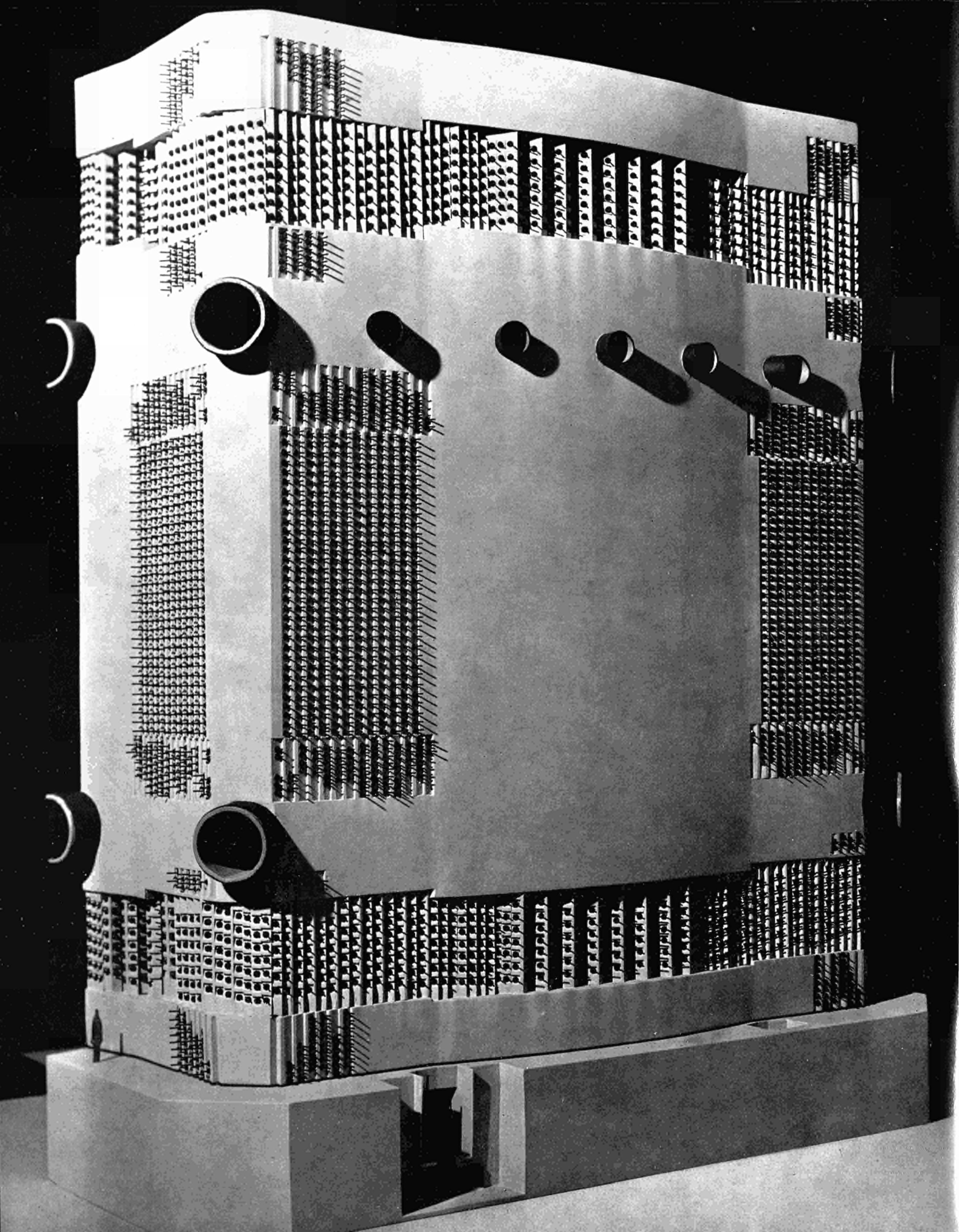

Quarterly Information Bulletin of the European Atomic Energy Community (Euratom)

1966-2

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Model of the EDF 3 *reactor (see page 56)*

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The Community's mission is to create the conditions necessary for the speedy establishment and growth of nuclear industries in the member States and thereby contribute to the raising of living standards and the development of exchanges with other countries (Article 1 of the Treaty instituting the European Atomic Energy Community).

On 8 April 1965, the Six signed the Treaty establishing a single council of Ministers and a single executive Commission for all three European Communities—the European Coal and Steel Community, the European Economic Community and the European Atomic Energy Community. This treaty can be expected to enter into force in the near future.

The Euratom Commission has always been in favour of this merger, being convinced that it would constitute a further move towards the construction of a united Europe as well as providing a considerable stimulus to Euratom's own activities. However, this is merely the prelude to an amalgamation of the Communities themselves and to the preparation of a single treaty which will supersede the three existing ones.

Developments must hence already be regarded from the viewpoint of a progression towards a uniform and unified structure. This does not mean, of course, that certain features of the three present treaties will not survive, but a suitable juridical framework will have to be devised to accommodate them. What is necessary, however, is to take a fresh look at the provisions of each treaty and, particularly, to decide, in the light of the experience gained in the course of their implementation, the extent to which a given clause or provision, at present applicable to a single field, could be adapted to Community objectives on a wider canvas. These are habits of thought which will inevitably make for the evolution of a whole which, constituting more than the sum of its parts, will represent the veritable synthesis of three units.

What contribution can the European Atomic Energy Community make to this development, by virtue of the provision of its own treaty and the experience which it has acquired over the past few years? The first point to be made here is that, like its elder sister, the European Coal and Steel Community, it was devoted to the development of a specific branch of the economy. Not all the problems to which Euratom has been obliged to seek solutions, however, can be said to come exclusively within the nuclear ambit. The Treaty of Rome itself sites Euratom's activities within an extremely wide framework. To quote Article 1: "It shall be the task of the Community to contribute to the raising of the standard of living in the Member States and to the development of interchange with other countries by creating the conditions necessary for the speedy establishment and growth of nuclear industries". Article 2 then gives a detailed list of the tasks *devolving upon the Community in the attainment of these objectives. This list has the merit of providing concrete instances of precisely what Euratom is required to do. We shall in this editorial single out the first of them, i.e. "The Community shall . . . develop research and ensure the dissemination of technical information", and then formulate, on this basis, a reply to the question posed.*

The dissemination by Euratom of the knowledge acquired at the establishments of its Joint Nuclear Research Centre, which it finances and manages directly, has not given rise to any particular difficulty. In fact, since this knowledge is the fruit of the work carried out by its own researchers and other employees, it was only natural that Euratom should appropriate it entirely and be at liberty to communicate it in accordance with the spirit of the Treaty, i.e. without discrimination.

On the other hand, intractable problems arose at first as regards the work entrusted to public and private bodies under research contracts. By claiming as full an ownership of the results of such work as in the case of the research projects conducted at the Joint Centre, Euratom would have been in danger of acting inconsistently with its terms of reference, namely the task of "creating the conditions necessary for the speedy establishment and growth of nuclear industries". Indeed, the effect of such a harsh policy would have been to encourage a passive attitude on the part of firms which were still venturing very timidly into the nuclear sector. As regards the opposite policy—that of allowing research contracts to be transformed into subsidy agreements—this would have been a flagrant breach of the Treaty.

In order to solve this dilemma, Euratom sought compromises which it was gradually able to define in the light of subsequent experience, reconciling the industrial and commercial interests of the contract-holders with the exigencies of the Community. Without going into the details of these solutions, we can say that they enable the contract-holder to enjoy, under certain conditions, some measure of preference in the application of the knowledge accruing from the contract, and that they recognise the value of the experience he contributes. Consequently, Euratom's research contracts are no longer merely instruments for the supply of know-how but are also a medium of industrial promotion.

By bringing up the problem of the dissemination of technical know-how before considering the actual research, we are in a sense putting the cart before the horse. There is, however, a logical reason for this reversal of the natural order: since research is not an end in itself but merely a means of acquiring knowledge, it is after all natural to be concerned about the goal before considering the means of attaining it. And the fundamental goal is in fact industrial promotion.

What is true of the research carried out under contract is also true of research conducted within other frameworks, e.g. that of the Joint Centre or that of "associations", under which the Community participates in a research project. In this context the Joint Centre is a tool which is not without originality, since it represents the pooling of material and human resources for the execution, on the basis of fairly long-term programmes, of work whose importance is acknowledged by all the Member States.

In short—and this is the point we wish to make—Euratom has not only supplied a mass of scientific data in return for the funds allocated to it, but has also tested and developed on a European scale a whole series of devices and methods designed to stimulate the emergence of a powerful nuclear industry.

Thus what Euratom had to do was to fashion for itself, so to speak, a set of tools, whilst taking account of certain specifically nuclear requirements and, above all, of numerous exigencies dictated by the industrial structure of the Member States. It follows, in the light of the foregoing, that these tools could be adapted for purposes of research and industrial promotion in spheres other than that of nuclear energy, e.g. space, electronics and aeronautics.

Hitherto we have been dealing with the Community's own nuclear research programme and the dissemination of the data issuing from it. However, no programme, whether it be on a Community or on a national level, can thrive in intellectual isolation; on the contrary, it must be able to benefit from the results of research previously or still being conducted under other programmes with similar objectives.

This requirement is so obvious as to require no underlining. On the other hand, the information and documentation activity that it involves is deserving of emphasis, because this is becoming more difficult every day.

The difficulties do not stem from any reluctance to publish scientific results; on the contrary, it is the very abundance of published infor-

mation that necessitates the spending of more and more time on locating the data which are relevant to a given scientific or technical problem. What in fact frequently happens is that the researcher, discouraged by the tedious nature of the work that awaits him if he wishes to collect adequate documentation himself, or—should there be an information centre at his disposal—by the inevitable lapse of time in the provision of such material, decides to do without it.

But sound administration requires that the researcher should have at his disposal all published information relating directly or indirectly to the field he is exploring. This will enable him to save himself unnecessary work, to avoid following a false trail, or even to discover that the problem concerned has already been solved and that he could more profitably turn his attention to the next one.

It would be both laughable and tragic if we were to allow the advance of nuclear science and technology in Europe to be held up merely because we would not deign to pick up information which is public property. In order to combat this danger, Euratom has taken various measures, two of which deserve special mention.

One of the potential barriers to the transmission of information is the language in which it is conveyed, especially, as far as the Western world is concerned, when this is a language such as Russian or Japanese. Euratom has therefore created a reference journal, entitled "Transatom Bulletin", in which are listed all documents of nuclear interest which were originally published in a "difficult" language but have been or are being translated into a Western language.

But Euratom's most ambitious undertaking in the information field is undoubtedly its automatic documentation project—the biggest of its kind in Europe—which is now in the final development stage and will shortly be taken into service. This project is based on a combination of man's analytical and critical faculty with an electronic computer's ability to store a virtually unlimited number of data and to perform even highly complex operations in fractions of a second. The user will merely have to ask a question; the machine, or rather the team of experts who operate it, will be able to give him a rapid answer in the form of a list of books, articles and reports containing the information he is seeking.

Euratom's automatic documentation system is certainly one of the least specifically nuclear aspects of its activities. Although it was designed to provide efficient retrieval of information in a well-defined sector, it is nonetheless fundamentally versatile. If its usefulness is confirmed, there would be no great difficulty about extending its application to the numerous other fields in which a rising flood of information is creating similar problems.

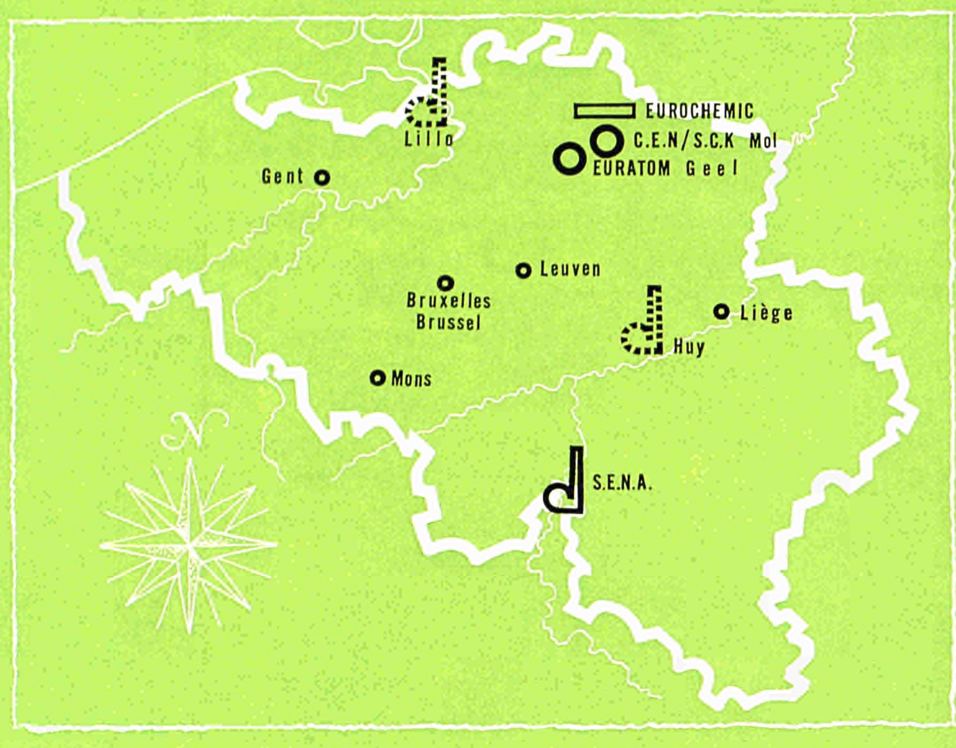
We have already spoken of industrial promotion as a basic objective of Euratom's activities. In this field there is one facet of Euratom's experience which is bound to be useful, and this is the procedure for setting up target programmes on nuclear power production goals and the investments called for.

This principle is already well-known in the other Communities, as in the case of the High Authority of the E.C.S.C., which sets out overall programmes, objectives and forecasts, and when, within the framework extended to cover the three Communities, the preparation is undertaken of a general medium-term economic policy programme. However, the studies which the Euratom Commission has had to carry out, particularly in connection with the recently published target programme, relate to the period 1970-2000, i.e. a period extending beyond the limits of the estimates arrived at in the other two cases.

There are plenty of other sectors in which Euratom can make a contribution to the common interest. Mention can be made of the experience gained as regards patents. The notion of a "European patent" is not new, but there is still a great deal of ground to be covered before it becomes a reality. What Euratom can contribute here is its solid every-day experience acquired through the filing of several hundred patent applications within the framework of a six-nation industrial community.

The list of examples could be extended by reference to such widely differing activities as the supplying of nuclear fuels on a Community scale and the compilation of a multilingual scientific and technical glossary.

From this, albeit brief, survey of some of its activities it can be seen that the European Atomic Energy Community is not such a highly specialised organisation as it appears to be. Its gradual integration into a single, wider, Community is bound to facilitate the accomplishment of the task assigned to it by the Treaty of Rome. There can be no doubt, however, that although Euratom will benefit by entering a much broader-based alliance, it will not come in empty-handed.



Mol — conventional and nuclear energy side by side.
Here we see part of the Belgian Nuclear Studies Centre (CEN) *and, in the background, two coal-fired electricity generators.*

NUCLEAR ENERGY IN BELGIUM

As far back as the pre-1940 period, Belgian industrialists had acquired wide experience in the mining and processing of radioactive substances, for there is a major deposit of uranium-bearing ore at Shinkolobwe, in Katanga. At that time, Belgium was the world's leading producer of uranium.

Even so, it was not until 1947 that nuclear research was given an official send-off in Belgium, with the launching of the *Inter-University Institute for Nuclear Physics*, which in 1951 became the *Inter-University Institute for Nuclear Sciences*. This body is responsible for initiating, promoting and coordinating fundamental studies relating to the nuclear sciences in the higher education and research establishments of Belgium.

In 1950, the *Atomic Energy Commission* was set up with the object of encouraging and coordinating all Belgian nuclear activities. In 1952, the Commission launched the *Study Centre for the Applications of Nuclear Energy*, which was in 1957 renamed the *Nuclear Studies Centre (CEN)*, and given the specific task of undertaking all technological research connected with the use of nuclear energy.

Resources

The laboratories whose work is coordinated by the *Inter-University Institute for Nuclear Science* employed 150 research scientists in 1965. The equipment at their disposal is considerable, and includes:

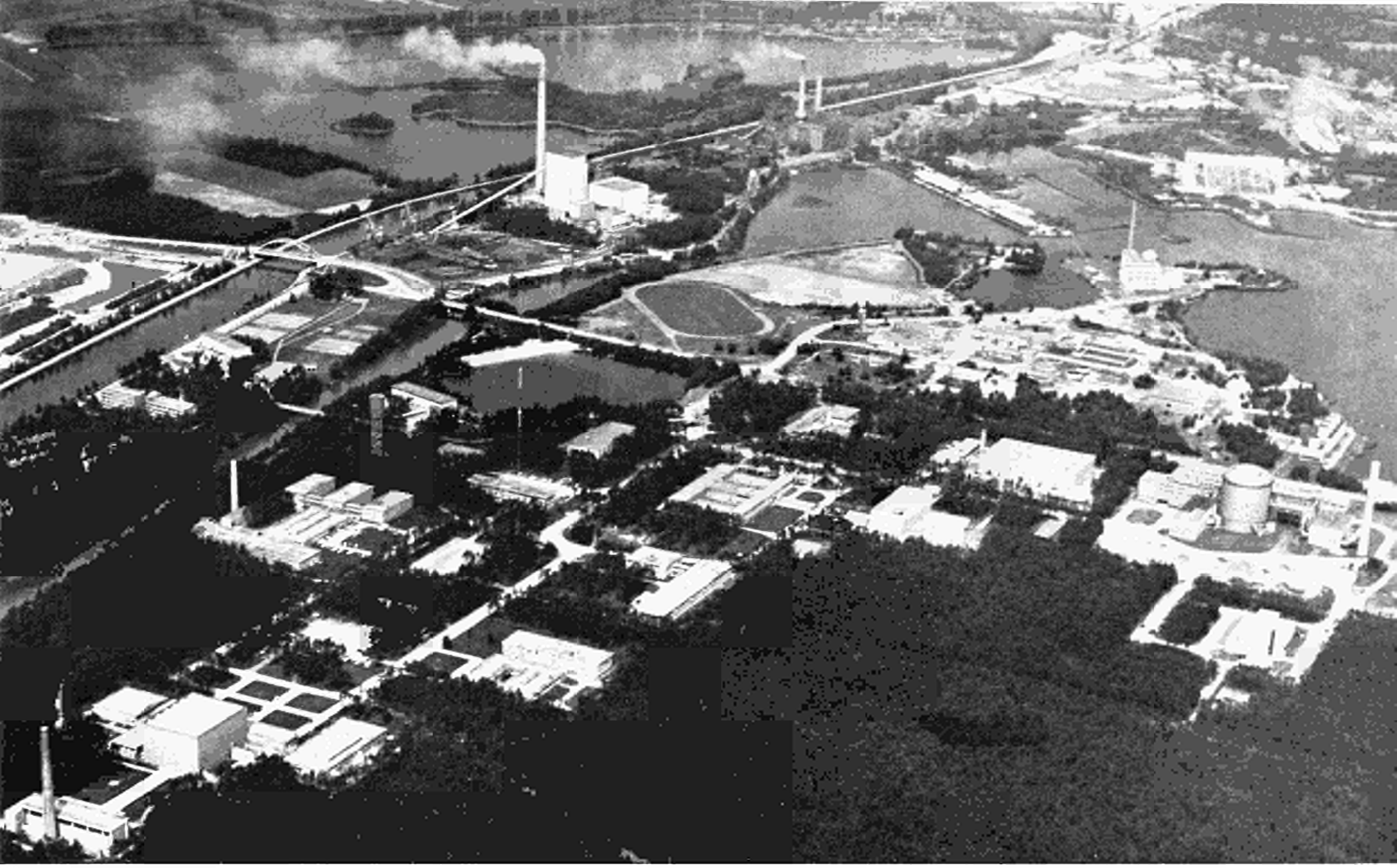
- a pool reactor, rated power 15 kW (*University of Ghent*),
- a 12 MeV deuteron and 24 MeV alpha cyclotron (*University of Louvain*),
- a van de Graaff 4 MeV electron accelerator (*University of Louvain*),
- a Cockcroft-Walton 1.4 MeV deuteron or proton accelerator (*Polytechnical Faculty, Mons*),
- a van de Graaff 0.4 MeV accelerator, employed as neutron generator (*Polytechnical Faculty, Mons*),
- a van de Graaff AN 400 accelerator for all charged particles up to 0.4 MeV (*University of Liège*),
- a van de Graaff 2 MeV proton and deuteron generator, with energy-stabilized and analysed beam (*University of Liège*),
- an 80 MeV linear electron accelerator (*University of Ghent*),
- a specialized installation for interpreting bubble-chamber films (*High Energies Laboratory, Brussels*).

In 1965, the sums made available to the Institute by the public authorities totalled 2.15 million dollars.

Founded in 1952, the *Nuclear Studies Centre (CEN)* occupies a site of 1420 acres at Mol, in northern Belgium. Investments to date amount to nearly 70 million dollars.

The installations comprise three reactors and two critical assemblies; chemistry, metallurgy, physics, electronics, radio-biology and medical laboratories; and the requisite ancillary services.

The BR-1 reactor, which started operating in 1956, is an air-cooled natural uranium and graphite research reactor, with a 4 MW thermal capacity. For many years, it was used for experimental purposes, for training personnel and for producing radioisotopes. Since the end of 1964, its operating power has been reduced to a few hundred kilowatts, as most experimental work is now carried out in the *BR-2* reactor.



EUBU 5-5

RÉGINALD LAMARCHE AND AIMÉ VAES,
Belgian Atomic Energy Commission

The *BR-2* is a very high neutron-flux reactor for studying the behaviour of materials under intense irradiation and for producing radioisotopes of high specific activity. The *BR-2* has a rated capacity of 50 MW(th) and produces a fast-neutron flux, with a power exceeding 100 keV, of 5×10^{14} n/cm² sec and a thermal-neutron flux of 9×10^{14} n/cm² sec. Since 1960, the *CEN* has been associated with Euratom in the operation of this reactor and its ancillary installations—dismantling cell, medium-activity laboratory, and the critical-reactor model called *BR-02*. This model is a vital factor in the operation of *BR 2*, as experiments can be prepared in it and then carried out in the reactor without necessitating a prolonged shutdown. Although it has a much lower neutron flux, the model can be used, for instance, to predict exactly the flux distribution in *BR-2* during a given experiment; thus it neatly rounds off a group of installations in which irradiations can be effected on behalf of the *CEN*, and more especially of foreign scientists engaged on experiments.

The *BR-3* ia a 10.5 MWe power reactor, of the pressurised water type, which was finally earmarked for training the staff of nuclear power plants of the future. Since its commissioning in 1962, it has contributed nearly 100 million kWh to the grid. After August 1964, it underwent conversions with a view to carrying out experiments with a *Vulcain* core.

The *CEN* also possesses, jointly with the *S.A. BelgoNucléaire*, an important laboratory for studies and work on *plutonium*.

The *CEN* employs a staff of about 1,000, roughly a third of whom are university graduates and engineers.

Mention must also be made of the important function which has been and is still being fulfilled by the *CEN* in training personnel of all levels in nuclear science and technology.

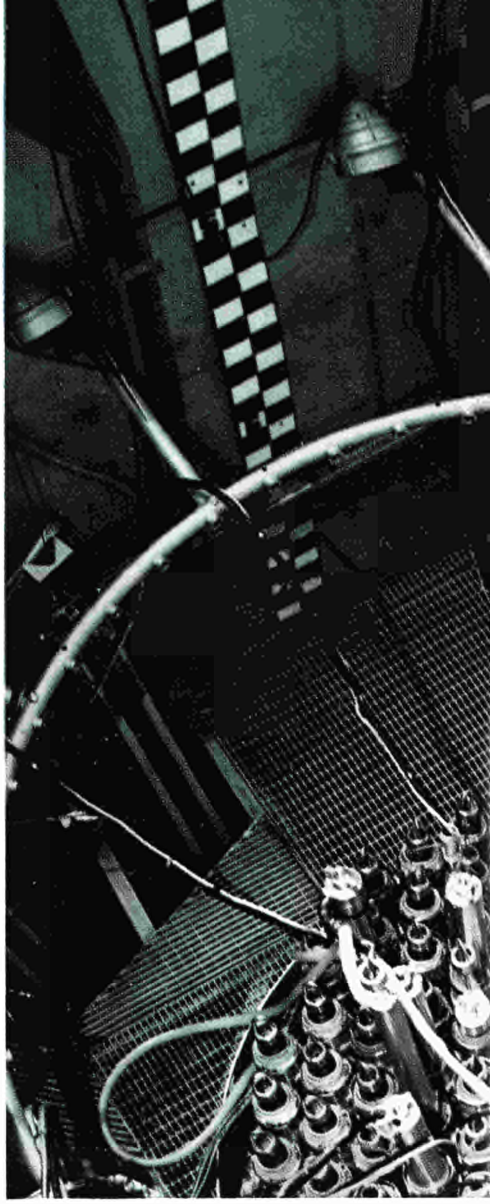
At present, the *CEN*'s annual expenditure amounts to 14 million dollars. Its income consists mainly of subsidies from the state and from industry, also from contracts which for the most part are with international organisations.

Belgium has a very wide gamut of production capacities which could form a major nuclear industry, capable not merely of sharing in domestic achievements but also of exporting a part of its output.

Ninety industrial enterprises concerned with nuclear energy are affiliated to the *Groupement professionnel de l'industrie nucléaire* (nuclear industry association), the object of which is to protect its members' interests.

As regards the *preparation of materials used* in the manufacture of fuels, *Métallurgie Hoboken*, of Olen, with long experience in the processing of uraniferous ores, is today engaged in producing uranium in the form of salts, oxide and metal of high nuclear purity.

In the field of *fuel-element manufacture*, the firm of *Métallurgie et Mécanique Nucléaires (MMN)*, through its experience in providing



supplies for Belgian and certain foreign reactors, has successfully developed the manufacture of the three established types of fuel—natural uranium metal, slightly enriched uranium oxides, and highly enriched uranium-alloy plates. The cladding materials used are aluminium, magnesium, stainless steel, nickel and Zircaloy.

As to the *reprocessing of irradiated fuels* and the *processing of radioactive effluents and waste*, the *S.A. BelgoNucléaire* has acted as industrial architect on behalf of *Eurochemic* and other Belgian and foreign concerns.

Belgium possesses a highly-developed *construction* industry, particularly in the field of mechanical engineering, boiler-making, shipbuilding, and electrical and electronic engineering. There are also major research offices skilled in the design of industrial installations, which have been able to build up useful experience through their participation in the design and construction of Belgian reactors and of certain foreign plants.

Some thirty firms have formed a syndicate to develop the *Vulcain* reactor already mentioned.

In the field of *electricity generation*, it should be pointed out that conventional fuel is relatively dear in Belgium, so that nuclear power reactors offer very attractive prospects.

An important project now under way is the Ardennes nuclear power plant, which is equipped with a pressurised water reactor. This 266 MWe unit is being built at Chooz in the French Ardennes and is scheduled to come into operation at the end of 1966. For the design, construction and operation of this power plant the *SENA* (*Société d'énergie nucléaire franco-belge des Ardennes*) was incorporated, its capital being held on a fifty-fifty basis by *Electricité de France* and the *Centre et Sud* group of Belgian firms. In consideration of the value to the Community of the Ardennes nuclear power plant, which is being built under the Euratom/United States Agreement for Co-operation, Euratom has conferred upon *SENA* "joint-enterprise" status within the meaning of the Rome Treaty.

Drawing up a programme

In order to be effective, a scientific policy must extend over a number of years, time-limits must be set for the various targets and the requisite funds must be allocated at the outset of the work, as otherwise the research workers drift off into a multiplicity of projects which are rarely carried through to a finish.

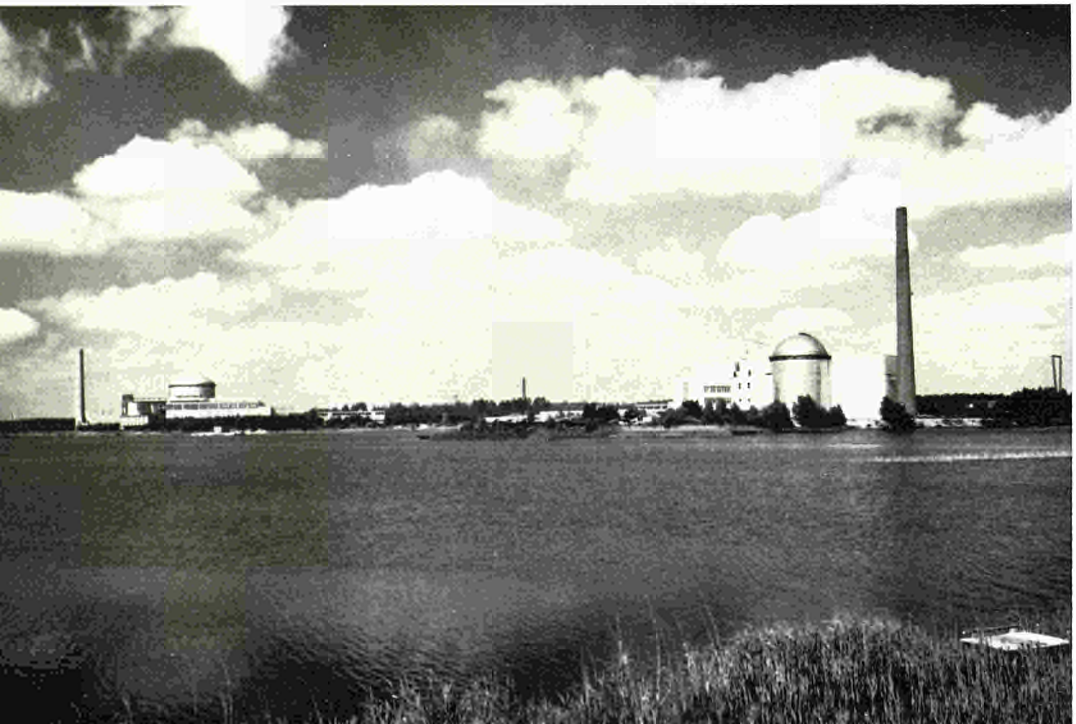
Hence the first requirement for a nuclear policy is a programme which unites the best possible choices.

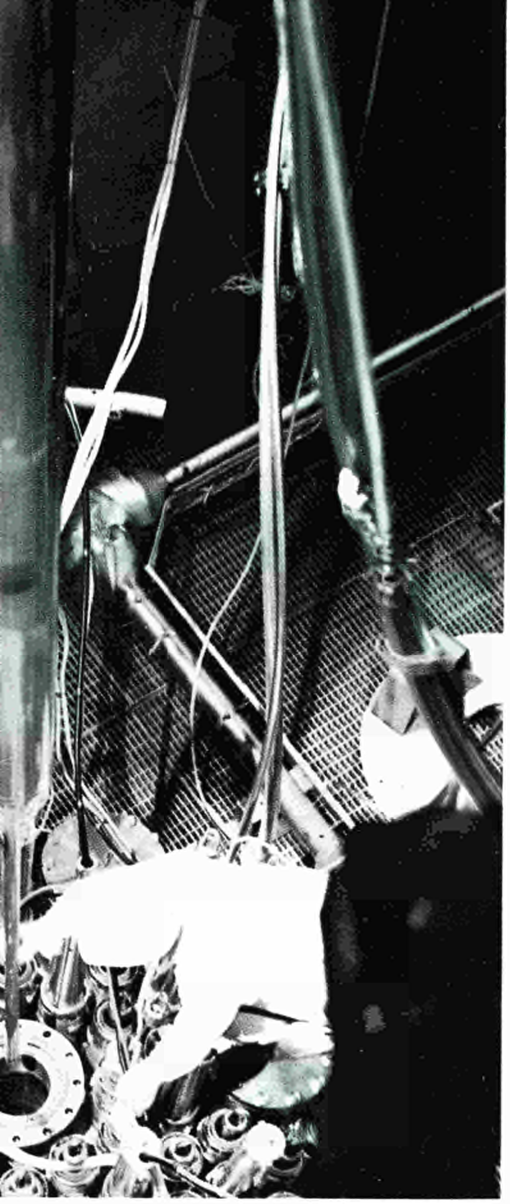
As early as 1958, therefore, the Atomic Energy Commission formed a committee composed of representatives of the State, the universities and industry, for the purpose of drawing up a programme. The document which emerged from this committee's labours was the first attempt to channel new undertakings towards national objectives.

The first three-year plan covered the period 1959-1962. After a transitional period, a second three-year plan was laid down for 1965-1967. It is based on a schedule of the research proposals financed, at least in part, by direct State subsidy, and takes into consideration, *inter alia*:

– Belgium's membership of Euratom and of *CERN*, which affects the choice of a national or international framework for certain research work;
– the presence at Mol of the *CEN*, with its

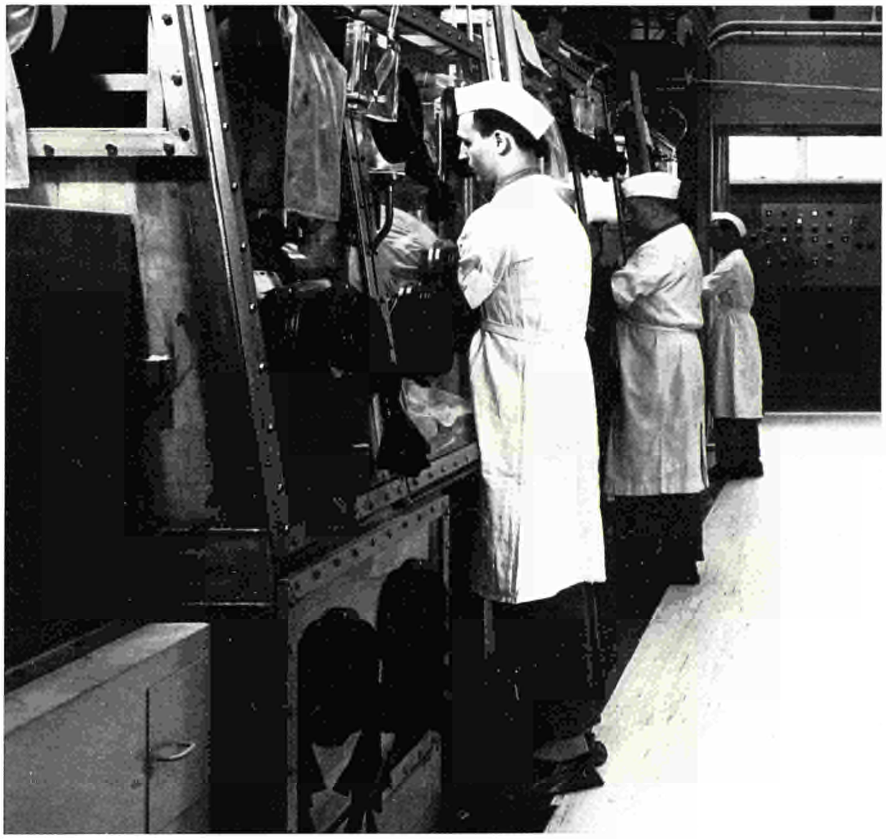
General view of the BR-2 *materials-testing reactor (left) and the* BR-3 *power reactor (right)*





Introduction of a sodium loop into the central channel of the BR-2 reactor

Fuel-element fabrication in the plutonium laboratory at Mol



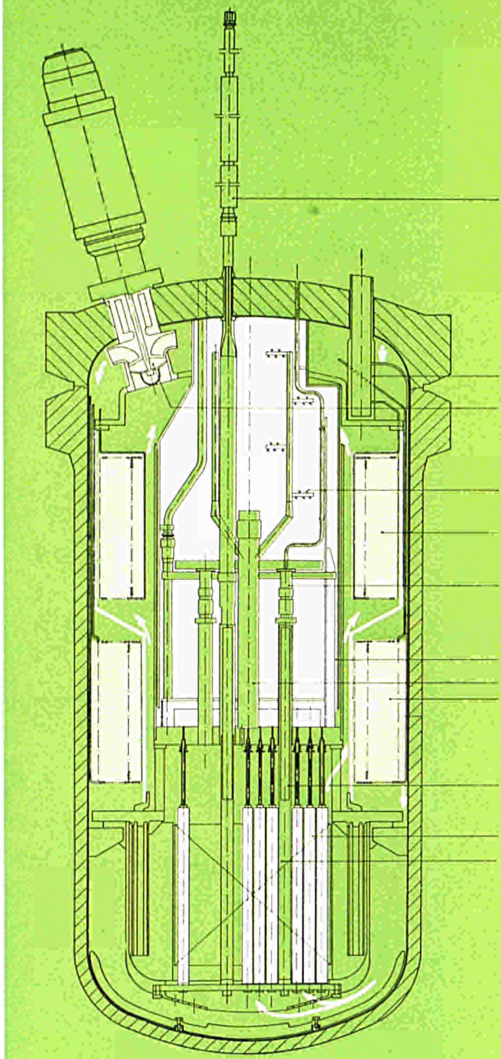
qualified staff and very comprehensive equipment;
– the fact that nuclear technology is entering the industrial stage.

Fundamental research

The results of fundamental research are far less predictable and still less easy to programme than those of applied research. Standards of priority are consequently hard to lay down in this field, and often it is the competence of the researcher, rather than the subject, which forms the focal point of the decisions.
The programme of fundamental studies is based largely on the proposals of the *Interuniversity Institute for Nuclear Sciences (IISN)*. The research relates in particular to experimental nuclear physics, theoretical nuclear physics, radiochemistry, radiogeology, radiobiology and high energies.
In the last-mentioned field, the Belgian activities are coordinated by the *High Energies Laboratory*, which works in close collaboration with the universities and with the *European Organisation for Nuclear Research (CERN)*. This laboratory, which specialises in the interpretation of photographs taken in the bubble chamber at the *CERN*, will be equipped with new apparatus in order to enable it to intensify its collaboration with this organisation.
As far as other fundamental research activities are concerned, the task of the *IISN* is to subsidise various university laboratories and to set up teams of highly specialised researchers.
With regard to the *CEN*, in view of the necessity of solving certain basic scientific problems raised by the programme of applied research and of the usefulness of certain exploratory research projects, this body likewise carries out various fundamental studies in cooperation with the universities. These are for the most part theoretical and experimental studies in low-energy nuclear physics relating essentially to nuclear spectroscopy, the measurement of effective cross-sections and studies on the fission phenomenon; studies in solid-state physics concerning the physical properties of fissile nuclear materials, claddings and lattice defects, especially defects caused by irradiation; and, finally, studies on matter conducted with the aid of neutron beams.

Applied research

The applied research calls for the greatest financial efforts; these must therefore be concentrated on a small number of projects carefully chosen with a view to ultimate industrial application, so that sufficient funds can be allocated to them to ensure their success.
The following factors were taken into account in the selection of these projects:
– the priorities were determined on the



Diagrammatic section of the present reference design for a Vulcain *reactor.*
Compactness is the salient feature of the Vulcain, *a pressurised water reactor using a mixture of heavy and light water as moderator and coolant. The core, the heat-exchanger, the pressuriser and even the pumps are all incorporated in the pressure vessel.*

basis of economic criteria, that is to say in accordance with the profitability of the products developed and with the potential market to which Belgian industry can reasonably hope to have access;

– the commercial yield of research is greatest during the period immediately following the industrial development of the products. Short-term research can therefore only be justified if it can be written off against definite orders;

– preference was thus given at the national level to medium-term research. As regards long-term research, the most desirable policy is one of participation without financial commitment;

– the selection was also influenced by the present position of certain Belgian industries. In Belgium, research and development work involving precision techniques, light engineering and non-ferrous metallurgy rests on extremely solid foundations;

– the present specialisation of Belgium's nuclear industry will not be modified but accentuated. The programme is therefore confined primarily to reactors which are based on the technology of water as coolant and on uranium and plutonium ceramics as fuel.

As a result of the application of these criteria, the bulk of the effort is being devoted to medium-term programmes, namely development of the *Vulcain* reactor and of plutonium-based fuels.

In the short term, the projects selected relate to the improvement of proven-type reactors and fuels, the study of corrosion problems and the operation of the *BR-2* reactor.

In addition, funds are being allocated to longer-term studies such as those on fast reactors and the halogenation treatment of irradiation fuels.

Short-term programme

Belgian activity in the field of proven-type reactors has been directed mainly towards pressurised water reactors—construction of the *BR-3* prototype power plant, participation in the *SENA* power plant, development of equipment for pressurised water reactors and of fuel elements based on uranium oxide and clad with stainless steel. The programme stipulates that the accent must be not on the development of complete power plants but on that of specialised components. Among those selected are the core instrumentation, the primary pumps, the control-rod drives, the fuel-handling appliances and equipment for the manufacture of piping by centrifugal casting.

The work currently in progress on fuels is a necessary prelude to the fabrication of fuel-element assemblies for large pressurised water reactors and for the *Vulcain* reactors.

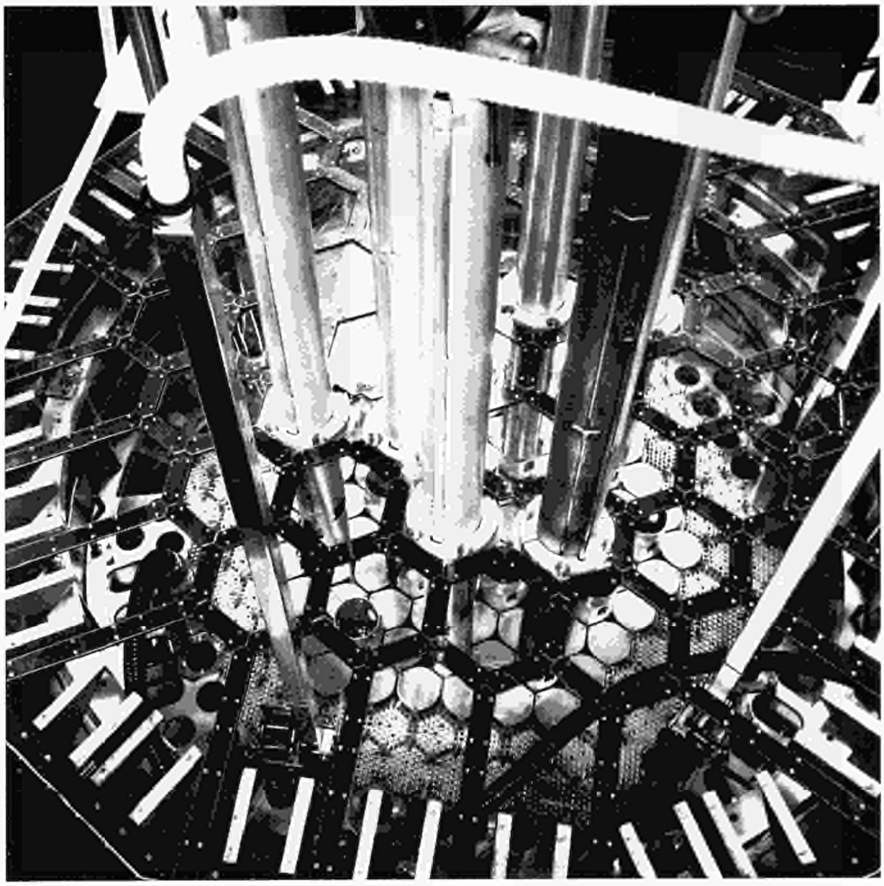
Furthermore, a project of limited scope aims at the improvement of *BR-2* type fuel elements (rodlets in an alloy of aluminium and 90%-enriched uranium, with aluminium cladding).

The *BR-2* materials-testing reactor is being used for the production of radioisotopes and above all for the execution of irradiation programmes. Moreover, the experiments performed in *BR-2* have enabled the *CEN* to tackle problems associated with other reactor types, notably high-temperature gas reactors (*Dragon* type), and with techniques for the handling of liquid metals (*Rapsodie*) and organic coolants (*ORGEL*).

With a view to ensuring optimum coordination of the existing irradiation facilities in the Community, the Belgian Government has submitted a proposal to the Euratom Commission for the setting-up of a single Community materials-testing centre which would combine the *BR-2* reactor and the *HFR* at Petten.

Medium-term programme

The principal aim of this programme is the development of *Vulcain*, a Belgian-designed reactor with a variable neutron spectrum. Studies are currently in hand at the *CEN*, in collaboration with the *Syndicat Vulcain* and the *UKAEA*, in the light of which it will be possible to decide whether the construction of a prototype is justified. This is a very compact type of reactor designed for a relatively low power of some 20-30 MWe but for a high fuel burn-up (see figure on page 40).
An initial phase of the work covered the construction and operation at the *CEN* of a zero-power reactor known as *Venus* (*Vulcain Experimental Nuclear Study*), which was taken into service in April 1964. A second major phase, being carried out at Mol, is the in-pile insertion and power-testing of a *Vulcain* core in the *BR-3* reactor, which has been modified for this purpose.
Another important medium-term activity consists in fuel-cycle studies, which are concerned chiefly with the development of plutonium-based fuel elements. For example, mixed uranium oxide/plutonium oxide ceramics have been developed which can replace enriched uranium oxide in thermal reactors. Fuel pins thus enriched with plutonium were inserted in the *BR-3* reactor and produced energy for several thousand hours. This work is being carried out jointly by the *CEN* and *BelgoNucléaire* under a Euratom contract.



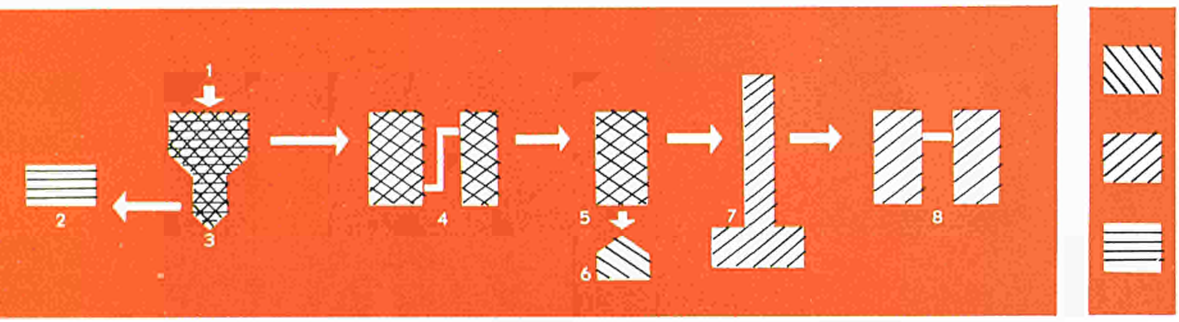
Bird's-eye view of the Venus *reactor*

Aerial view of the BR-3 *nuclear power plant*

Long-term programme

Fast reactors enjoy pride of place in the long-term programme. Indeed, this type of reactor, by means of which the potential energy contained in uranium can be utilised much more fully, undoubtedly constitutes the solution of the future.
Belgium's position in this field is determined by the existence in the country of a nucleus of qualified specialists and by Belgian industry's participation in the programme of the European Community, especially in the form of contracts for the provision of industrial-architect services for the *Masurca* critical model and for the *Harmonie* source reactor being built under the *CEA/Euratom Association*.

Very recently, an association agreement was concluded with Euratom for the integration of the Belgian programme into that of the Community. The work being done in Belgium supplements that carried out by the *GfK* (Germany)/Euratom Association and relates essentially to the following points: study of sodium-cooled reactors, a more limited study on steam-cooled reactors and the development of fuels in collaboration with the *Enrico Fermi* group in the United States.
Among the long-term projects, mention must also be made of the work undertaken by the *CEN*, in cooperation with Euratom, on the reprocessing of irradiated fuel elements. The *CEN* is engaged on the study of non-aqueous techniques eminently suitable for ceramic fuels, with the object of developing a method which, as compared with the aqueous treatment, will lead to a considerable reduction of the reprocessing costs and to a retrenchment of capital investments. The *CEN* will shortly have at its disposal a "hot" semi-pilot plant for reprocessing by halogenation (see figure on this page).



Ceramic fuel processing by means of fluorine 1. Irradiated fuel feed-in (uranium + plutonium + fission products) 2. Drawing-off of solid fission products 3. Production of UF_6 and PuF_6 4. Condensation of UF_6 and PuF_6 5. Reduction of PuF_6 to PuF_4 and U/Pu separation 6. Conversion of PuF_4 to PuO_2 7. Distillation of UF_6 8. Conversion of UF_6 to UO_2

Research in the public interest

Under this heading are included all activities the main object of which is either to promote the use of radioisotopes in industry or improve methods of protection against radiation hazards. The production of radioisotopes in Belgium is in the hands of the *CEN* and will continue to be until the country's industry is economically capable of taking over. Thanks to the *BR-2* reactor, it has been possible to expand the range of products, notably by the production of cobalt and iridium with very high specific activities. Radioelement production and the relevant research are carried out under the terms of an association with the French Atomic Energy Commission (*CEA*) and the Italian company *SORIN*, this collaboration having been undertaken in the interests of rationalisation. Such production currently has a value of some 400,000 dollars a year.
In order to expand the use of radioisotopes in industry, a *Belgian Radioisotopes Bureau* has been set up, whose task it is, in cooperation with the *CEN*, to provide Belgian industrialists with information and assistance on the subject.
As regards radiological protection, work on radiophysical control and medical research on contamination are carried out in accordance with the exigencies of public health.
A related problem which has had to be resolved is that of radioactive-effluent and -waste treatment. The bulk of the *CEN*'s work has been directed to the development, in conjunction with Euratom, of two processes. By means of the first of these, it is possible to separate highly active elements with long half-lives, such as strontium and caesium, in mineral exchangers. The second process consists in coating the waste with bitumen in a solid and insoluble form.

International cooperation

Belgium is cooperating in the activities of numerous international bodies and in particular is a member state of Euratom, the *European Nuclear Energy Agency* (established under the auspices of the *OECD*), the *International Atomic Energy Agency* and the *European Organisation for Nuclear Research* (*CERN*). Our collaboration with Euratom is particularly close and absorbs an appreciable proportion of the resources devoted by our country to nuclear research (10.8 million dollars out of a total of 25.5 million in 1963). In return, the *CEN* and Belgian industry have been awarded a large number of research contracts, and Euratom operates the *BR-2* and its ancillary installations jointly with the *CEN*. Furthermore, the Community has set up on Belgian territory the *Central Nuclear Measurements Bureau* (*BCMN*), which is one of the Joint Research

Centre establishments. Belgium is also the country in which the first *OECD* joint enterprise was established, namely the *Eurochemic* plant, which is to be commissioned very shortly and is capable of reprocessing annually about a hundred tonnes of natural or slightly enriched uranium as well as a certain quantity of highly enriched fuel.
Mention should also be made of the agreements signed, on the initiative of the Atomic Energy Commission, with India, Pakistan, Poland and the USSR. A further agreement is being negotiated with the United Kingdom, which is already participating in the development of the *Vulcain* reactor.

Nuclear power plants

As has already been stated, Belgium is a country in which fossil fuel is relatively expensive and in which the construction of competitive nuclear power plants offers considerable benefits for the national economy.
In the field of nuclear power plants, a first 10.5 MWe unit, called *BR-3*, was taken into service in 1962 and has been employed mainly for manpower training. Also noteworthy is the fact that Belgian enterprises are participating in the construction and operation of a second nuclear power plant, the 266 MWe *SENA* unit, together with *Electricité de France*.
It is now the intention of Belgian electricity companies to have two large 600 MWe nuclear power plants constructed, one on the Scheldt to the north of Antwerp and the other on the Meuse upstream of Liège. These units are scheduled for commissioning during the 1970-75 period and will be constructed for the most part by Belgian industry.
Such vast-scale projects involve a whole range of technical, economic and social problems, which are now being studied by numerous working groups sponsored by both the responsible public authorities and the private sector.
Among all these problems are three which assume an acute and what for Belgium is an entirely new form, to wit:

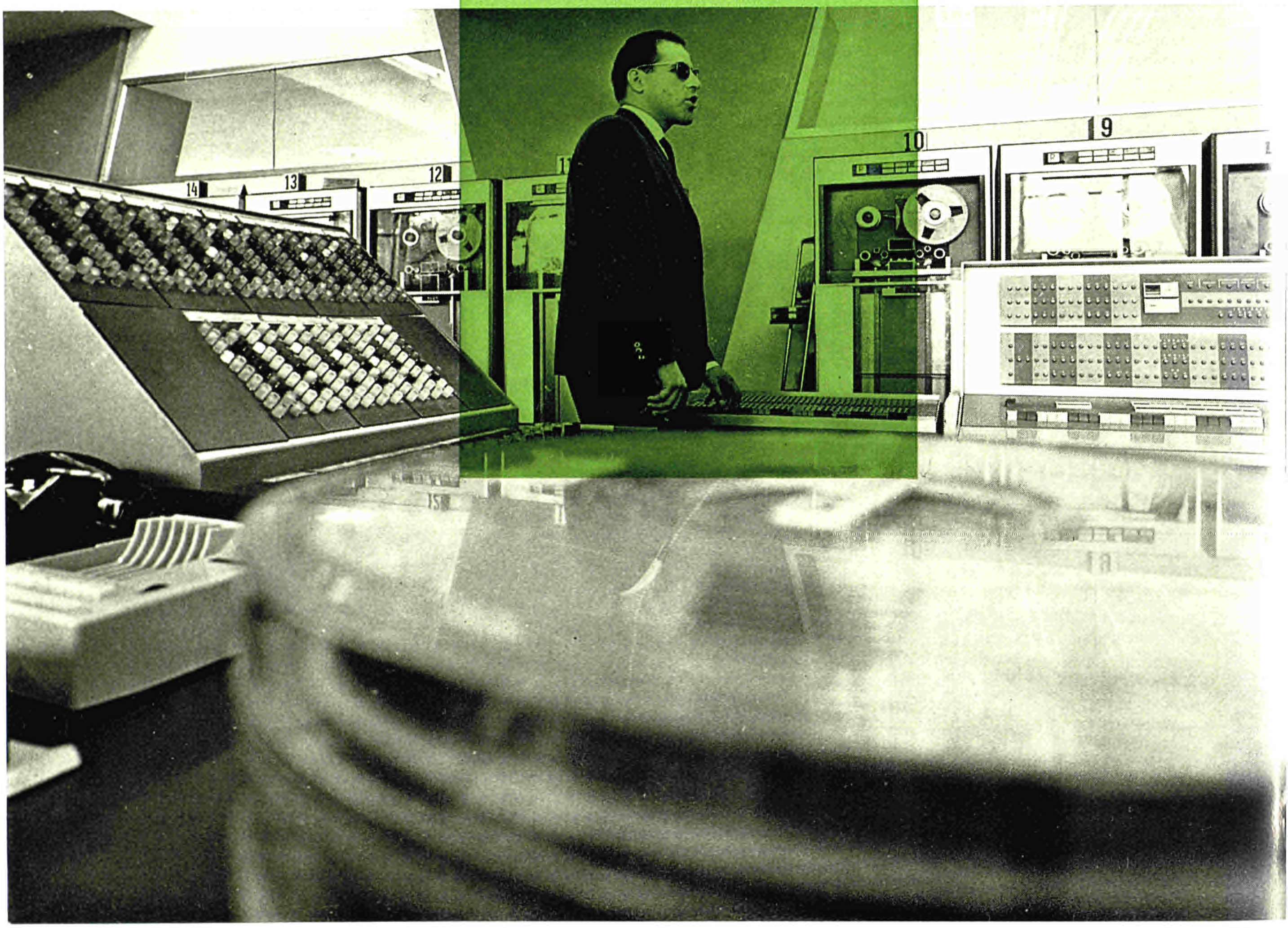
– what should be the share of nuclear energy in our overall power supply scheme?
– what are the problems raised by the introduction of 600 MWe basic units into our electricity grid?
– what part should be played by Belgian enterprises in the construction of the planned generating plants?

The constant increase in electricity consumption in Belgium and throughout the European Community, coming as it does at a time when nearly all "privileged" sources of energy are being utilised, makes it necessary to map out a concerted supply policy aimed at ensuring, in the best conditions, dependability of supply at the lowest prices in the short and the long term.
As regards the problem of reliable and regular supply, there is now general agreement that a wide variety of sources affords the best guarantees. From this standpoint, nuclear fuel adds to the diversity in question. Furthermore, storage of the uranium necessary for fuel element fabrication entails capital expenditure which is about half that required for the storage of fossil fuels. Such stocks also occupy far less space.
On the score of prices, nuclear fuel used in large 600 MWe power plants costs approximately 1.2 dollars per large calorie, whereas the corresponding cost for indigenous fuel is 1.7 dollars and for indigenous washed fines 2.5 dollars per large calorie. By reason of the fact that most of the phases in nuclear fuel fabrication are carried out in Belgium, the Belgian added value in the final price is comparable to that in the price of imported liquid fuel and appreciably higher than the corresponding proportion in the price of imported coal.
Lastly, the commissioning of the planned generators will in no way affect the regular sale of indigenous refuse coal or of other privileged energy sources which may become available.
It may therefore be concluded that as far as Belgium is concerned production of electrical energy from large-scale nuclear power plants offers worthwhile advantages and that this sector is marked out for expansion.
In 1964, net electricity output in Belgium totalled 19,500 million kWh, calling for a net maximum capacity of 4,383 MWe. For the past ten years, the annual growth rate has been 6.5%, which means that a production level of 27,300 million kWh could be reached in 1970. The consumption increase between 1970 and 1975 would necessitate a stepping-up of the maximum capacity by about 2,400 MW, i.e. double that of the two planned nuclear power plants.

Eurochemic *fuel-reprocessing plant*

Belgium, as has been seen, was called upon to concern itself with nuclear energy at quite an early stage, but it is obvious that, being a small country, it could not risk embarking on unduly ambitious research and development programmes on its own. Nevertheless, it has an industry whose skills entitle it to aspire to an honourable place in the nuclear world. It believes it can achieve this aim by means of close cooperation with other countries, especially with other member states of the European Community.

NUCLEAR CODES-What are they used



It is no more than fifteen years since the Americans started using computers as a tool for solving problems encountered in nuclear reactor design. The complex of the instructions, codified in a language which the computer can digest, required for the solution of a set of equations describing a problem in physics, is called the nuclear "programme" or "code".

The setting up of a nuclear code is obviously a highly complicated and usually a fairly protracted affair. But it is clear that once it is finally ready a code can be used for the solution of an unlimited number of problems of the same type, but of varying input data.

In this as in other fields, automation may give rise to certain hazards, and the initial

* *Scientific Data Processing Centre*

for? What future do they have?

CARLA MONGINI TAMAGNINI, *CETIS**, *Ispra Establishment of Euratom's Joint Research Centre*

introduction of codes was accompanied by a little head-shaking.

Two of the "fathers" of reactor physics, A. M. Weinberg and E. P. Wigner, in the preface to their authoritative work "The Physical Theory of Neutron Chain Reactors" wrote, in justification of their lack of interest in computer techniques for the solution of reactor problems:

"However, this omission also represents an attempt on our part to resist what is surely a deplorable trend in reactor design—the tendency to substitute a "code" for a theory. Yet we believe strongly that only when there is a true understanding of the physical and analytical basis of reactor calculation can the machine be used to full effect. In this we may be regarded as old-fashioned; if so, let the new generation remember that the first full-scale reactors, in Hanford, were designed with desk calculators and slide rules!".

Since 1958, when this book came out, the use of codes for reactor computations has become far more widespread than the authors would probably have foreseen or wished. The causes of the spread of nuclear codes through the world are many. Among them we may mention the fast-reactor trend—for this type of reactor the preliminary experimentation is very sophisticated, and advanced computer techniques can be of assistance—; the increasing practice, even in conventional plants, of optimising costs, long-term performance or design dimensions, in which case the mass of calculations to be effected calls for the use of electronic computers; lastly, the growing availability of ever-faster computers at ever lower prices, which has often made it cheaper to carry out a long series of calculations than to construct experimental prototypes. In fact the majority of nuclear centres are now either equipped with an electronic computer and a library of nuclear codes, or else make use of facilities belonging to nearby centres.

While being convinced of the enormous and still growing usefulness and importance of nuclear codes, I wish to reiterate the words of Weinberg and Wigner, which I wholeheartedly endorse: "... only when there is a true understanding of the physical and analytical basis of reactor calculation can the machine be used to full effect".

An outline of the computations involved in reactor design

When a nucleus is split by the impact of a neutron, two phenomena occur which are basic to the whole conception of nuclear reactors. The first, the liberation of energy, enables heat and then electrical energy to be produced; the second, the formation of new neutrons, once the process has been triggered off, causes the neutron chain reaction which permits the reactor to operate continuously.

The emergent neutrons, having energies of several million electron volts, collide with the nuclei of the surrounding materials, in which process they may be "captured" by the nucleus, or deflected, generally with loss of velocity, or give rise to further fissions.

The reactor generally consists of a "core" of fissile material, usually in the form of compact rods, a reflector designed to return part of the escaped neutrons to the core, and lastly a shield preventing radiation leakage to the outside.

A given reactor is said to be "supercritical", "critical" or "subcritical" according to whether the number of neutrons generated is greater than, equal to or less than the number of neutrons which are captured or escape.

The state of criticality (or reactivity) of the reactor varies during operation: in fact the phenomena of capture and fission alter the state of the nucleus affected, leading in turn to a change in the composition of the core.

A problem basic to reactor neutronics resides in the need to ensure continuous criticality and at the same time to preclude either dangerous excursions, resulting from excess of neutrons, or unscheduled shutdowns caused by shortage of neutrons.

Bearing all these points in mind, now let us see how we can split up the reactor design calculations into the various headings.

The input data of a reactor computation, apart from the reactor's physical and geometrical configuration, are the values (generally experimental) which describe the probability of nucleus/neutron interaction at the various energies and for all the isotopes concerned. The entire set of these values is contained in the so-called "nuclear libraries".

It is a common practice to suppose the variable energy of the neutrons to be subdivided into groups. For each of the energy groups, on the basis of the nuclear libraries, calculations are made of the average interaction probabilities by weighting them over appropriate neutron energy distributions (the so-called spectra). Since the energy range concerned is generally subdivided into a thermal and a fast range in view of the different phenomena involved, it is usual to make two computations, one to determine average nuclear spectra and constants in the thermal range, and the other to determine them in the fast range.

The average group constants can be used to calculate, for each group and each reactor region, neutron density distributions from which the reactor's criticality state can be determined.

Depending upon whether the regions considered are of high or low absorption, two

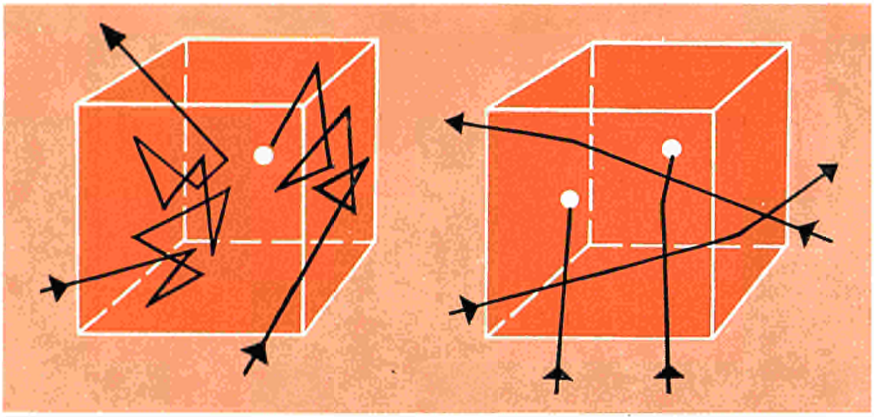


Figure 1: Diffusion theory and transport theory. Over a path of one centimetre, a neutron has a probability A of being absorbed, S of being scattered (i.e. deflected) and L of escaping from the region under consideration. If S is very great in relation to A and L, then the actual direction of the neutron at a given point of time is not important with regard to the neutron distribution over the region, whereas it is if S is small in relation to A and L. In the first case, which obtains for fairly extensive low-absorption regions, and for neutrons distant from the delimitation surfaces, the diffusion theory applies (drawing on left). In the second case it is the transport theory which is applicable (drawing on right).

different theoretical models are customarily used, designated the theory of transport and theory of diffusion (cf. fig. 1).

As has been pointed out, the determination of the reactor's criticality state is repeated at various stages in the life of the core owing to the progressive changes which occur in the isotopic concentrations during operation. The investigation of the change versus time in the isotopes initially present is called the "burnup" or "depletion" study.

The reactivity of a reactor generally diminishes as operation proceeds, as a result of the formation of nuclei with a high capture capacity and as the initial fuel charge becomes depleted. This means that the reactor must have an initial excess of reactivity, controlled by means of absorbent rods (control rods) which will be withdrawn little by little as time goes on. The control problem relates to the study of the reactivity absorbed by a given set of control rods and the techniques of moving the rods in such a pattern as to ensure a constant state of criticality during reactor operation.

During the reactor lifetime there may occur incidents which suddenly alter the state of the reactor and result in an unexpected rise in the neutron population. The department of reactor physics which studies the reactor's response to an insertion of reactivity and thence evaluates its operational safety, is called "reactor kinetics".

Apart from the above questions of a strictly neutronic nature, there are other problems of major importance in reactor design, such as the study of the efficiency of the shield as a radiation barrier and the design of the cooling plant (heat exchangers).

Classification of codes—their distribution

The reactor computation codes, commonly called "nuclear codes" are usually classified both in Europe and in America in categories which reflect the various above-mentioned problems, namely:

a. Thermal spectra and data,
b. Fast spectra and data,
c. Solution of the diffusion equation,
d. Solution of the transport equation,
e. Burnup,
f. Kinetics,
g. Control,
h. Shielding,
i. Heat exchangers.

The volume of nuclear codes available for the various categories of problems is considerable.

As an indication we give two tables showing the state at the *CETIS* programme library at the beginning of the present year.

The relatively small number of American codes may cause surprise, when it is recalled that nuclear plants and electronic processing facilities are vastly more numerous in the USA than in Europe. Various factors, however, must be taken into consideration: first the policy of several of the best-known American nuclear firms—*General Electric*, *General Atomic*, *Westinghouse*—of not making their codes available to Europe except on a limited basis, and sometimes only on the basis of a sale; in the second place it is easier for codes to be exchanged between neighbouring countries, since the research staff have often established personal contacts; finally the understandable tendency on the part of the user to prefer, given equal performance, a code developed by the organisation to which he belongs, or by organisations with which there is active

collaboration, to codes from other, less familiar organisations.
An easier and cheaper dissemination of American codes in Europe is at present taking place through the offices of the programme library created by the *European Nuclear Energy Agency* of the *OECD*. The *ENEA* library, which has been functioning for about two years at Ispra beside *CETIS* and which collaborates closely with *CETIS*, has the particular task of collecting and distributing existing nuclear codes, either Americain or European, a task facilitated by the intimate ties between *ENEA* and the two similar American centres—the *Argonne Code Center* and the *RSIC (Radiation Shielding Information Center)* at Oak Ridge.

The problem of testing the codes

Unlike an ordinary library, a programme library is not, however, confined to the collection and distribution of codes; it also tests them, an operation which is more delicate and complex than may appear at first sight, and calls for a parallel effort on the part of computer programmers and mathematicians specialising in reactor physics.
It is customary to distinguish two test stages—a first stage of routine testing, and a second stage of full testing.
Routine testing consists in ensuring that the sample problem is accepted by the code and carried through to the end. It is clear that whenever the computer for which the code has been evolved does not correspond exactly in its central and peripheral units to that on which it is desired to perform the testing, grave problems may arise in the routine testing stage.
Even when the two computers are exactly identical, the routine testing may still not be particularly simple, since in many cases the operating instructions for the code received are not sufficiently clear. In all such instances a detailed study of the organisation of the programme is indispensable; a sample case can then receive a complete run through and the code can be said to be routine-tested.
The second stage, i.e. full testing, consists in arriving at a statement of the mathematical and physical hypotheses on which the programme is based and canvassing the whole range of possibilities which it offers. The solution of fairly complex problems, such as those which arise in reactor design, often entails the use of simplified models for the description of certain physical phenomena. Now the full testing of a code calls for the knowledge of any such models, although it will be the task of the reactor designer to ascertain whether, and to what extent, these models are valid for the type of reactor in question.
Once the problem to be tackled is defined, the next step is to choose the numerical methods to solve it, methods which are examined with the object of demarcating their validity limits.
In this connection it should be noted that various methods of computation are usually provided in a code, corresponding to various options to be specified in the input data. Very often the descriptive report is not at all explicit as to which are the computations which are to be carried out in connection with a given choice on the part of the user. In order to gain a thorough grasp of the various possibilities contemplated, and thus to exploit to the full the flexibility of the code, it will therefore be necessary to study the organisation of the programme and to set up other problems than the sample problem.
From the above it will be clear that both

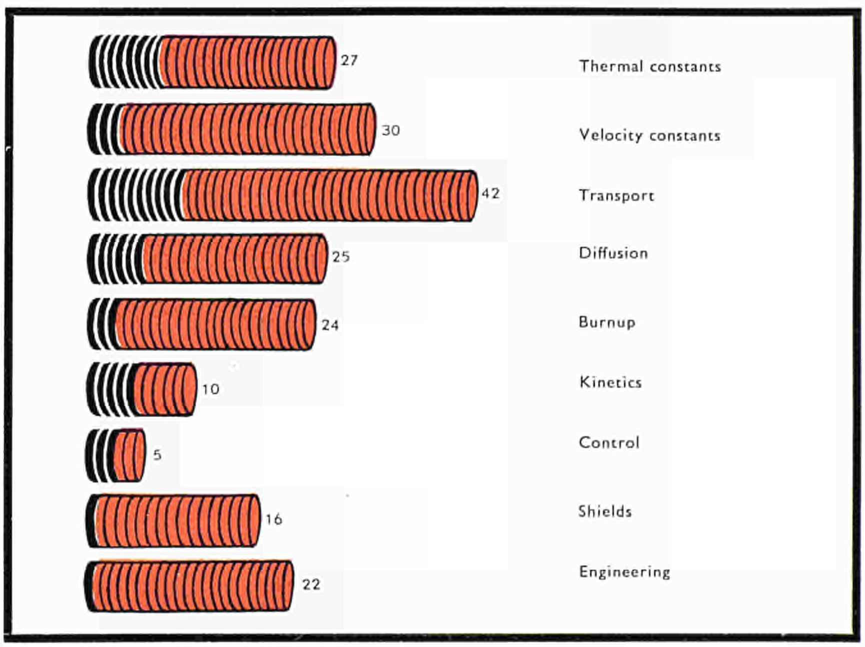
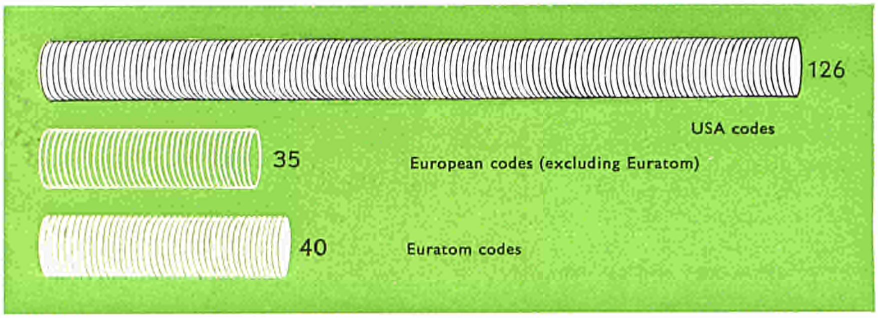


Table 1: The range of nuclear codes now available in the CETIS programme library, split up according to the category of problems to which they apply. Euratom's contribution is in black.

Table II: Nuclear codes available in the CETIS *programme library at Ispra, split up according to their origin.*



in routine testing and in full testing of a nuclear code, but undoubtedly more in the second than in the first, mathematicians and reactor physics experts play a decisive part alongside the programmers.
In order to schematise the characteristics which distinguish one code from others relating to the same problem, and to facilitate its use, *CETIS* prepares and distributes to users manuals in English called "How to Use" for each code examined. Two bulletins will be sent out per year describing the status of the nuclear code library.

What future have the codes?

In my opinion—an opinion confirmed in the course of visits to numerous nuclear and computation centres in Europe and the United States—nuclear codes will develop along two relatively new lines which are at one and the same time distinct and complementary. These two trends are partly dictated by the advent of a new generation of electronic computers, operating much faster, equipped with more fast memories than their predecessors, and possessed of new capacities for solving different types of problem in parallel.
The first line concerns the development of new and ever more advanced techniques of numerical computation for the various types of reactor design calculation sketched out above. The mathematical problems which arise in reactor studies now constitute an extensive and well-defined mathematical field concerned with the solution of a fairly limited number of equations. All over the world now, mathematics is bringing heavy guns to bear on the solution of transport, diffusion and kinetic equations, while international congresses such as the recent conference on "Applications of Computing Methods to Reactor Problems" are being held, entirely dedicated to reactor computation methods.
An interesting report published by W. Sangren on the above symposium indicates the lines of study now being pursued by mathematicians of various countries—the application of variational methods to the solution of transport and diffusion problems, the use of Monte Carlo techniques for criticality problems, the improvement of iterative techniques for the solution of problems of multidimensional diffusion and the numerical solution of problems of spatial kinetics.
The second line of development concerns the possibility of carrying out series of nuclear codes in sequence, linked together by the fact that the output data of one code, suitably arranged, may (in part) constitute the input data of one or more subsequent codes. The tendency is thus to link nuclear codes in a system rather than to carry them out individually, thus eliminating human intervention between the successive executions of the individual codes.
There is a whole range of possibilities, from the automatic sequential linking of a given series of codes to the highly-complicated sequential linking of a series of codes, each of which may be chosen by the user in an assigned "set".
Systems of the first type, for example, are now under study in various centres.
CETIS some time ago initiated the study of a system of the second type. This system, known as *Charon*, should make it possible to carry out any sort of code-series in sequence, provided the codes are chosen among those relating to the determination of thermal or fast data and to the solution of diffusion and transport equations.
In both directions, a great deal of ground still remains to be covered by those engaged in these studies in various countries. However, we are confident that reactor designers will be able, on an increasing scale, to make use of computer techniques, even for the solution of problems which have up till now been dealt with experimentally.

Business pattern of the nuclear fuel industry

ROLAND TURK, *Deputy Head of the Economy Directorate, Euratom*

Figure 1: Estimated annual uranium requirements in the European Community for the period 1970-1999.
Both enriched and natural uranium requirements are taken into account in the graph, but they are expressed in tonnes of uranium metal. No account is taken of any plutonium recycling. The Western world's total requirements, which can be estimated at approximately six times those of the Community, will have to be met from production capacities which at present amount to only about 13,000 tonnes of uranium metal per annum.

As early as 1963, the Euratom Commission brought the problem of long-term uranium supplies in the Community to the notice of the general public when it issued the report drawn up by the Supply Agency's Consultative Committee.

The Commission has since reverted to the question in each of its annual reports, while there has been a growing number of long-term studies and forecasts, both official and private, and Euratom's first target programme for nuclear development within the Community has just been published. This document raises the problem of fuel supplies in direct relation to the attainment of the targets set in the nuclear electricity generation programme, the final date of which is 1980 and the "horizon" 2000.

At a time when in the Community, and indeed throughout the world, the nuclear industry is starting out with prospects of swift and large-scale development, and when industrial policies are being mapped out, it is worthwhile taking a look at the various aspects of the problem of long-term supply in this major energy sector. It may be split up into three heads — requirements, industrial resources for satisfying them and commercial relationships between producer and consumer.

How big exactly is the Community's long-term supply problem?

Is it necessary to consider the needs of the nuclear power plants up to 2,000? It is true that many official forecasts take 2000 as their final date. There is increasing agreement that a nuclear plant's prospective lifetime is thirty years, so that a plant commissioned in 1970 would be maintained in operation until 2000.

Furthermore thirty years is the period in terms of which many nuclear energy producers will no doubt assess their fuel-supply problem. They are accustomed to taking a very long view in this field.

Some figures may be quoted to give an idea of the foreseeable trend of Community nuclear industry requirements in metric tons of natural uranium metal:

Cumulative requirements	1970-1980	54,000
	1970-2000	332,000
Annual requirements	1970	2,300
	1980	8,200
	2000	15,600

This is the overall demand, i.e. including the uranium necessary for the production of enriched fuel (cf. fig. 1).

Expressed likewise in tons of natural uranium metal, the *enriched uranium* requirements envisaged in the target programme can be summarised as follows:

Cumulative requirements	1970-1980	17,000
	1970-2000	106,200
Annual requirements	1970	1,500
	1980	3,700
	2000	2,500

As regards *plutonium requirements* these will not assume industrial proportions until near the end of the next decade.

A first general comment is called for concerning these estimates: they represent a minimum. On what are they actually based? On targets for nuclear electricity production which are increasingly coming to be considered modest in view of the competitive capacity of nuclear energy, and the fixing of which has been dictated mainly by anxiety to integrate nuclear energy smoothly into the overall pattern of energy production and to permit a reasonable rate of construction. No account has been taken of applications of nuclear energy other than electricity generation, since the data available are inadequate as a basis for forecasting.

In the second place, these estimates of demand are founded on what is, generally speaking, deemed to be a realistic assumption as to the pace of technical progress, namely that the "proven-type" thermal reactors as we know them today (for example, graphite-gas reactors operating on natural uranium and water reactors using enriched uranium[1]) will at some future date be joined by "advanced" thermal reactors[2] (which are inter alia better plutonium producers than the proven type), and subsequently fast breeders also.

Advanced thermal reactors burn less uranium per kWh than the proven type, and fast breeders beat all records for uranium economy. Fast reactors comprise, on the one hand, a core containing plutonium, a fissile material, and, on the other hand, a "blanket" consisting mainly of fertile materials, e.g. "depleted" uranium. During operation, fast reactors convert depleted uranium into plutonium with an efficiency which sets them apart from other types and which results in the production of quantities of plutonium in excess of those consumed. The plutonium required for the startup of fast reactors can be drawn from the spent and reprocessed fuel of thermal reactors, while fertile materials can be obtained from the latter source as well as from enrichment plant wastage. They could therefore obviously be fuelled with the by-products of thermal reactors; in any case their fresh uranium requirements will be small.

Taking the most pessimistic view — that in 2000 proven-type reactors would still be alone in the field — the cumulative uranium demand over the next 30 years would be double the figure given and the enriched uranium requirements would be trebled. A great deal of uncertainty persists, hinging upon the course to be pursued in nuclear industrial policy; the figures quoted make no allowance for plutonium recycling in thermal reactors or the possibility of fuelling all or some advanced reactors with enriched uranium. It is at all events manifest that the respective shares of natural uranium, enriched uranium and plutonium are still imprecise. What is certain, however, is firstly that the figure given for

1. Natural uranium contains about 0.7% uranium-235, a fissile isotope, and 99.3% uranium-238, a fertile isotope. In enriched uranium, the percentage of uranium-235 is artificially increased. Uranium-238 is considered as fertile because during reactor operation it can be converted into plutonium, a fissile material comparable to uranium-235.

2. The data at present available make it seem likely that recourse will be had eventually to thorium as well as uranium in the advanced thermal reactors, Thorium-232, a *fertile* material, is converted into uranium-233, which is a *fissile* material, in line with a mechanism similar to that which governs the conversion of uranium-238 into plutonium. Thorium, however, has been left out of account in this article, since the prospects which it offers still involve too many uncertainties. Moreover, thorium is not a direct competitor of uranium since it contains no fissile material. At all events the industrial and commercial arguments expounded in this article are not invalidated by the possibility that the uranium cycle may be accompanied by a thorium one, except insofar as the uranium demand would in such case be reduced.

Figure 2. Left: Estimated cumulative requirements of uranium (in metric tons of uranium metal) in the Western world for the period 1970-1999. The entire square represents the total requirements for the Western world; the red area represents the Community's requirements.

Right: *Present proven reserves of uranium exploitable at a cost of less than 8-10 dollars per lb of U_3O_8.*

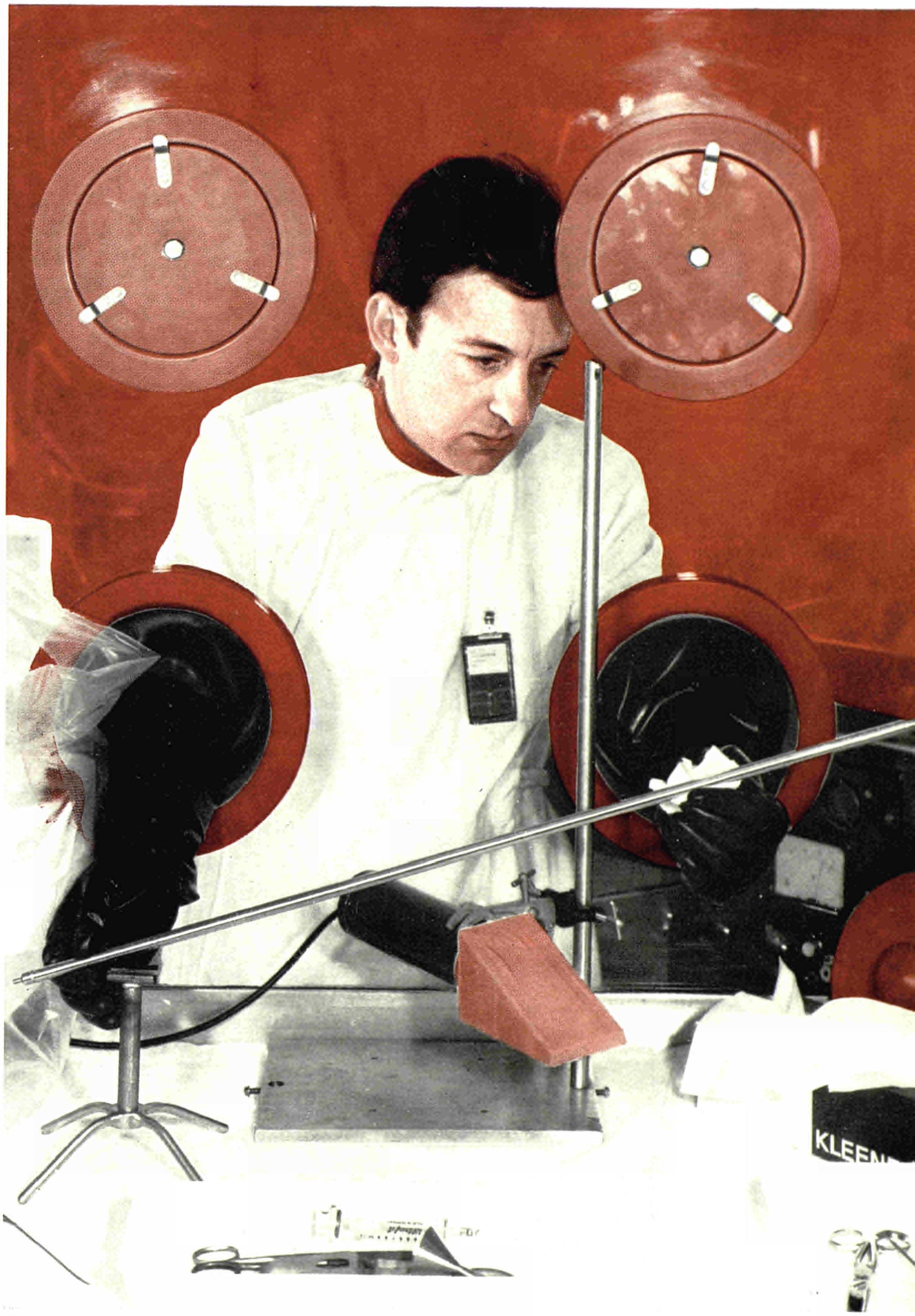
The entire square represents the total reserves of the Western world; the red area represents the Community's reserves.

overall uranium needs is a rock-bottom estimate, and secondly that technical advance is a key factor in determining the extent of the problem of nuclear fuel supply. It may even be said that by paving the way for the use of plutonium as a main fuel we reduce the problem of natural uranium supply, over the very long term, to very minor proportions, particularly for the Community, which would suddenly find that its bonds of dependence with regard to the outside world for fuel supplies had been loosed. But this trend will only assert itself in the period 1980-2000, on the dual proviso that the use of uranium as a basic fuel in thermal reactors has by then led to the production of significant quantities of plutonium and that fast reactors make the grade industrially in due course. Thus, a steep rise in uranium requirements will give place to a decline towards the end of the century.

In order to meet the rising demand, which will be marked by a constantly shifting pattern, it will be necessary to push ahead vigorously with the development of a large-scale mining and fuel-processing industry.

Meeting demand — the rôle of the mining industry

The first essential is that uranium resources should keep pace with the growth in



Final decontamination of a plutonium-enriched fuel pin (CEN-BelgoNucléaire *Laboratory, Mol).*

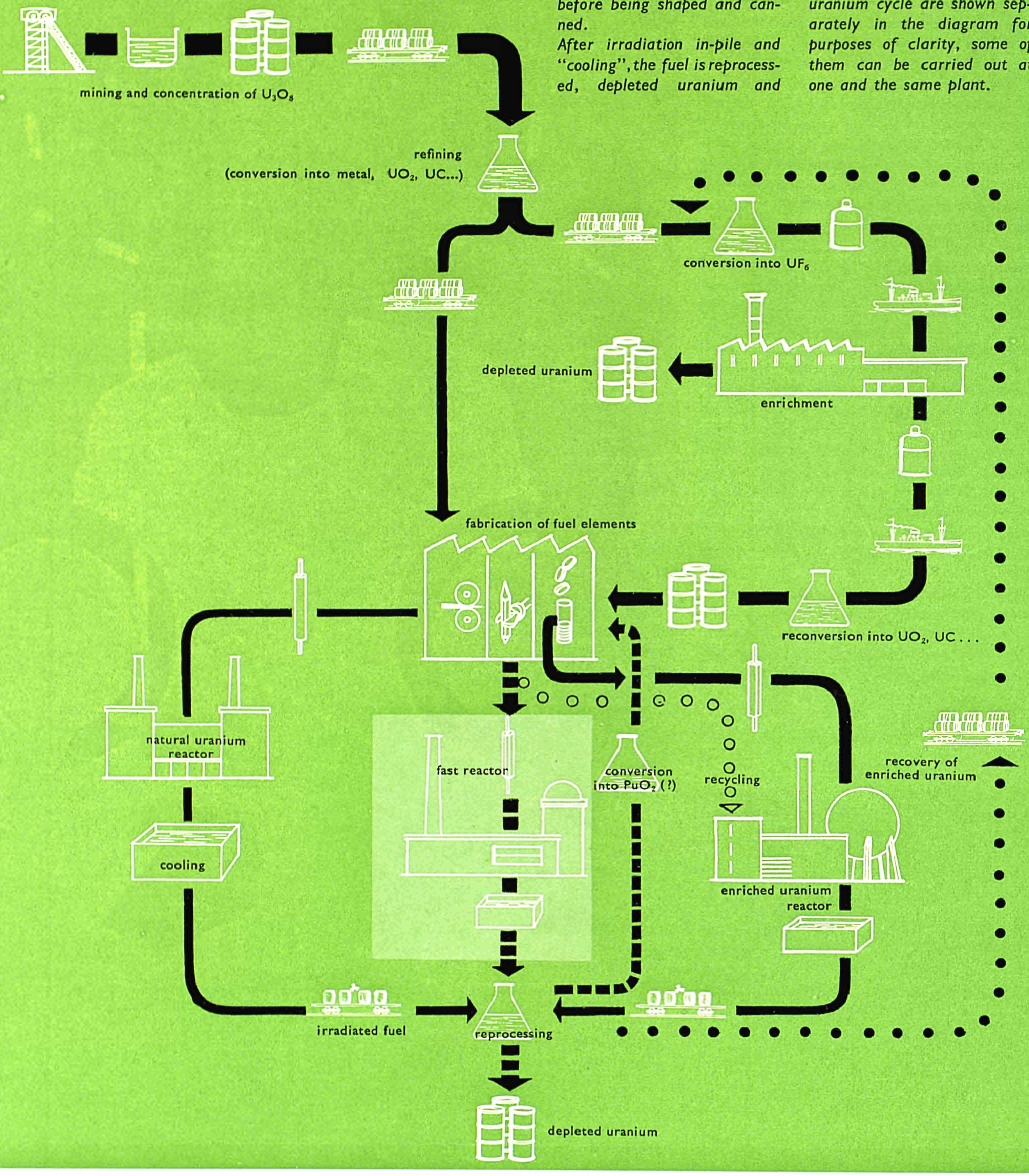


Figure 3: The uranium cycle. After refining, uranium must be prepared for use in a reactor fuelled with either natural or enriched uranium. In the first case the cycle is fairly simple, the uranium being converted directly into fuel elements. In the second, it has to go through an isotope separation stage (enrichment) before being shaped and canned.

After irradiation in-pile and "cooling", the fuel is reprocessed, depleted uranium and plutonium being recovered as well as uranium which is still partly enriched. As things stand at present, the former two materials are intended mainly for use in fast reactors, while there is a further possibility of recycling plutonium in thermal reactors.

It should be noted that, while the different stages in the uranium cycle are shown separately in the diagram for purposes of clarity, some of them can be carried out at one and the same plant.

demand. In the Western world, low-priced reserves, i.e. at $8 to $10 per lb. of uranium concentrate (U_3O_8)—the primary product for the market, the ore not being suitable for transportation in view of its average content of one to two parts per thousand—could theoretically meet industrial needs until around the end of the next decade, disregarding possible extraction rates. (cf. fig. 2).

But on account of the practice of concluding long-term supply contracts, demand will anticipate supply on the market by several years. Having regard to the time required to discover new uranium deposits, it is generally agreed that prospecting must be resumed without delay and on a large scale, as the Euratom Commission has repeatedly stressed.

This process has begun, but will not spontaneously develop the necessary impetus until such time as producers derive a fair return from the opening of a genuine uranium market. Meantime only assistance from the public authorities serving to reduce the financial burdens and political risks involved will induce the mining industry to force the pace and exploit the opportunities, which experts consider favourable, for the discovery of cheap uranium.

Unless they are able to conclude long-term contracts, countries without uranium of their own cannot rely on having access to the most advantageous resources as regards cost and dependability, except to the extent to which their industry has shared the prospecting effort.

The Community can hope to cover only a small part of its needs from internal resources, which ought primarily to be employed as a stop-gap in the event of breakdown of imports which might occur.

There is a reluctance at present to venture long-term forecasts of uranium price-trends. It may be expected, however, that prices will be in inverse proportion to the growth in the volume of economically exploitable reserves. But they will also be affected by the operating costs of marginal mines and by the amortisation rate which the producers will need to maintain—and which may have to be fairly high in anticipation of a contraction in demand after 20 to 25 years of rapid expansion. This will apply all the more the later the mines in question have been brought into production.

Although it is of course accepted that fluctuation in the cost of fuel, even in the highly-processed state, can have only a slight effect on the overall nuclear energy economy, the advantage of cheap fuel supplies as a factor liable to improve the competitive position and as a credit item in the balance of payments should not be minimised.

Meeting demand—the rôle of the fuel processing industry

Even if no account is taken of the final stage, the cladding, which calls for high-precision engineering, the fuel used in reactors is the outcome of a series of extremely complex industrial operations, as a result of which its value has been raised way beyond that of the primary product for the market (cf. fig. 3).

To this must be added the transportation costs, which will be in direct proportion to the geographical dispersion of the different reprocessing stages. For their fuel supplies, therefore, reactors are dependent on a complete branch of industry which has to meet exceptional physical and chemical specifications, far beyond those normally accepted for non-ferrous metals and fossil fuels. It thus follows that, since the user bases his estimate of the cost of fuel supplies on the price of the finished product, the existence of an efficient nuclear fuel industry constitutes just as significant a component of the nuclear energy cost as the cost of the raw fuel.

The added value which the fuel acquires during industrial processing is a good reason for having these operations carried out in the Community: such a development would be of advantage to Community industry as well as helping the balance of payments. The producer countries are similarly motivated in wishing for the setting up of a nuclear fuel industry on their territory and of exporting their resources in the most highly-processed possible state. Over the long-term, however, at a time when plutonium has become the most common nuclear fuel, the Community's fuel-processing industry will be virtually independent of imports. But at the same time users will not be giving it their business unless it can deliver the goods on terms of price and quality which can compete with those offered by foreign suppliers.

Turning to the question of reliability of supplies, although it is basically the conditions governing the availability of the raw fuel which determine whether supplies can be said to be "dependable", the user will be alive to the fact that any shortage or bottleneck arising at any stage whatever in the industrial processing of the fuel would risk cutting off deliveries. In this connection, it is definitely to the Community's advantage to have a sound industry equipped for the processing of fuels, particularly since the various stages involved are fairly protracted—the nearer the fuel is to the raw state when imported, the sooner it arrives in the Community and the greater is the guarantee that the user will not be affected by cuts in his supplies. The sum total of fuel under fabrication at any given moment amounts to a considerable reserve of supplies, for the user at least if not for the fuel industry.

Relations between user and producer industries

Owing to the wide variety of industrial stages culminating in the production of finished fuel elements, a number of different types of business relationships are possible between the user sector and the producer sector, depending on the structural set-up of the latter, but the users, i.e., the clients, do have at their disposal means of promoting an organisational set-up in the producer sector which is most satisfactory to them from the cost and reliability angle.

It is difficult to arrive at an a priori conclusion as to the set-up which should be adopted, from the user's standpoint, by the fuel industry. One view is that things would be made easier for the users by a degree of "vertical" concentration, i.e., if a number of different operations were all carried out by the same concern. This would obviate the need to draw up an individual contract for each industrial operation and for each service provided. Furthermore, it would constitute an element of financial soundness which would bolster the dependability of reactor supplies. A particularly advanced instance of this type of concentration would be afforded by an extension of the reactor construction industry's activities to the fuel sector, in view of the possibilities thus afforded for sub-contract-

ing or preparing to supply not only reactors but the fuel as well.
In view of the present balance of existing resources versus estimated future demand, it is not surprising that users in the Community have been prompted to make arrangements for meeting their long-term uranium requirements, but they would be able to contemplate a single long-term contract with a fuel element manufacturer only if the latter had adequate uranium supplies of his own.
Where this is not the case, it does not appear that users can expect the manufacturer to shoulder the responsibility for acquiring uranium on the best possible terms with regard to reliability and cost. For its part, the mining industry may well be impelled to deal solely with the user himself, to the exclusion of those engaged in any intermediate operations, for reasons connected with the necessary guarantees relating to the applications to which the nuclear fuels are finally put.
Another consideration which makes for separate contracts for uranium supplies and for its conversion is the fact that the appeal of long-term arrangements for access to uranium resources does not extend to fuel fabrication, where the user has good grounds for restricting himself to short-term commitments in view of the greater degree of competition which is likely to obtain.
The beginnings of this trend towards "vertical" concentration are in evidence throughout the free world and are liable to increase. However, the depressed state of the uranium market has prompted certain ore-mining undertakings to abandon all or part of their activities to larger concerns. This development has led to a "horizontal concentration" in this sector, and even to a certain monopolistic tendency. This form of concentration is, moreover, not confined to mining, but is also to be observed in the enrichment industry, where the *USAEC* has virtually cornered the market.
It follows that users, in particular those in the Community, are in a better position if they can maintain some kind of united front on the market. By not competing with each other against producers from non-member states, they can substantially improve their bargaining position.
Quite apart from the organisational set-up (vertical or horizontal) adopted by the producers, it is in any case to users' advantage to pool their resources for certain fuel cycling operations in order to enable the presest installations to make the best use of their capacity. One way, for instance, would be for several power plant operators to dovetail their reprocessing, conversion, transportation programmes, etc., in order to obtain better terms from their contractors.
The problem facing the producer states with regard to the proliferation of nuclear weapons would suggest that trading in nuclear fuels will continue to be subject to special conditions with respect to the applications to which they are put. This may well place certain limitations on the attempts of users and producers alike to bring about a more rational use of the available plant, but the recently initiated trend towards a removal of restrictions may nonetheless be expected to continue, ultimately leading to a market somewhat similar to that for fossil fuels.
The purpose of the ideas and prospects outlined above is once again to focus attention on the magnitude of the problem involved in fuelling the Community's power reactors and at the same time to stress its industrial facets.
If the present estimates turn out to be correct, these specifically industrial features will become progressively accentuated as uranium is gradually ousted by plutonium as a reactor fuel. There is good reason to think, in fact, that given another 25 years or so the problem of getting at the fuel reserves present in the earth will be overshadowed by that of reprocessing a fuel which is essentially artificial and which occurs as an inevitable byproduct. For the Community the switchover would prove all the more dramatic since its fuel (apart from the fresh uranium required at the outset) would then be home-produced, whereas uranium requirements have largely to be met from imports.
In the meantime, undertakings in the Community would be well advised to keep in the forefront of their attention the problem of obtaining access to uranium resources, in view of the delays and uncertainty involved in prospecting, and a long-term solution is vital for the development of nuclear energy within the Community.
The foregoing arguments represent an attempt to analyze the relationships which might come about between energy producers and the fuel industry.

Photograph taken during propagation of a brittle fracture in a steel plate ▶

A solution to the problem of brittle fracture?

MICHEL GIBB, *Editor*

One of the key components of water reactors, whether of the boiling water or pressurised water type, is the vessel housing the reactor core and the water circuits which draw off the energy produced.

As the temperatures and pressures imposed on a reactor vessel are "classical" or even sub-classical, its fabrication does not at first sight raise any exceptional problem, and it could be made from ordinary steel plate. However, certain factors peculiar to the operation of a water reactor prevent this, in particular the fact that a vessel must constantly undergo neutron bombardment. This raises the problem of "radiation damage", especially the well-known problem of the abnormal brittleness characteristic of a steel which has received a heavy dose of neutrons.

With the exception of austenitic stainless steels, which cannot be used for a number of reasons, especially cost, all steels are subject to brittle rupture; for each of them a "transition temperature" is determined experimentally in a range in which the ductility of the metal varies rapidly with the temperature. Below this transition temperature, which in most cases is below 0°C, the plastic properties of the steel are reduced to a point at which a very slight shock can cause a fracture which spreads instantaneously. Neutrons—and the neutrons in question are those with an energy above 1 MeV—have the effect of raising this transition temperature. Normally this does not reach the working temperature of the vessel, but it may be high enough to be above the temperature of the vessel during even momentary reactor shutdown.

The phenomenon does not have any more dramatic result than the need for regular inspections, the findings of which may cause the vessel to be taken out of service before its time. Attempts are also being made by various methods to reduce as far as possible the neutron dose which the vessel receives. In addition, in order to minimise the effect of a rise in the transition temperature, there is a tendency to choose steels for which it is initially very low, for example nickel steels similar to those used in the refrigerating industry.

However, these solutions are only half-measures, since they do not attack the root of the trouble. Basic research has indeed been carried out or is in progress; a study has been made of the various parameters which define the inherent nature of the steel—its chemical composition, microstructure, methods of manufacture, etc.—in the hope of reaching at least a diagnosis, if not a cure, but conclusive results have not yet been obtained.

It was thought, for example, that the inevitable presence of certain other elements than iron and carbon in steel might be the cause of the radiation damage observed. In-pile tests were therefore stepped up with the aim of pinpointing the element or impurity responsible, but in vain, no significant difference being found in the irradiation behaviour of steels of different compositions. It was tempting to conclude that it was the iron itself, an essential constituent of steel, which changed directly and irrevocably under the effect of irradiation, and that it was therefore useless to dwell on the subtleties of the chemical composition of steels.

This line of research has, however, not been completely abandoned. At Euratom, for example, a theory was advanced about three years ago according to which the presence of free "interstitial" elements and in particular free nitrogen in the steel might be the cause of the marked rise in the transition temperature after irradiation. The atoms in question are truly "interstitial", i.e., they are incorporated directly in the crystal lattice of the steel, and are not bound atoms which combine with elements such as titanium, aluminium, niobium, etc., to form nitrides.

It is not possible to make entirely nitrogen-free steels by conventional metallurgical processes. But during manufacture it is relatively easy, by the judicious addition of elements such as those just mentioned, which have a strong affinity for nitrogen, to reduce the proportion of free nitrogen considerably.

Tests on *unirradiated* samples have confirmed that ferrous alloys containing nitrogen primarily in the form of stable nitrides have transition temperatures appreciably lower than those in which it is present primarily in the form of interstitials, a fact which was already known. This is a finding which immediately favours their use in a reactor. In addition, tests on *irradiated* samples in the *SORIN* reactor at Saluggia (Italy) have revealed a new fact: under the effect of irradiation these stable nitride alloys undergo *only one-third* of the degradation of those which contain nitrogen in the free state.

The hypothesis advanced at the outset has therefore been verified. At the practical level it follows that if these results are confirmed industrially, it should no longer be necessary to accept a rise in the transition temperature of about 150°C towards the end of the life of a vessel. By treating steels in such a way that the formation of nitrides is favoured as much as possible, this rise in the transition temperature under neutron irradiation could be kept within reasonable limits, of about 50 to 60°C.

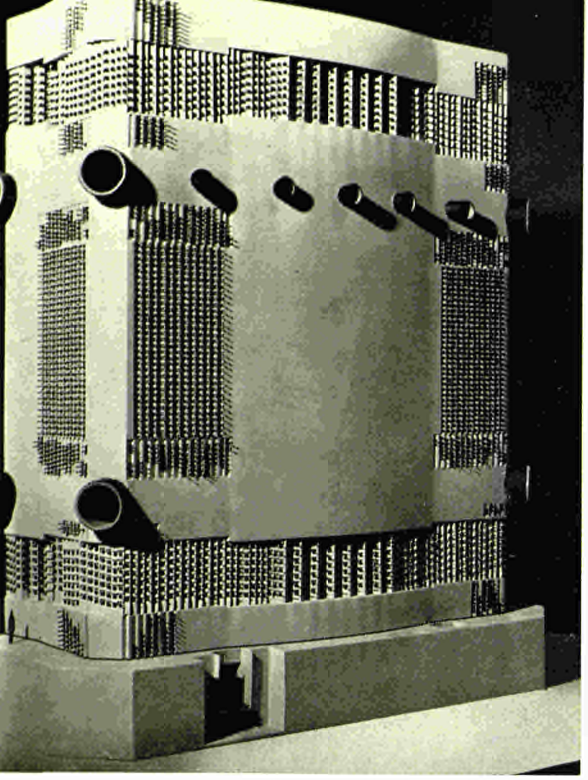


Figure 1: EDF 3 *reactor — View of the outside of the vessel.*

Prestressed concrete

It was in the year 1954, when work was started on the site of the French graphite-moderated gas-cooled *G 1* reactor, that concrete was used for the first time as the material of a reactor vessel. Although this constituted an innovation, it was a fairly cautious one, since the operating pressure of the reactor was fixed at a few inches of mercury only and therefore did not set serious problems in connection with the mechanical resistance of the concrete.
Then, a few years later, came the *G 2* and *G 3* Marcoule reactors, which were to operate at considerably higher pressures, of the order of 15 atmospheres. It is with them that the era of *prestressed* concrete reactor vessels really began.

Concrete is in fashion

This does not mean that prestressed concrete irrevocably ousted all other candidate materials for gas-graphite reactor vessels. In Britain, gas-graphite reactors continued for some time to be equipped with steel pressure-vessels as they had been from the very beginning, and it was only with the Oldbury nuclear plant that the changeover to prestressed concrete was made. Even the French switched back to steel in the case of the *EDF 1* and *EDF 2* power reactors, which followed *G 2* and *G 3*. But with the next reactor, *EDF 3*, concrete staged a comeback, and everything suggests that it was a final one, since *EDF 4* and *EDF 5* are both to have concrete pressure vessels.
As for water reactors, although those operating or under construction today are all without exception equipped with steel vessels, there are signs that water reactor manufacturers are becoming interested in the possibilities offered by prestressed concrete, witness the research contract concluded recently between the French firm *S.E.E.E.* and *General Electric*, for instance, under the U.S./Euratom Agreement (see *Euratom Bulletin* 1965 n° 4, p. 128).
From the few historical facts which have just been sketched in one can draw the conclusion that it must after all be something more than fashion which is making prestressed concrete so popular. But before tackling this point it would be as well to have a closer look at prestressed concrete and remember what it actually is.

Prestressing—a 4800 years old technique

It should be remembered in the first place that the prestressing technique is not as new-fangled as it seems. In the cooper's shop, for instance, it has been an essential technique for centuries: when assembling a barrel, the cooper tightens the hoops round the staves and thus ensures that the wood is under compression in all circumstances, even when the barrel is full; no liquid will therefore leak out between the staves.

But it appears that the history of prestressing can be traced back not merely through hundreds but through thousands of years. There is some evidence that the Egyptians applied the technique in ship-building as long ago as about 2,700 B.C.

Prestressed concrete

It seems that it was an American, P. H. Jackson, who first proposed, in 1886, that prestressing should be applied to concrete, but it was probably the Frenchman E. Freyssinet who brought to light the full potential of this idea in the earlier part of this century.
As soon as good quality cements started being produced at low cost, the economic advantages of using concrete in all kinds of structures instead of steel became evident. However concrete, although it can be subjected to high compressive stresses without damage, can only stand relatively moderate tensile stresses.
If a pillar is required, this is not embarrassing, but in the case of a beam it poses problems. Any load on a beam tends to make it bend and therefore to compress the layers of material which are near the top and to stretch those which are near the bottom. In the case of a beam with a rectangular section, for instance (see fig. 2), two symmetrical sets of stresses are set up, compressive above the neutral plane and tensile below it. This means in practice that the limit to the load the beam can carry will be set by the tensile strength of the concrete. The ability of the material to resist much higher compressive stresses will thus be wasted.
One way out of this situation is to reinforce the same beam with steel bars as shown in figure 3a, in such a way that the steel virtually takes over from the concrete in the regions where the highest tensile stresses are encountered. If the reinforcement is adequate, the load can then be

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in reactor technology

increased with safety and the concrete above the neutral plane will be working closer to its full potential. However, when the steel is working at full stretch, cracks will develop in the concrete (see fig. 3b). This may not appear at first sight to be a major objection, at least in the case of a beam, but it is often a drawback: for example, the cracks will let in air and thus expose the steel to corrosion.

Thanks to prestressing, this drawback can be overcome, as fig. 4 shows: a beam can be designed in such a way that the concrete is never in tension or, if so, only very slightly, even when the beam is carrying its maximum load. Consequently no cracks will develop in the beam.

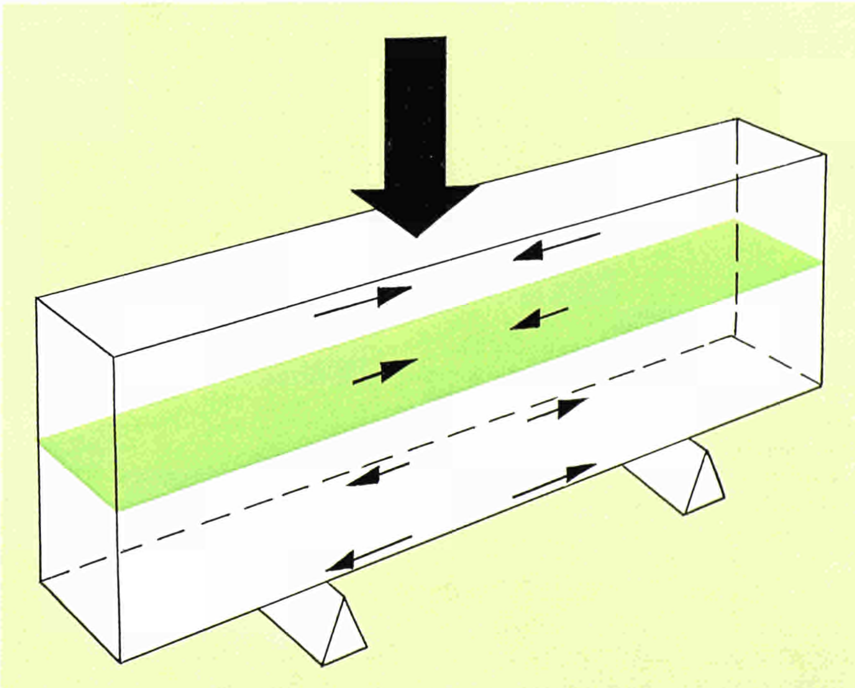
Because of these properties a widespread use has been made of prestressed concrete for beams, bridges, in a word for what one may call load-carrying structures. But similar reasons make its use attractive for various other structures, not least for those which have to hold the pressure of a fluid and remain leak-tight: oil-tanks, water towers, high-pressure water-pipes ... and reactor pressure-vessels.

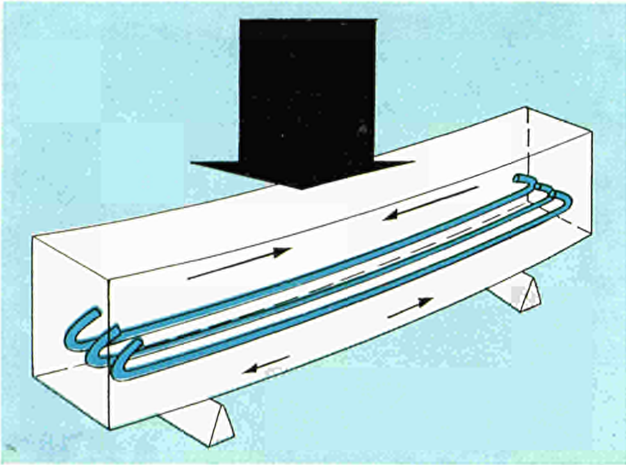
In these sophisticated versions of the cooper's barrel the task allotted to the steel is exclusively that of holding the tensions set up by the fluid under pressure.

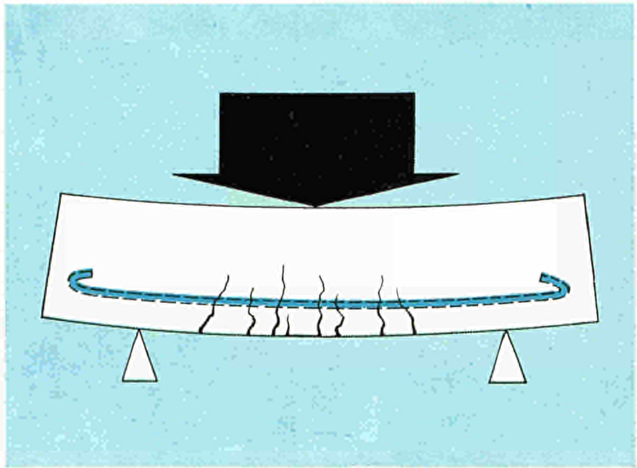
Gas-graphite reactors—prestressed concrete replaces steel

However, the adoption of prestressed concrete for gas-graphite reactor vessels is to be assigned ultimately to special circumstances. The efforts to improve the economics of this type of reactor were centred on the design of larger units, in order to reap the benefits of size, and on an increase of the gas pressure, in order to achieve higher power densities. Inevitably, pressure vessels had to become bigger and their walls thicker. Not only had they, because of their size, to be assembled on site, but the technological problems associated with welding together satisfactorily ever thicker plates, and then testing the welds, became extremely arduous and therefore costly to

Figure 2: An ordinary concrete beam. When the beam is loaded, the layers of material above the neutral plane (in colour) are compressed and those below it stretched, and thus subjected to compressive and tensile stresses respectively (symbolised by the arrows). The greater the distance from the neutral plane, the higher is the stress.







Figures 3a and 3b: Reinforced concrete beam. Steel bars are set into the concrete near the bottom of the beam. As in the case of an ordinary beam, the effect of loading is to stretch the layers of the beam which are below the neutral plane. However, as steel is stiffer than concrete, it does most of the work involved in resisting this effect. As it is at the same time much stronger, it will be possible to put a higher load on this beam than on the ordinary beam even when using relatively small amounts of steel. In the imaginary example represented by fig. 3a, it will be seen that the compressive stresses in the top layers of the concrete have risen (the arrows are shown longer), whereas the tensile stresses in the bottom layers have not changed.

At a certain stage, even though the beam will not fail, thanks to the steel bars, cracks will develop in the concrete (fig. 3b).

solve. On the other hand switching to prestressed concrete turned the construction of the vessel into just one more civil engineering job, albeit a fairly delicate one. Besides, it must be remembered that any reactor must be surrounded by a concrete biological shield, designed to stop radiation. One of the advantages of the prestressed concrete solution is therefore its simplicity, inasmuch as pressure vessel and biological shield are one and the same structure (see fig. 5).

New problems

This is not to say that the concept is pervaded by simplicity and that it is devoid of drawbacks. How far, one may justifiably ask, are the mechanical properties of concrete affected by radiation? But perhaps the major and immediate difficulty which the concept holds out stems from the fact that it is considered out of the question, as things stand today, to let temperatures in concrete rise much above 70°C. Higher temperatures could have an unfavourable influence on the mechanical properties of the material, and would set up a complex of thermal stresses, with the consequence that the safety of the whole structure could be affected. As the temperature of the cooling gas in a proven-type gas-graphite reactor can reach 400°C (it comes nearer to 700°C in the advanced gas-cooled reactor), it follows that a means has to be found of insulating the concrete from the gas.

There are a variety of devices through which this result can be achieved, but experience has shown that they are all complicated and costly (they can account for as much as 40% of the cost of the whole vessel). Insulation consists either of a system of corrugated steel plates, with layers of gas between them, or of a low conductivity material. Additionally, special cooling circuits have to be devised to drain away the heat which gets through the insulation. Fig. 6 illustrates the principles which today guide the design of insulation and cooling systems in prestressed concrete reactor vessels.

A good deal of thinking has been devoted to the search for simpler and therefore cheaper solutions. The most elegant way of getting round the problem would undoubtedly be to develop a kind of concrete capable of resisting higher temperatures without losing the mechanical properties which are required of it in a prestressed structure. The results of the research carried out to date along these lines indicate that such a radical solution is not to be ruled out.

In view of its interesting prospects, the technology of prestressed concrete received a prominent position in the section of the Euratom research programme which is devoted to proven-type reactors. A brief review of the various projects which it covers will help to show how the search for more economic solutions is being tackled.

Fundamental research

Since December 1962, the Italian group *SNAM* has been investigating, on behalf of Euratom, the behaviour of concrete at high temperatures and under irradiation. The first part of the programme, which has been completed, covered a thorough investigation of the effects of temperature on concrete, radiation being deliberately kept out of the picture at that stage. Experiments were carried out on a large number of test-pieces in order to bring out the influence of different important parameters such as the type of material mixed in with the cement, the water/cement ratio, etc. As it was found that the conditions under which the concrete set also had an influence on its properties, these were also taken into account. As for the heat-treatment itself, it was carried out at several different temperatures, ranging from 110° to 400°C, and for different lengths of time. Finally, after treatment, the mechanical properties of the test-pieces were measured and compared to those of similar untreated test-pieces.

It is impossible to go into the details here of the results yielded by this first programme. It has however become apparent that the important mechanical properties of concrete, such as its resistance to compression, are little affected by heat-treatment up to temperatures of 200°C. Beyond this temperature, the mechanical properties undoubtedly suffer, but it is interesting to note that in all cases, even in the extreme case of heat-treatment at 400°C, the figures obtained for the breaking stress of the concrete lay above the minimum values normally considered as acceptable.

One of the other important phases of this study, which introduces an additional factor, namely radiation, is under way at the moment. As the test-pieces will otherwise receive a treatment identical to that which they underwent in the course of the first phase, it will be possible to assess with accuracy, by comparing the results of the second phase with those of the first, the effects which can be ascribed to radiation alone. The *Galileo Galilei* swimming-pool reactor of the *CAMEN* research centre near Pisa is being used for this purpose.

It should be pointed out in this connection that Euratom has also concluded a contract with the Dutch firm *Verenigde Bedrijven Bredero N.V.* covering a similar if less ambitious investigation. Using the Petten centre's low-flux and high-flux reactors, *Bredero* are applying a set of testing techniques of their own invention to different kinds of concrete under high temperature conditions and under irradiation. It will be interesting to compare their results with those of *SNAM*.

Rethinking insulation devices

The kind of fundamental research which has just been described may well lead to the most radical solutions of the temperature problem, but this does not mean that all other possible ways of improving on the present situation should be neglected.

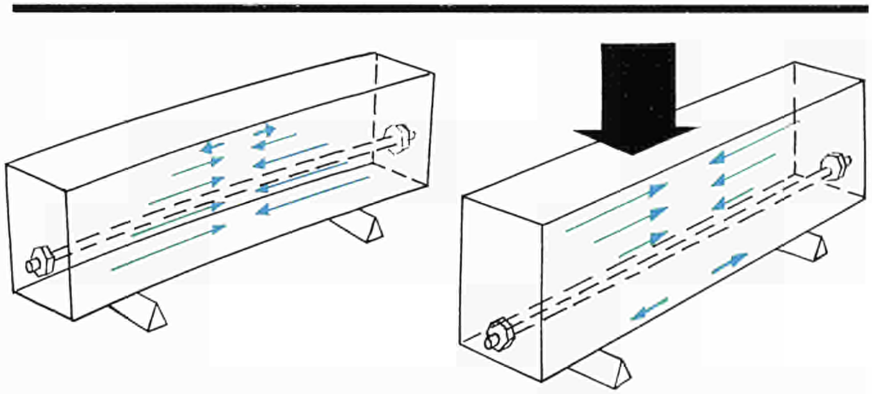
Let us have a closer look at this present situation as it is represented in fig. 6. Moving from the inside of the vessel towards the outside we meet first of all with the insulating material; then comes a relatively thick (12 to 25 mm) gas-tight "skin", made out of steel and serving as shuttering for the concrete, which is equipped with an *external* cooling system. This may seem complicated, but it has to be so far a number of reasons.

These reasons become clearer if one supposes for a moment a simplified system involving the "skin" and, apart from this, only a layer of insulating material. To be certain of obtaining the necessary temperature drop through this layer, one would have to select a material with a very low conductivity indeed. Unfortunately no such material, which at the same time possesses the requisite mechanical and chemical properties—and is cheap enough —,has been found yet. This is why it is necessary to fall back on a material with only a moderately low conductivity and to combine it with a cooling system which "sucks away" efficiently the calories which get through it. At the same time this cooling system contributes to safety because it constitutes an insurance against a possible deterioration of the insulating material in the course of the reactor's lifetime.

The French firm *Indatom* and *Deutsche Babcock and Wilcox* are working out jointly, under contract to Euratom, an alternative arrangement which it is hoped will turn out to be more economical. Expressed very crudely the aim of this research project is to push the argument which has just been outlined to its logical conclusion and do completely without insulating materials. As fig. 7 shows, the idea consists in keeping the "skin" cool simply by placing a screen of water tubes in front of it. Apart from this, all that is needed is a system of baffles, for instance, which acts not as an insulator, but merely as a brake on heat transfer. It is even considered that the efficiency of this thermal "brake" is not an acute question. In the limit the water tubes could cope with the situation alone, the only difficulty being then that this increase in their activity would entail a substantial drain on the amount of heat produced by the reactor. The way out of this difficulty would be to work the water tube screen into the thermodynamic cycle at the preheating stage.

Deutsche Babcock and Wilcox have built a loop in which panels of water tubes of

Figure 4: Prestressed concrete beam.
Left: before loading
Right: after loading.
Although subjected to a loading similar to that considered in fig. 2b, this beam does not show any cracks. The effect of the loading is, as always, to stretch the layers of material below the neutral plane, but this effect will have to cancel out the compression set up by prestressing before actually setting up tensile stresses in the concrete.



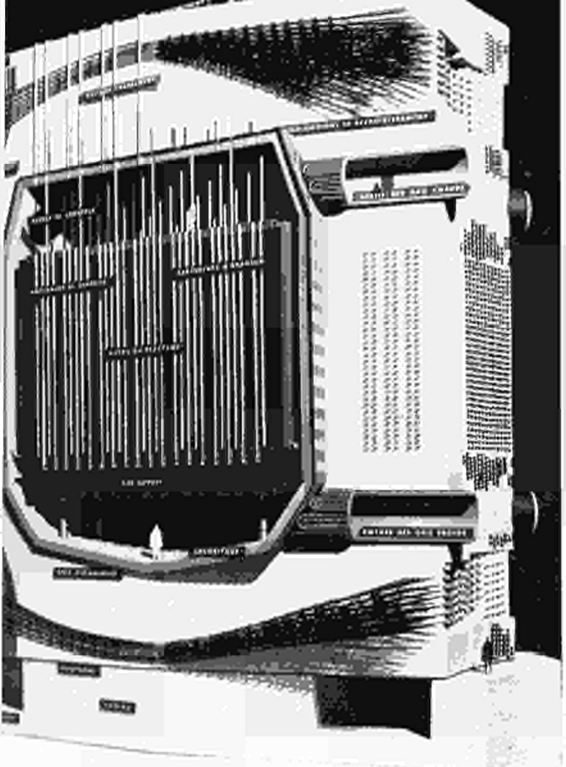
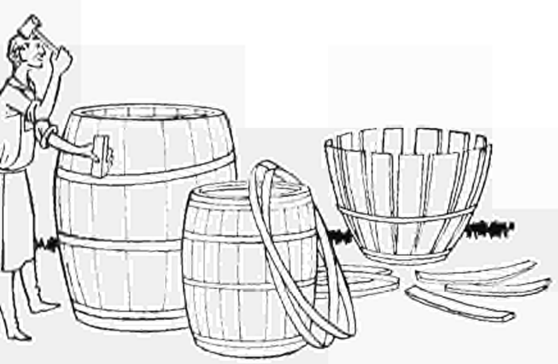


Figure 5: EDF 3 reactor — Vertical cross section of the vessel.

Figure 6: Principle of insulation and cooling systems today.

various designs are being tested at the present time.
In the laboratories of the French firm *Bertin et Cie* insulation problems are being tackled from a fundamental point of view. For the purposes of this research it is assumed that a material owes its insulating properties to the fact that it is porous or that it consists of cells filled with a substance which is a poor conductor of heat. In everyday practice, this substance is simply air; in the case of a gas-reactor, it is the cooling gas. There are several mechanisms which govern the transfer of heat through such a network of cells, but that which gives the most concern is the phenomenon of natural convection. *Bertin et Cie* have therefore launched a programme of theoretical and experimental research based essentially on a study of this phenomenon in rectangular cells filled with carbon dioxide under pressure.
Some of the results of these studies have already been useful to *Indatom*, as well as to the French aircraft company *Sud-Aviation*, which has also worked on insulation problems under contract to Euratom. *Sud-Aviation*'s task has consisted in assessing the technical prospects of honeycomb stainless steel structures for the insulation of reactor vessels. Similar structures, developed under the trade-name *NIDA* by *Sud-Aviation*, have found many applications in the aircraft industry. Among their advantages one may mention their lightness, their strength and the relative ease with which they can be mounted onto the surface of the vessel. Latest results show that a honeycomb structure 10 cm thick would be adequate for the purpose of a reactor. It now remains to be seen how far this solution is cheaper than more conventional ones.



Rethinking the vessel itself

The research projects which have just been outlined take for granted that no major alterations are introduced into the design of the prestressed concrete vessel itself: it remains basically a shell of concrete several metres thick.
Under a contract concluded by Euratom with *F. Krupp* of Essen, a different approach is being investigated, which seems to have been sparked off initially by a set of theoretical considerations. Before launching on calculations dealing with the stresses which can be set up in a pressure vessel, it is always necessary to decide whether the vessel is "thin"-walled or "thick"-walled, because a different set of equations is applicable in each case. A thin-walled does not differ from a thick-walled vessel in the way a cat differs from a dog. It is just that many of the factors which complicate the calculation of a thick-walled structure can be neglected when dealing with thin-walled structures. Engineers therefore prefer to deal with the latter, not out of shear sloth, but because the solution of the equations which have to be used in connection with thick-walled vessels is beset, unlike their simpler counterparts, by a number of theoretical uncertainties. The practical consequence of this is that safety considerations make it necessary to allow for these uncertainties at the design stage and thereby add to the cost of the structure.
The concrete pressure vessels which have been developed to date for reactors are definitely of the thick-walled variety and their design is therefore subject to the difficulty which has just been mentioned. In order to avoid it, *F. Krupp* have sought a design which could introduce thin-walled vessel theory and are building a model which will enable it to be put to the test. Fig. 8 illustrates the kind of solution they are investigating: the pressure-vessel is in this case divided into two completely distinct concentric shells, separated by a layer of water, a special device ensuring that the pressure of the water is the same as the pressure of the gas inside the vessel. Only the outer shell is equipped with prestressing cables and its sole function is to cope with the hoop stress and longitudinal stress set up under operating conditions by the pressure transmitted by the water. In the instance under consideration, it might be classed as "thin-walled", which means that its calculation is straightforward. As for the inner shell, which could be as

thick as about one metre, it is clear that it is not at all submitted to hoop stress or longitudinal stress, but only to the direct effect of the gas and water pressures which set up relatively small compressive stresses. It is made of a special concrete and has two main functions: the first is to absorb the radiation from the reactor (some neutrons will succeed in getting through it, but they will be absorbed by the water); its second function is to serve as a thermal insulator. The heat that it lets through will be transferred to the water, which can be cooled so that its temperature never rises above, say, 50°C. It follows of course that the temperatures in this inner shell will be high, as it is directly exposed to the heat of the reactor, but this need not be a major objection in this case since the inner shell has practically no mechancial role to fulfill.

Yet another solution is being envisaged under Euratom contract by the French firm *C.I.T.E. (Compagnie d'ingénieurs et techniciens d'études)*. Superficially, it resembles the *Krupp* concept inasmuch as it too consists in splitting up the vessel into an inner and an outer shell, but this is about as far as the analogy goes. The inner shell is made of concrete and the outer shell of *reinforced* concrete. Compression of the inner shell is obtained by injecting an ordinary liquid, or a liquid which can set, into the cavity which separates the two shells.

In this concept, no attempt is made to deal with the temperature problem, which is assumed to be solved by suitable insulation. The aim is essentially to obtain a structure which is at least as good, mechanically, as those which have already been developed, but is at the same time cheaper. A preliminary study on the economics of the system has indicated that such factors as the absence of a need for prestressing cables made of special high tensile steel and the simplicity of the method whereby the inner concrete shell is prestressed should be able to contribute to the fulfilment of this aim.

The prestressed concrete technique seems to have established itself firmly, at least as far as gas-graphite reactors are concerned. Will this situation last, or will a new technique supersede it, perhaps partly reinstating welded steel structures? It would be imprudent to hazard an answer to this question, but one thing is clear: as the few examples just given have shown, prestressed concrete reactor vessels leave plenty of scope for development.

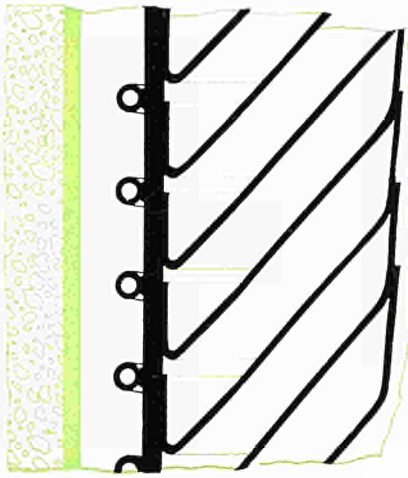


Figure 7: Water screen with heat "brake". This is an example of what a water screen system could look like. No insulating material is used, but only a heat "brake", which in this case consists of a series of cells (right-hand side of the diagram) which communicate with the hot gas inside the vessel. Heat transfer inside these cells must take place from right to left, i.e. from top to bottom. As this direction is opposite to that of natural convection, heat transfer is impeded (after a patent by Indatom, *France).*

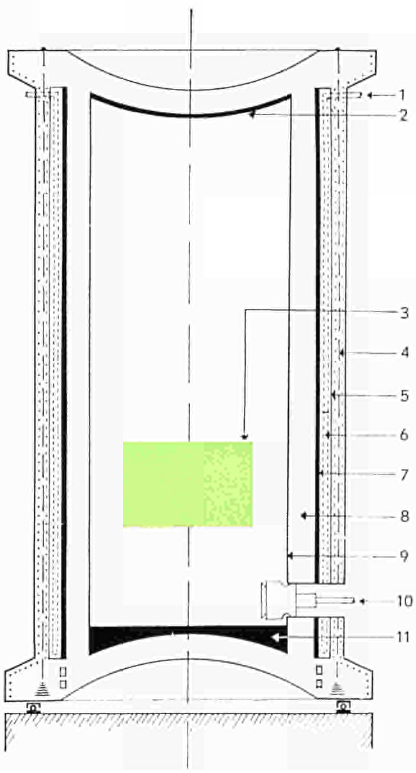


Figure 8: Prestressed concrete reactor pressure vessel — Principle of F. Krupp design.

1. *Heat removal*
2. *Insulating material*
3. *Reactor core*
4. *Outer concrete shell (with prestressing cables)*
5. *Pressure and heat transfer medium (e.g. water)*
6. *Secondary cooling system for heat removal*
7. *Insulating material*
8. *Inner concrete shell*
9. *Steel skin*
10. *Gas circulator*
11. *Insulation*

EURATOM NEWS

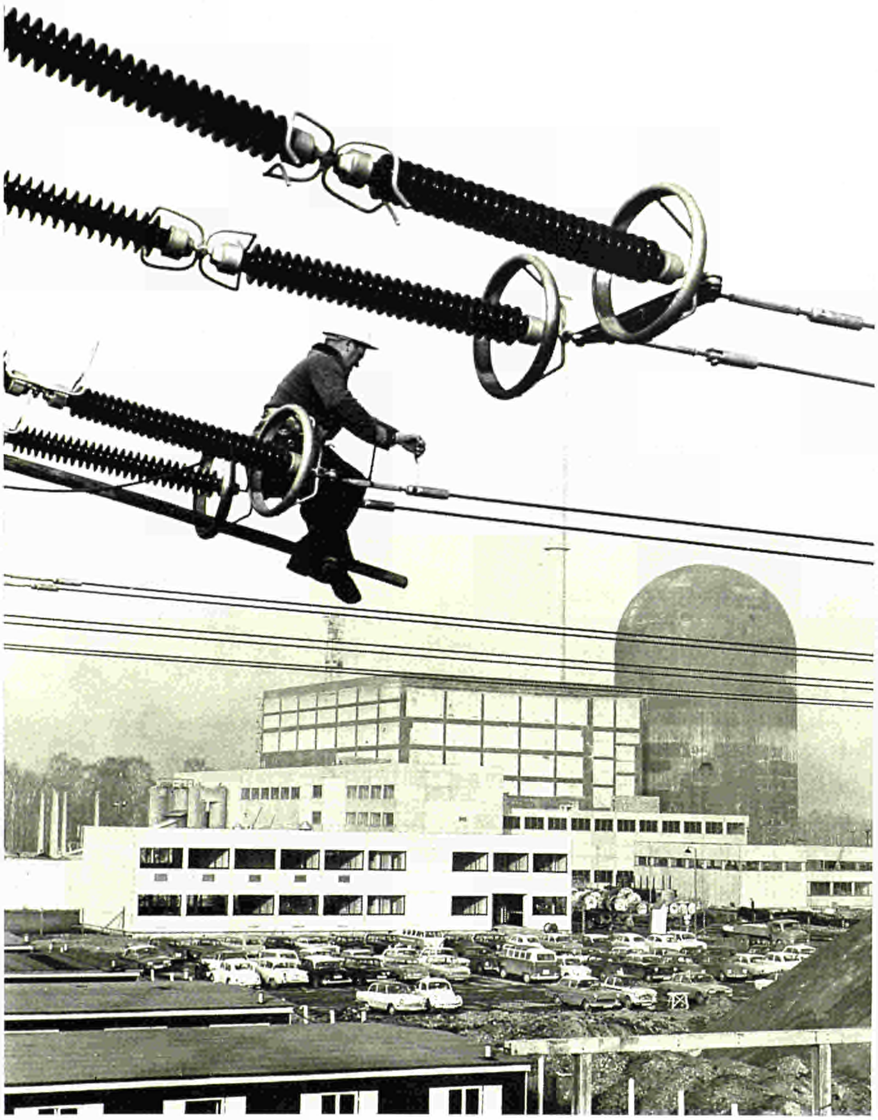
Euratom signs contract with USAEC for KRB reactor fuel

The Euratom Supply Agency signed on 19 February 1966 two contracts for the supply of enriched uranium fuel for the *KRB (Kernkraftwerk RWE-Bayernwerk)* 237 MWe power reactor at Gundremmingen, near Ulm, German Federal Republic. The first, under the US-Euratom Co-operation Agreement, was with the *United States Atomic Energy Commission (USAEC)* for the supply of 2,000 kg. of contained uranium-235 in uranium enriched to an average of 2.5% and valued at approximately $ 15 million. The second, between *KRB* and the Supply Agency, covers the transfer to the German firm of the right to use and consume the fuel supplied by the *USAEC* under the first contract.

Under this contract, the *USAEC* has offered an ad hoc barter arrangement to the Community pending entry into full operation on 1 January 1969 of the *USAEC*'s full toll enrichment policy (under which natural uranium supplied by the consumer is enriched by the *USAEC*). In this case the Supply Agency and *KRB* will supply natural uranium which they have acquired directly as partial payment for the enriched material to be delivered.

Along with all other nuclear materials supplied to or produced in the Community, the fuel supplied under this contract is directly and automatically subjected to the Euratom Security Control System.

Under this control system, all holders of nuclear materials must declare to the Euratom Commission the technical characteristics of their installations and submit monthly material balances and inventory reports. These declarations are verified through inspections carried out by Euratom inspectors. This system assures in particular that the guarantees concerning the peaceful use of nuclear materials which the Community has underwritten in agreements with the supplier countries are respected. The system has now been in operation for seven years and applies to 160 installations.



Gundremmingen nuclear power plant

Reprocessing of Euratom fuels by Eurochemic

On 7 March 1966, the Euratom Commission and the *Société européenne pour le traitement chimique des combustibles irradiés*, better known by the name of *Eurochemic*, signed a contract relating to the reprocessing of fuels unloaded from the *HFR* (Petten) and *BR-2* (Mol) research reactors. A quantity of approximately 4,000 kg of uranium/aluminium alloys will have to be reprocessed during 1967 and 1968.
It is after examining the various existing possibilities, both in and outside the Community, that Euratom decided to award the contract to *Eurochemic*, a joint enterprise of the *OECD* nuclear energy agency *(ENEA)*, whose plant at Mol will be starting up in July this year.

Symposium on accidental irradiations

A *symposium on accidental irradiations*, held by Euratom at Nice from 26 to 29 April 1966, was attended by representatives from the 6 member states of the European Community, as well as from non-member countries and the international organisations concerned.
The symposium had a dual objective: on the one hand to derive from the information gained on the most serious accidents the lessons to be drawn for dosimetry, industrial medicine, industrial hygiene and the administrative setup for the various radiological safeguards departments, and on the other hand to take stock of the most up-to-date information calculated to bring about improvements in dosimetry techniques and accident therapy.

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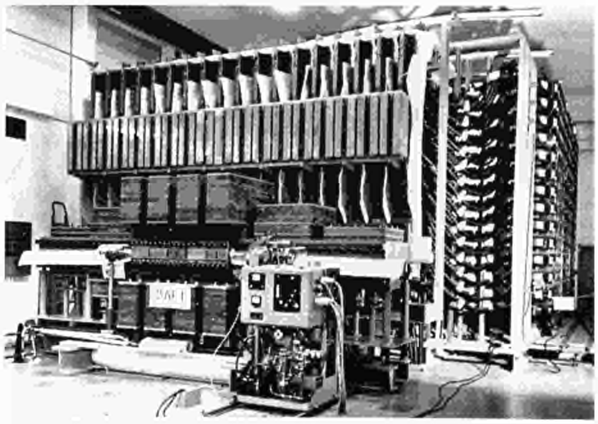
60 million degrees in Garching

A few weeks ago a newsflash announced that the scientists of the *Institute for Plasma Physics* at Garching, near Munich, had obtained a hydrogen plasma with one of the highest ion temperatures on record: 60 million degrees Centigrade, which is about three times the temperature inside the sun. The experiment which yielded this result was carried out in a cylinder some 150 centimetres in length inside which heavy hydrogen atoms were compressed to form a thin pencil of plasma, only a few millimetres in diameter. Some 150 million kilowatts of electrical power, unleashed for ten microseconds by a capacitor bank, were necessary to generate the magnetic field which compressed the plasma, thus bringing it up to such a high temperature.
Experiments had been carried out before in other laboratories in which similar densities were obtained and comparable amounts of energy were supplied, but somehow energy losses were such that the maximum obtainable ion temperature seemed to hit a ceiling of the order of 40 million degrees. It was recognised that the electrons present in the plasma were primarily responsible for this (a fully ionised hydrogen plasma is made up not only of ions, i.e. hydrogen nuclei, but also of the electrons set free by ionisation): the electrons, which could only be heated up to the comparatively low temperature of the order of 4 million degrees, acted as a drag on the achievement of high ion temperatures.

Various explanations were put forward, some more pessimistic than others. As for the Garching group, it thought that it could well be merely the presence of impurities that put a limit on electron temperature. Electrons are, even assuming an absolutely

Plasma Physics Institute *at Garching, near Munich. 1.5-2.6 MJ capacitor bank intended for the production of very-high-temperature and high-density plasmas by theta pinch.*



pure plasma, subject to losing energy through *Bremsstrahlung* radiation, which is consequent mainly on the collisions which take place between electrons and ions, but this effect is increased if impurities are present. To this has to be added the fact that the impurities themselves lose energy through radiation at a still higher rate and thus contribute to a general degradation of temperature.
In Garching, the view was taken that these effects played a crucial part and that it was therefore worth while to reduce impurities to a minimum. In fact, by reducing them by a factor of ten with respect to their own previous experiments, electron temperature was pushed up from 4 to 20 million degrees. There was therefore less drag on the ion temperature, which could rise to 60 million degrees.
However, the end of the road to practical thermonuclear fusion is still a long way off. To give an idea of the distance still to be covered, it is enough to point out that the temperature of 60 million degrees was held for about one hundred thousandth of a second only, whereas, at the gas densities used, several hundredths of a second would be required to make it possible for a substantial thermonuclear reaction to set in. In order to try and get nearer to this order of magnitude, the Institute is proceeding with further experiments, in which recent and encouraging progress in the mastering of instabilities will be exploited.
The *Institute for Plasma Physics*, which is an institute of the *Max-Planck Gesellschaft*, has a staff of 732. It is associated with Euratom, which pays one third of its running costs.

A programme of interdisciplinary training

The European Atomic Energy Community has recently concluded an agreement with the Free University of Brussels, the University of Leyden, the Max Planck Institute at Munich, the *Commissariat à l'énergie atomique* (French Atomic Energy Commission) Paris, the *Centre national de la recherche scientifique* (National Centre for Scientific Research) Paris, the *Consiglio Nazionale delle Ricerche* (National Research Council) Rome and the *Comitato Nazionale per l'Energia Nucleare* (Italian Atomic Energy Commission) Rome. The object of the agreement is to carry out jointly *a programme of interdisciplinary training for young research scientists, in the parallel fields of molecular biology and radiobiology.*
The organisers' specific aim is to give young physicists and chemists an opportunity of meeting the group of research workers—of whom there are too few in the Community—engaged on modern biological research.
The contracting organisations will turn by turn hold a yearly *course*, lasting about a month and centred on a subject in molecular biology or radiobiology.
The course will comprise a theory section, practical work and seminars. The programme will be drawn up each year by the organising committee, whose members include Professors J. Brachet (Brussels), A. A. Buzzati-Traverso (Naples), J. A. Cohen (Leyden), J. Coursaget (Paris), F. Kaudewitz (Berlin), A. Monroy (Palermo) and C. Sadron (Strasbourg).
Grants will be awarded to a certain number of applicants.
No charge will be made for participation in the course. Applicants for the course and for grants must, in principle:

- come from a member country of the European Atomic Energy Community;
- hold a university degree;
- have one or two years' practical experience of scientific research;
- have a satisfactory knowledge of another Community language.

Awards of grants and admission to the course will be adjudged by the organising committee.
A notice was recently sent to Community universities and research institutes, advising them of the programme for the forthcoming course and of the procedure for applying for the course and for grants. The general subject chosen for 1966 is "Replication, transcription and expression of genetic information".
Any further information can be obtained from the following address:
Secretariat du cours de biologie moléculaire et de radiobiologie, 51-53 rue Belliard, Brussels 4.

Journal of Labelled Coumponds

The Journal of Labelled Compounds, a quarterly, was first issued early in 1965. Its aims are to publish papers on new methods of preparing labelled compounds, on the improvement and generalisation of methods already known and on all problems directly relevant to the preparation of labelled compounds, such as purification, analysis and storage. It is edited by J. Sirchis, Euratom, and published by Presses Académiques Européennes, 98, chaussée de Charleroi, Brussels 6.

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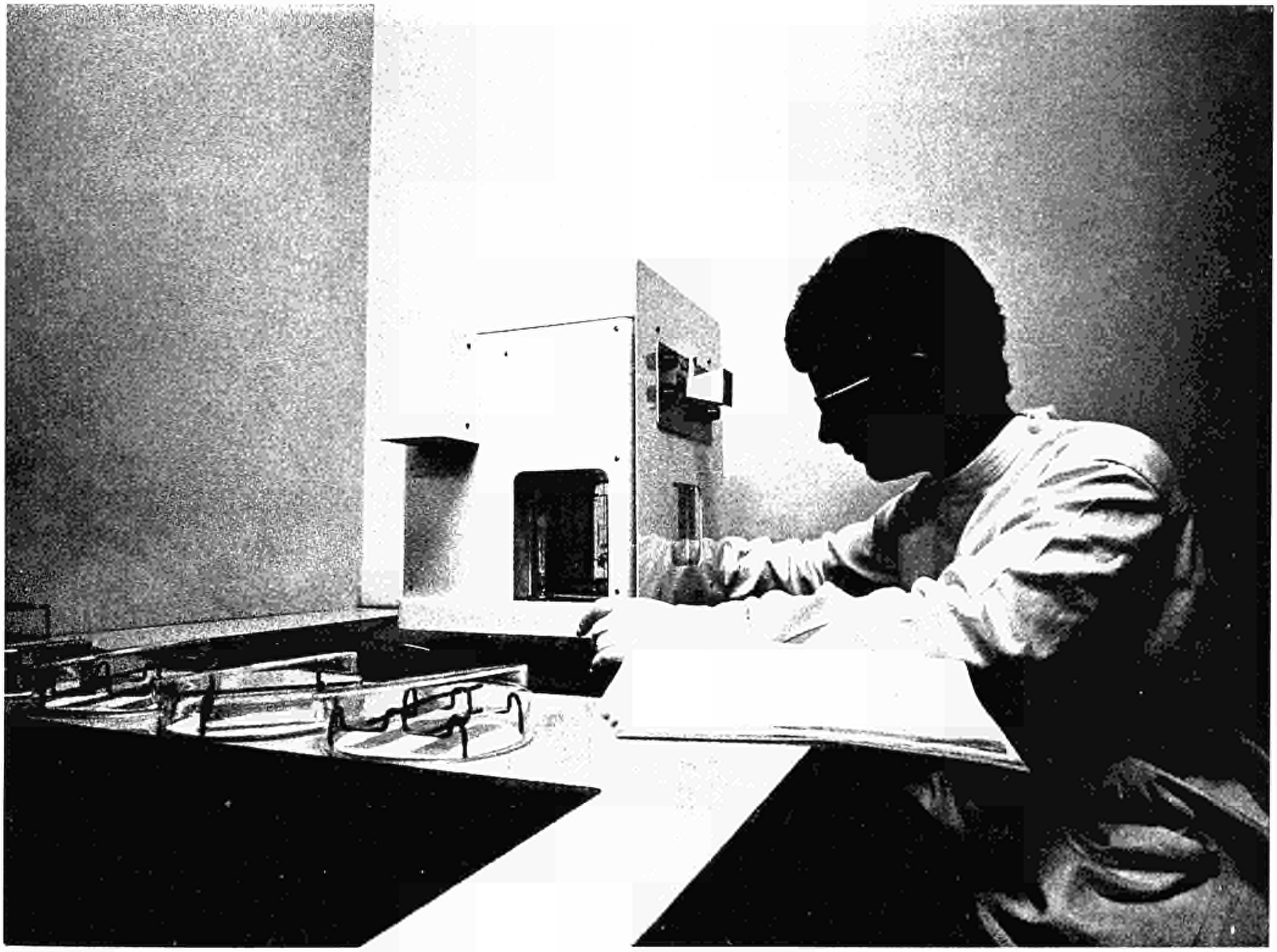
Cooperation between Euratom and the International Bureau of Weights and Measures

The staff of Euratom's *Central Nuclear Measurements Bureau*, the laboratories of which are located at Geel (Belgium), have been collaborating for some time now with the *International Bureau of Weights and Measures* at Sèvres (France), a fact which has naturally led both staffs to wish for a further strengthening of their ties, mainly by exchange of information, consultations, and by sending observers to represent them at meetings held on subjects of common interest.

This wish has been granted through an exchange of letters which took place recently between Euratom and the International Bureau.



Central Nuclear Measurements Bureau, Geel (Belgium): Weighing room

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