EUROPEAN ATOMIC
ENERGY COMMUNITY

EURATOM

THE COMMISSION

REPORT ON THE POSITION OF NUCLEAR INDUSTRIES IN THE COMMUNITY

Brussels — June 30, 1958 — Luxembourg

The President
and the
Members of the Commission
to
The President of the Parliamentary Assembly

Mr. President,

Article 213 of the Treaty establishing the European Atomic Energy Community states that the Commission shall, within a period of six months of entering upon its duties, address a report to the Assembly on the position of the nuclear industries within the Community.

In accordance with the provisions of this article, we have the honour to submit to you the following Report.

Please accept, Mr. President, the expression of our high consideration.

June 30, 1958

Louis ARMAND
President

Enrico MEDI
Vice-President

P. DE GROOTE

H. KREKELER

E.M.J.A. SASSEN

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INTRODUCTION

In accordance with Article 213 of the Treaty establishing the European Atomic Energy Community, the Commission shall, within six months of taking up its duties, furnish the Assembly with a Report on the position of nuclear industries within the Community.

The present Report has been prepared within the prescribed time and the Commission hopes that it will give the Assembly a preliminary impression of the progress already made in the nuclear field within the Community.

The purpose of this Report is to give a general survey, the imperfections of which should be recognized and explained, rather than concealed. To give an exact, objective account of all that has been done in the nuclear field within the Community would have required far more time than six months, a more complete administration than is possible in a newly-created organization, and a better coordinated system of documentation and statistics than is available at the moment. However, notwithstanding the obvious shortcomings of a report of this kind, it has been prepared in a far shorter time than would have been possible if perfection had been the aim. The preparation of this survey has made it possible to establish contact with the various atomic industries of Europe and, on a broader plane, with all those concerned with atomic energy ; they form a basis for the work which Euratom has to carry out in the field of documentation and statistics. In accordance with the wishes of the Commission this investigation has been made keeping the formalities, questionnaires and correspondence with the institutions and firms concerned with nuclear energy to a minimum. It will always be a cardinal point of policy with Euratom not to involve the members of the Community in intricate formalities, questions of procedure and excessive paperwork ; at the same time, however, the Commission will endeavour to obtain indispensable information from the appropriate sources. The collaboration so far offered on all sides has been most encouraging, and the Commission wishes to express its thanks to all those concerned. This willing cooperation is a good sign for the future.

This first Report will in due course be systematized and enlarged in order to provide the sort of detailed information required by a large Atomic Energy Community, which aims at greater efficacy through coordination of its efforts — a Community with a free hand to act, yet aware of the weaknesses of inconsequent and uncoordinated action.

It was not possible to undertake an exact study of the achievements and prospects of the Members of the Community in relation to those of other countries in the nuclear field, since there was not sufficient time to examine critically all the sources of information and estimates. Particular attention will be paid to this question in future reports issued by the Commission.

The subdivisions adopted in the present Report result from the methods employed in obtaining the information. They will later be modified as more exact and detailed information becomes available. Finally, thanks to the intended policy of Euratom for close cooperation with the European Coal and Steel Community and with the European Economic Community, it is hoped in the future to define more accurately the present position and the future possibilities of nuclear energy within the framework of the general economy of power production.

Having duly pointed out the shortcomings inherent in the present Report, the Commission now wishes to submit it to the Assembly for its critical and serious consideration.

To facilitate the reading of this Report, some of the basic notions and terminology involved in nuclear energy are clarified in an appendix.

CHAPTER I

NATIONAL AND INTERNATIONAL ORGANIZATIONS

1.1. INTRODUCTION

To deal with the many new problems arising from the use of nuclear energy, specialist bodies have been created, not only by private and public undertakings, but also by the State.

Instead of employing the traditional administrative structure, most countries have created « Commissions » for atomic energy. The Federal Republic of Germany has a special Ministry for the purpose.

Various undertakings have formed « syndicates » or « groups », within which they collaborate in a number of different ways, in some cases even pooling their manpower, technical and financial resources. They also form professional groups, which aim at establishing relations with public bodies and authorities, and also with international organizations.

To ensure that sufficient numbers of qualified personnel will be available both for research and for the practical application of the new techniques necessitates immediate action in adapting educational programmes both at university level and in the technical and professional spheres.

The use of nuclear energy may involve certain risks for the operating personnel and for the population as a whole. It is expedient, therefore, to develop methods to ensure protection against such hazards.

The peaceful use of nuclear energy has led to considerable international activity, both governmental and private. Organizations have been founded, such as the European Organization for Nuclear Research (CERN), the International Atomic Energy Agency, and the European Nuclear Energy Agency. At the same time, other organizations already in existence but not specifically concerned with nuclear energy have turned their attention to the same problems ; they include the Western

European Union (WEU), the International Labour Organization (ILO), the World Health Organization (WHO), and the Food and Agriculture Organization of the United Nations (FAO).

1.2. NATIONAL ORGANIZATIONS

1.2.1. **Belgium**

1) *Public Sector*

There are four organizations :

- The *Commissariat à l'énergie atomique* (Commission for Atomic Energy),
- The *Ministère des affaires économiques* (Ministry for Economic Affairs),
- The *Commission Nationale pour l'étude de l'utilisation pacifique de l'énergie nucléaire* (National Commission for the Study of the Peaceful Use of Atomic Energy),
- The *Institut interuniversitaire des sciences nucléaires* (Combined Universities Institute for Nuclear Science).

The most specialized work is done by the *Commissariat à l'énergie atomique* (Commission for Atomic Energy), which was formed in 1951.

The aims and functions of this Commission are :

- To keep abreast of research and development in nuclear science, in Belgium as well as abroad, and to take the necessary steps to enable Belgium to benefit from all important developments ;
- To ensure coordination of all activities in the field of nuclear energy ;
- To promote all measures likely to further Belgian interests, particularly in respect to research, the acquisition of radioactive minerals, and the utilization and application of new knowledge in the field of nuclear science.

In the *Ministère des affaires économiques* (Ministry for Economic Affairs) there exists under the Department for Industrial Administration a section dealing with the use of nuclear energy.

The *Commission nationale pour l'étude de l'utilisation pacifique de l'énergie nucléaire* (National Commission for the Study of the Peaceful Use of Nuclear Energy) furnishes the government with advice and information on :

— The organization of nuclear research ;

— The promotion of the industrial use of atomic energy ;

— International cooperation in the peaceful use of nuclear energy.

The *Commission* consists of representatives of the various public and private institutions concerned, e.g., the nuclear industry, the electricity producers, the universities, and the public authorities. It is presided over by the Minister for Economic Affairs.

The *Institut interuniversitaire des sciences nucléaires* (Combined Universities Institute for Nuclear Science) was formed in 1947 as an independent body within the *Fond National de la Recherche Scientifique* (National Fund for Scientific Research). Its aim is to encourage, promote and coordinate study and research in the nuclear sciences, with the exception of the field of the applied sciences, in establishments for higher education and research in Belgium and the Belgian Congo.

2) *Combined Sector (Public and Private)*

The joint activities of the public authorities and private interests are of great importance in Belgian nuclear organization. Mention should be made in particular of the Centre for Nuclear Research and the Belgian Association for the Peaceful Development of Nuclear Energy.

The *Centre d'étude de l'énergie nucléaire* (CEN - Centre for Nuclear Research), whose present statutes were laid down in 1957, is recognized as constituting a public utility. It is presided over by the *Commissaire général à l'énergie atomique.* Its executive committee is composed of representatives of industry, scientific bodies and the public authorities.

The functions of the Centre are to undertake comprehensive research on the applications of nuclear energy and to promote and encourage the scientific and technical study of these applications.

The CEN founded the Research Centre in Mol. A research reactor has been in operation there since 1956. In addition, a high flux reactor for the testing of materials and an experimental nuclear power station with a capacity of 11,500 kWe (1) are already under construction. The Research Centre possesses chemical, physical, metallurgical, and electronics laboratories, and medical, agronomical and biological laboratories will eventually be added. It has also established a large documentation library devoted to nuclear science and allied subjects.

On completion of the present programme of development in 1960, the total expenditure on the Centre at Mol, which costs about 4 million EPU units a year to operate, will have reached a sum of 50 million EPU units.

The *Association belge pour le développement pacifique de l'énergie atomique* (Belgian Association for the Peaceful Development of Atomic Energy) is a non-profit-making organization whose object is to study and further the peaceful use of nuclear energy.

This Association may participate in the activity of international organizations, set up study groups and committees to deal with publicity, and form a centre for documentation. It aims, in particular, at supplying information for young people ; it arranges visits to factories and plants, organizes lectures and exhibitions, and awards research scholarships.

3) *Private Sector*

Private firms have combined to form one professional body and a number of associations for research and the practical applications of nuclear energy.

A *Groupement professionnel de l'industrie nucléaire* (Professional Association for Nuclear Industry) was created in 1957. Its aim is to act on behalf of all the interests in the private sector in order to ensure that they are adequately represented in national and international organizations and given proper support. It comprises about seventy firms now already actively engaged in various branches of atomic industry. (2)

The Professional Association has also set up and directs a *Fondation nucléaire,* whose aim it is to assist in the develop-

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(1) The units and symbols employed in this Report are given in Appendix 3.

(2) The appendix to this chapter gives a list of the associations and concerns operating in the various branches of atomic industry.

ment of research, particularly by creating and subsidizing organizations dedicated to this task. The entire contribution of private industry to the budget of the CEN is made through the Foundation.

Numerous firms in various branches of industry have developed special departments for putting into practice the special techniques required in the field of nuclear power. In addition, research centres and specialized firms have been set up.

The *Syndicat d'étude de l'énergie nucléaire* (SEEN - Nuclear Energy Research Syndicate), which comprises twenty-two undertakings, is concerned with the training of specialists, the study of nuclear techniques, and their application in industry. It can also form commercial companies to develop or utilize commercially the results of its work.

The *Syndicat d'étude des centrales atomiques* (SYCA - Association for the Study of Atomic Power Stations) comprises eight undertakings. Its aims are :

— To study the establishment and operation of plants for producing electric power based on nuclear energy ;

— To take any action directly or indirectly connected with the above ;

— To form, if necessary, commercial undertakings to develop, in whole or in part, the work of the *Syndicat* or to apply its findings commercially.

Furthermore, five companies, which design plant used in the production, transport and distribution of electricity, have formed a commercial company operating as consulting engineers for the construction of power stations and other nuclear installations.

A company has been formed by undertakings specially interested in the manufacture of reactors and fuel elements, the chemical processing of irradiated nuclear fuels, and the production, distribution and use of radio-isotopes. It is noteworthy that this company has no monopolistic rights and the firms concerned have retained full freedom of action in these fields. In actual fact, there are many undertakings with the same aim as this company working either individually or collectively.

4) *Public Utilities*

The electricity authorities of Liège and Ghent, the *Société coopérative liégeoise d'électricité* (Cooperative Electricity Society of Liège) and the *Association liégeoise d'électricité* (The Electricity Association of Liège), have formed an organization called the *Syndicat des entreprises publiques pour l'étude et la construction des centrales nucléaires* (Association of Public Undertakings for the Study and Construction of Nuclear Power Stations).

1.2.2. Federal Republic of Germany

1) *Public Sector*

At the end of 1955 a Parliamentary Committee for Atomic Energy was formed in the Bundestag. This committee deals with all questions relating to research on and utilization of nuclear energy for peaceful purposes.

By a decree of the Federal Government dated October 6, 1955, a *Bundesministerium für Atomfragen* (Federal Ministry for Atomic Affairs) was created. In October, 1957 this Ministry was also made responsible for water supply and given the title of *Bundesministerium für Atomkernenergie und Wasserwirtschaft* (Federal Ministry for Nuclear Energy and Waterworks).

As far as nuclear questions are concerned, this Ministry has two departments :

Department I : Legal and economic questions, administration, international cooperation ;

Department II : Research, technical matters, protection against radiation.

The Ministry for Nuclear Energy and Waterworks is assisted by the *Deutsche Atomkommission* (German Commission for Atomic Energy), an advisory body created by government decree on December 21, 1955. This Commission works under the authority of the Federal Minister for Atomic Energy and Waterworks and is composed of men prominent in the sciences, in industry and in public life.

Working with the German Commission for Atomic Energy are five commissions of experts dealing with legislation in the field of atomic energy, research and training, the technical and economic aspects of reactors, and economic, financial and social questions. Some two hundred persons are employed in an advisory capacity in these commissions and in the various special working parties associated with them.

It is the conviction of the Federal Government that the peaceful use of atomic energy in the Federal Republic of Germany should be left in the hands of private industry. The State should concentrate on promoting research and the training of adequate scientific personnel. The State will only take direct action insofar as this is necessary to ensure the safety of personnel employed in atomic plants or the security or safety of the general public. Industrial concerns in the nuclear field receive State aid only in the early stages of their development.

This attitude is also reflected in the provisions of a federal atomic law which is still in the committee stage. In the absence of federal atomic legislation, the necessary laws during the initial period were passed by the various Länder governments. The Federal Government considers that nuclear legislation on a federal basis is a matter of extreme urgency and this opinion is shared by the governments of the Länder.

It is the policy of the Federal Ministry for Nuclear Energy and Waterworks, whilst preserving freedom of research and teaching, to promote research and the development of nuclear techniques, and also to encourage private initiative in the nuclear field. Furthermore, the Ministry endeavours to further international cooperation through bilateral and multilateral agreements concluded on a non-preferential and reciprocal basis.

The Ministry's budget for the financial year 1957 allows for an expenditure of 20 million EPU units. The Federal budget proposals for 1958 grant the Ministry for Nuclear Energy and Waterworks a sum of 34 million EPU units, to which are added an extra 11 million EPU units allotted under other items of the federal budget. A considerable part of these funds is assigned for research-aid and to encourage the training of new personnel.

Research and development work in the field of nuclear energy is also subsidized from funds allotted by the budgets of the various Länder as well as by industry.

Other institutions created by the State are the Atomic Energy Commissions which advise the governments of certain Länder. The members of these commissions are generally also members of the German Commission for Atomic Energy, mentioned above.

2) *Combined Sector (Public and Private)*

An example of collaboration between state-owned and private industry is the *Kernreaktor Bau- und Betriebsgesellschaft mbH* (Limited Liability Company for the Building and Operating of Nuclear Reactors), founded in 1956 in Karlsruhe. Half of the registered capital of this undertaking belongs to private industry, and of the other half, 60 % is subscribed by the federal budget and 40 % by the budget of Baden-Württemberg. Industry is represented by the *Kernreaktor-Finanzierungs-Gesellschaft mbH* (Limited Company for Financing Nuclear Reactors). (1)

3) *Private Sector*

Amongst the business organizations which have formed special committees on the peaceful use of atomic energy, mention can be made of the *Bundesverband der Deutschen Industrie e.V.* (BDI — Federation of German Industry) in Cologne and the *Vereinigung Deutscher Elektrizitätswerke* (VDEW — Federation of German Electricity Undertakings) in Frankfurt-am-Main.

In addition, various industrial working parties composed mainly of electricity producers have been formed for the construction of nuclear power stations. These groups are :

- *Studiengesellschaft für Kernkraftwerke GmbH* (SKW — Company for the Study of Nuclear Power Stations) in Hannover. This Company comprises four undertakings.
- *Arbeitsgemeinschaft Deutscher Energieversorgungsunternehmen zur Vorbereitung der Errichtung eines Leistungsversuchsreaktors e.V.* (AVR — Association of German Power Supply Companies for Preparing the Construction of an Experimental Power Reactor) in Düsseldorf. It comprises nine undertakings.
- *Arbeitsgemeinschaft Baden-Württemberg zum Studium der Errichtung eines Kernkraftwerkes* (Baden-Württemberg Association to Study the Construction of a Nuclear Power Station) in Stuttgart. It comprises six undertakings.
- *Gesellschaft für die Entwicklung der Kernkraft in Bayern mbH* (Company for the Development of Nuclear Energy in Bavaria) in Munich. Although this company comprises five

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(1) See appendix to this chapter.

undertakings and in addition, includes the Bavarian state as a member, it nevertheless operates as a private concern much in the same way as the other organizations mentioned above.

1.2.3. France

1) *Public Sector*

In France activity in the nuclear field centres on the *Commissariat à l'Energie atomique* (CEA — Atomic Energy Commission), which was created by statute on October 18, 1945, after the almost complete suspension in that country of research and progress in the field of atomic energy more than five years earlier. The object of the CEA is to prepare the way for the use of nuclear energy in the various branches of science, industry and national defence in France.

Placed under the authority and control of the Président du Conseil des Ministres (the French Premier), the CEA has a status unique in France. It is a public undertaking, administratively and financially independent; its interests range from the purely scientific to the technical and industrial aspects of atomic energy.

The CEA is controlled by the *Comité de l'Energie atomique* (Committee for Atomic Energy), which is composed of ten members chosen from top ranking civil servants, scientists and industrialists. This committee is presided over by the Président du Conseil (the French Premier) or by his deputy. In case of their absence the committee is under the chairmanship of the Administrateur général, a Government representative. The latter is also in charge of administration and finance, whilst the Haut-Commissaire is responsible for the scientific and technical side of the *Commissariat.*

Liaison between public services, state institutions and universities is ensured by certain advisory bodies, namely the *Conseil scientifique* (Scientific Board), the *Comité des Mines* (Committee for Mines) and the *Comité de l'équipement industriel* (Committee for Industrial Plants).

The CEA has drawn up two five-year plans, 1952-56 and 1957-61, which aim at laying the necessary foundations for the industrial use of atomic energy in France. The second five-year plan will involve the cooperation of a large number of administrative departments, important public undertakings (in particular *Electricité de France*) and a substantial section of French industry. Its basic aims cover three fields :

— The production of energy in the form of heat and electricity;

— Propulsion by means of nuclear engines;

— The utilization and the distribution on a commercial basis of artificially produced radio-isotopes in medicine, agriculture, industry and research.

The CEA has three nuclear research centres at Fontenay-aux-Roses, Saclay and Grenoble.

The task of utilizing nuclear energy to produce electricity for general distribution has been entrusted to a public utility, the *Electricité de France* (EDF).

2) *Private Sector*

An association for the special technical developments involved in the production and use of nuclear energy has been created under the patronage of the CEA and *Electricité de France*. This association is called the *Association technique pour la production et l'utilisation de l'énergie nucléaire* (ATEN — Technical Association for the Production and Utilization of Nuclear Energy). It is particularly concerned with the acquisition of markets for this new form of power, both at home and abroad. (1)

Other groups have been formed by concerns specializing in different fields with a view to studying and designing industrial plant for the release and utilization of nuclear energy.

One of these groups, for example, includes a number of specialist firms for glass and chemical products, aluminium, graphite, beryllium, stainless steels, workshop techniques, forgings, pressure tubes and tanks, water turbines, electrical parts, cables and electronics.

Other more highly specialized groups are concerned partly with supplies, partly with the development of auxiliary equipment for atomic energy and partly with the design of parts for industrial plants.

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(1) See list of members in the appendix to this chapter.

3) *Public Authorities in Collaboration with Business Concerns*

In France, as in most other countries, the public authorities have set themselves a dual aim :

— To play a considerable part in creating a nuclear infrastructure in the initial and most costly stages;

— To coordinate the activity of private firms and to facilitate the transition to nuclear technology.

The important role of the CEA has already been mentioned. It should be added that, in the field of nuclear power, the State has a virtual monopoly of orders placed; orders which are not financed by the CEA are either financed by the *Electricité de France,* a nationalized undertaking, or by various Ministries.

Collaboration, particularly between industry and the CEA, has been most effective, both in the exchange of research experience and in the conclusion of manufacturing and building contracts. The CEA is concerned with basic studies and laboratory research; in order to coordinate the work and benefit from the research carried out by the CEA, industry collaborates with the CEA already at research level. The relationship between the CEA and industry is the same as that between the laboratory and the design and development department of a factory.

Industry was soon called in to assist in what may be termed the specific tasks of the CEA and played an active part in the building of such factories as the uranium factory at le Bouchet, the second uranium refinery which is due to be erected at Narbonne, the new urano-thorianite factory at le Bouchet and the two factories for chemical concentrates at Vendée and Limoges. Cooperation with industry is particularly important in the case of the Marcoule Centre. In each case the main contract was given to a single company.

So far, after once completing the necessary preliminary work, the CEA has remained in charge of construction and has supervised the subsequent work carried out by industry.

In future the CEA will in the main not itself execute any building projects in the nuclear field, but it will as before play an important part in general research, in the study, construction and operation of prototypes, in the treatment of nuclear fuels, and in the capacity of consultant to industry.

It is in this way that the CEA will cooperate in the so-called « associated » programmes, especially in the construction of nuclear power stations, whose building and operation will be the responsibility of the *Electricité de France.*

On the whole, French policy is similar to that pursued from the start by the United States, where the general contracts for the construction of non-military atomic energy establishments are given to industrial groups, whose work is supervised by a Government commission. In France, however, the CEA was obliged to bring into operation several uranium mines itself.

1.2.4. Italy

Three main organizations — two of them public enterprises and one semi-public — are concerned with the study of nuclear power and the problems relating to its utilization. In addition, some firms have formed groups to fulfill certain tasks in connection with the utilization of atomic energy.

1) *Public Sector*

The principal, official organization for the development of nuclear power in Italy is the *Comitato Nazionale per le Ricerche Nucleari* (CNRN — National Commission for Nuclear Research).

The CNRN was formed by decree of the Premier in June 1952.

Since then, Government and Parliament have on several occasion endeavoured to secure legislation in nuclear affairs. The latest legislative proposal was put forward by the Minister for Industry and Commerce in the Senate on December 12, 1957. This proposal suggested a budget for nuclear research for a period of five years. It also suggested that the scientific work of the CNRN should be the responsibility of the Minister for Education whereas its industrial activities should be controlled by the Minister of Industry and Commerce.

The governing body of the CNRN has a president, two vice-presidents, seven professionally qualified members and a general secretary.

The CNRN has four main aims :

1) To carry out studies, research and experimental work, both in the pure and the applied fields;

2) To organize and encourage the uses of nuclear energy;

3) To organize the training of a staff and to coordinate the future programme on a national and an international basis.

4) To participate in international atomic development.

In the six years since the formation of the CNRN it has largely succeeded in laying the necessary technical foundations for nuclear research in Italy. This has been done by creating two important organizations :

- The Centre for Applied Nuclear Research at Ispra, where a nuclear research reactor of the type CP-5 is at present under construction (2 million EPU units for the reactor, plus 7 million for the associated laboratories).

- The Centre for Research in Pure Physics at Frascati, which has a 1,000 MeV synchrotron.

Other aims of the Commission are :

- To carry out systematic *geological and mineralogical investigations* with a view to assessing Italy's potential uranium resources and the possibility of obtaining an indigenous supply of nuclear fuels.

- To carry out *technological studies* for the production of special nuclear materials. One of the most significant results of this has been the construction of an experimental plant for producing metallic uranium.

- To undertake the *technical study of prototype power reactors* in order to determine the path Italy should follow in this field;

- *To study the applications of nuclear energy in agriculture and medicine;*

- *To study the use of electronic equipment in nuclear installations* and especially in connection with the synchrotron experiments at Frascati and the test reactor and prototypes;

- *To study the properties of ionized gases.*

The budget of the CNRN as fixed by the « interim law » of December 12, 1957 is 80 million EPU units for the next five years. Of this amount a total sum of 29 million is allowed for the financial years 1958 and 1959.

The *Istituto Nazionale di Fisica Nucleare* (INFN — National Institute for Nuclear Physics) became a subsidiary organization of the CNRN at the beginning of 1957. This organization is now financed partly by the CNRN and for certain special purposes from other public or private sources.

The INFN is concerned with problems of basic research. Later on it will direct the Frascati national laboratory for the CNRN.

The INFN at present has six branch departments in the Universities of Rome, Milan, Padua, Turin, Pisa and Bologna and sub-departments in the Universities of Florence, Genoa and Trieste, as well as in the University Institute for Health in Rome, the Polytechnical Institute in Milan and the Institute of Theoretical Physics at Naples.

The *Centro Applicazioni Militari Energia Nucleare* (CAMEN — Centre for Military Applications of Nuclear Power) was founded on the initiative of the University of Pisa and the Naval Academy at Livorno. The CAMEN is planning the construction of a nuclear research laboratory at a cost of more than 3 million EPU units which will comprise various departments (engineering, physics, chemistry, biology) and a « swimming pool » reactor.

The present, temporary seat of the CAMEN is at the Naval Academy of Livorno pending the construction of a suitable centre in the vicinity of Livorno itself.

2) *Combined Sector (Public and Private)*

The *Centro Informazioni Studi Esperienze* (CISE — Centre for Information and Research). Formed at the end of the war, this organization was a first attempt to reorganize Italian activity in the field of nuclear power. It was formed by a number of private industrial undertakings at the end of 1945 and from it have come a large proportion of the nuclear technicians and research-workers now employed in Italy. (1) Although various public undertakings have recently joined the CISE, the nature of its work has not changed, and it is still an organization for pure and applied research and for consultation.

Of the many tasks accomplished by the CISE the following deserve special mention :

— The study of a research reactor (the CP-5 of the CNRN);

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(1) See list of participating concerns appended to this chapter.

- The planning and construction of a pilot plant for the production of metallic uranium;
- The planning and construction of a pilot plant for the production of heavy water.

3) *Private Sector*

A large number of Italian firms are engaged in the production of materials and equipment for the nuclear industry.

Other concerns are engaged in the construction of nuclear power reactors and have drawn up nuclear development programmes. They have formed various associations, all working in a private capacity, although in some of them the State or certain public undertakings are represented. Some of the more important of these power producing associations are the following :

- The AGIP Nuclear Group and its subsidiaries SOMIREN and SIMEA ;
- The SELNI — *Società Elettronucleare Italiana* — which comprises eight undertakings ;
- The SORIN — *Società Ricerche Impianti Nucleari* — consisting of two companies ;
- The SENN — *Società Elettronucleare Nazionale* — with thirteen companies.

1.2.5. **Luxembourg**

Combined Sector (Public and Private)

The *Conseil national de l'Energie nucléaire* (National Board for Nuclear Power), under the chairmanship of the Ministre de l'Energie, is composed of qualified representatives of industry and commerce.

The aims of this organization are :

- To study the economic, legal, financial and technical aspects of the utilization of atomic power especially in its application in industry;
- To participate in the study and work of similar foreign, international or supranational organizations.

1.2.6. The Netherlands

1) *Public Sector*

The *Commissie voor Atoomenergie* (Commission for Atomic Energy) has been entrusted with the task of advising the Dutch Government on questions relating to nuclear energy.

The Commission includes representatives of the various Ministries.

2) *Combined Sector (Public and Private)*

In Holland, as in other countries, there is close cooperation between the Government, electric power producers, and industry for the development of nuclear power. The national organization responsible for this development is the *Reactor Centrum Nederland* (RCN — Dutch Reactor Centre) which has the task of acquiring the necessary knowledge and experience, both scientific and technical, for developing the peaceful utilization of nuclear power and making it available to the population.

The present capital of this foundation, created in 1955, is 6.2 million EPU units, half of which has been contributed by the Government, a quarter by the electric power companies and a quarter by industry.

The power companies which finance the RCN, most of which are joint-stock companies, belong to the provincial and municipal authorities. They have formed a joint-stock company, the *Samenwerkende Electriciteitsproducenten* (SEP — Associated Electricity Producers) which is concerned with the exchange of power. They also have a joint institute for research, the *N.V. tot Keuring van Electrotechnische Materialen* (KEMA — Company for the Testing of Electrotechnical Materials) at Arnhem, which represents them within the administrative organs of the RCN.

The greater part of the capital of the RCN is employed for the construction of a high flux reactor, whilst another part (about one million EPU units) is used for research on homogeneous aqueous suspension reactors, work which the RCN has entrusted to the KEMA. The RCN also subsidizes various other research projects, as for example the designing of an ultracentrifuge for the separation of uranium isotopes.

The links between industry and the RCN are not solely of a financial nature. About forty-five large or medium-sized undertakings, have contributed some 25 % of the capital, and have thereby obtained certain rights. Their interests are represented by an *Industrial Commission.*

In connection with the construction of nuclear power stations the SEP has instructed the KEMA to establish a Commission for examining tenders sent in by undertakings in various countries for the construction of nuclear power stations.

Shipping interests are represented by the *Stichting Kernvoortstuwing Koopvaardijschepen* (SKK — Foundation for the Nuclear Propulsion of Merchant Ships), which was formed by the shipowners and shipbuilders. The RCN, the *Stichting voor Toegepast Natuurwetenschappelijk Onderzoek* (TNO — Foundation for Applied Scientific Research) and the Technical University of Delft are represented on the Board of the SKK. The SKK coordinates the nuclear research work carried out in this field for the shipowning, shipbuilding and marine engineering industries.

Apart from this, industrial activities are restricted to the conclusion of contracts for the supply of parts and the execution of nuclear development orders at the technical level.

Work on the utilization of nuclear energy in agriculture is centred at Wageningen, where the School for Advanced Agricultural Studies is situated. The *Instituut voor Toepassing van Atoomenergie in de Landbouw* (ITAL — Institute for the Application of Atomic Energy in Agriculture), which will be established here, will have its own research reactor, probably of Dutch design.

As far as documentation is concerned, a central organization is being set up as a result of action taken by a large number of institutions interested in the development of nuclear energy.

The *Documentatie-Centrum voor Atoomenergie* (DCA — Centre for Documentation on Atomic Energy) will be organized by the documentation department of the RCN and by the *Nederlands Instituut voor Documentatie en Registratuur* (NIDER — Netherlands' Institute for Documentation and Classification).

1.3. TEACHING

One of the main problems arising out of the development of the nuclear industry is manpower. To deal with this problem attempts are being made in every country to develop an adequate system of university and technical training. The importance of this question is illustrated by the fact that the authors of the Treaty considered it essential to make it a special aim of Euratom. The Commission may establish special schools for the training of specialists within the framework of the common research centre. In addition, an institution of university standing will be established. This action of Euratom will strengthen the national efforts which are already showing tangible results. (1)

The following subjects relating to the applications of nuclear energy are taught in the universities, technical high schools and research centres :

— Nuclear physics as applied to nuclear energy. In 47 institutions in Belgium, Germany, France, Italy and the Netherlands and in a combined Dutch-Norwegian establishment.

— Theory of construction of reactors. In 27 institutions in the same countries and in the combined Dutch-Norwegian establishment.

— The technology of heat and thermodynamics applied to nuclear reactors. In 7 institutions in Belgium, France and Italy, and in the combined Dutch-Norwegian establishment.

— Electronic design and apparatus of importance in nuclear energy. In 20 institutions in Belgium, Germany, France, Italy, and in the combined Dutch-Norwegian establishment.

— The preparation and treatment of nuclear source and fissile materials. In 16 establishments in Belgium, Germany, France, Italy, and the Netherlands and in the combined Dutch-Norwegian establishment.

— The metallurgy of metals employed in the field of nuclear energy. In 13 institutions in Belgium, Germany, France, Italy and the Netherlands, and in the combined Dutch-Norwegian establishment.

— The prospecting and extraction of uranium and thorium ores. In 4 institutions in France and Italy.

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(1) The information given is based on a the OEEC report « 1957-1958 - List of Courses on Nuclear Energy in the Countries of the OEEC. »

- Production and utilization of radioactive isotopes. In 17 institutions in Belgium, Germany, France, Italy and the Netherlands, and in the combined Dutch-Norwegian establishment.
- The biological and chemical action of radiation. In 20 establishments in Belgium, Germany, France, Italy and the Netherlands.
- The economic aspects of nuclear energy. In 2 institutions in Belgium and Italy.
- Meteorology in its relation to nuclear energy. In 2 Italian institutions.

Similar efforts are being made in the field of professional training.

Some firms are training specialists by means of practical and theoretical training courses.

This vital question will be considered in greater detail in a future report. In view of the fact that no comparative information and details on the 6 countries are available, in a suitable form, this report is restricted to a general consideration of the position.

1.4. MEASURES TAKEN FOR PROTECTION AGAINST IONIZING RADIATION

Whilst welcoming the progress offered to humanity by the peaceful uses of nuclear energy, serious thought must be given to the immediate and long-term dangers which may result from the use of this source of energy. It is therefore vital to devote special attention to the problem of health-protection and that of safeguarding against nuclear hazards.

This question affects both the operating personnel working in nuclear industries and the population as a whole.

This chapter would be incomplete if mention were not made of the obligations involved in organizing a system of health-protection. In its future reports, the Commission will give detailed information on the progress made in this field.

In accordance with the provisions of the Treaty, a comprehensive system of protection is now being worked out by the Euratom Commission. This system will cover in particular the following points :

1) Determination of the permissible maximum doses, known as basic standards.

2) Determination of the maximum permissible exposure (external) and the maximum contamination (internal), known as practical standards.

3) Definition of the principles governing medical supervision of personnel.

4) The legal and official arrangements necessary to ensure that the above conditions are respected.

5) Permanent control of the level of radioactivity of the air, water and ground in all areas concerned.

6) Special provisions, for example, the disposal of radioactive effluents from nuclear installations (disposal of waste material).

The basic standards covering the first 3 points are being worked out by the Commission, which in accordance with the Treaty has sought the advice of a group of individuals selected by the Scientific and Technical Committee from amongst the scientific experts of the Member States, specially the experts on public health. The Commission will seek the opinion of the Economic and Social Committee on the basic standards which it has established.

The protective measures — legal, official, or administrative — should be supported in each country by parallel measures in teaching, education and professional training.

In order to allow for the different customs and traditions of each country, the Treaty gives full liberty of action in respect of the legal, official and administrative measures, provided that such measures respect the basic standards. Before finally making their own internal arrangements, the six Member States shall therefore familiarize themselves with the standards which the Commission shall fix during the year in which the Treaty enters into force.

Special installations will make it possible to keep a close check on the level of radioactivity throughout all the territories of the six Member States. The Member States shall supply general information on all projects relating to the disposal of radioactive effluents. It then devolves upon the Commission to determine whether the implementation of a given project is likely or not to involve radioactive contamination of the water, the ground or the atmosphere of another Member State.

The Commission is thus determined to ensure that the efforts to promote nuclear industries, both on the national and the international plain, do not endanger public health.

1.5. INTERNATIONAL ACTIVITY

In recent years, a great many practical measures have been taken, both in the governmental and private spheres, to deal with the many problems arising from the peaceful use of atomic energy. Bilateral agreements have been concluded between Member States and other countries. The nations of Euratom take part in the work of various international organizations which have been specially created in the nuclear field. Other international organizations founded earlier and not dealing specifically with nuclear energy devote a part of their activities to these new problems.

1.5.1. Bilateral Agreements

Before the Treaty came into force, Belgium, the Federal Republic of Germany, France, Italy, and the Netherlands had concluded bilateral agreements for cooperation with the United States. The main object of these skeleton agreements was to facilitate the exchange of information and to ensure the supply to the countries of Europe of power and research reactors, as well as certain quantities of special fissile materials.

There are agreements for cooperation in the sphere of research between the Federal Republic of Germany, Belgium, France, the Netherlands and Great Britain, and an agreement has been concluded between Italy and Great Britain providing for the supply of power reactors.

In addition to these intergovernmental agreements, mention must also be made of the agreements which have been concluded by public bodies in the Member States. Thus, the French *Commissariat à l'Energie atomique* has concluded agreements with similar bodies in India, Israel, the United Kingdom, and Jugoslavia, and also with the *Aktiebolaget Atomenergi* of Sweden. The Italian CNRN is in constant touch with the UK

Atomic Energy Authority. Finally, in the Netherlands the RCN has concluded agreements with the UK Atomic Energy Authority and the Norwegian *Institutt for Atomenergi.*

1.5.2. New Organizations in the Nuclear Field Formed by Multilateral Agreements

— The European Organization for Nuclear Research (CERN);
— The International Atomic Energy Agency;
— The European Nuclear Energy Agency;
— The Combined Nuclear Research Institute in Dubno.

1) *The CERN*

The Convention creating the European Organization for Nuclear Research came into force on September 29, 1954. Its members are: *Belgium,* Denmark, *France, the Federal Republic of Germany,* Greece, *Italy,* the *Netherlands,* Norway, the United Kingdom, Sweden, Switzerland and Jugoslavia.

The aim of the Organization is to promote cooperation between European States in nuclear research of a purely scientific and fundamental character; the results of its theoretical and experimental work will be published or otherwise made available to the public.

The basic programme of the Organization is :

— To construct and operate (on the territory of the Canton of Geneva) an International Laboratory using two accelerators for research on high-energy particles (a synchro-cyclotron of 600 MeV and a proton-synchroton of 25 GeV); investments involved amount to approximately 50 million EPU units;
— To provide for international cooperation in nuclear research (theoretical research, exchange of reactors) (research on cosmic rays, organization of congresses). (1)

The Organization is also empowered to carry out any work outside this basic programme, provided the plans have the prior approval of at least a two thirds majority of the Member States.

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(1) It should be added that the contributions of the Euratom Countries account for 60.3 % of the total CERN budget: Belgium 4.88 %; France 23.84 %; Italy 10.2 %; Netherlands 3.68 %; Federal Republic of Germany 17.7 %.

Since 1955 the CERN has concentrated almost entirely on the construction of the two accelerators provided for under the programme. The synchro-cyclotron has been in operation since August, 1957; the proton-synchroton is scheduled to be completed in 1960.

At the same time, CERN scientists have been conducting investigations in Copenhagen, Liverpool and Upsala, and research on cosmic rays has been carried out in Geneva and on the Jungfraujoch.

2) *International Atomic Energy Agency (IAEA)*

The International Agency, which has its headquarters in Vienna, is an independent organization and operates under the aegis of the United Nations.

Its main function is to facilitate the exchange of scientific information between the Member States and to redistribute the fissile materials and plants made available to it by some of the Member States. It also provides technical assistance for projects to which it gives its approval. It can also assist any Member State or States to find outside the organization the funds required to implement such projects.

A system of control has been designed to prevent any materials, plants or information supplied by the Agency from being used for military purposes.

A Conference of representatives of all Member States, which meets annually, elects the members of the Board of Governors, the executive organ of the Agency. The Director General is nominated by the Board of Governors, subject to the approval of the Conference. In electing the first Board of Governors, the principle of distributing seats along geographical lines was adopted ; members of two Euratom countries are represented on this Board of Governors.

For its first year's activity, the Agency's budget was fixed at 4 million EPU units. Fissile materials to a value of 100 million EPU units have so far been made available to the Agency, contributions coming mainly from the USA, the USSR and Great Britain.

At the Agency's first general conference in October, 1957, the French delegate indicated that the Euratom countries might also place a certain amount of nuclear fuels at the disposal of the International Agency. He further stated that, with the agreement of the other Member States of Euratom, he would inform the Agency at the earliest possible date after the Euratom Treaty came into force of the contribution which the Community countries would be able to make from their reserves in nuclear fuels.

3) *The European Nuclear Energy Agency*

On December 20, 1957, the seventeen Member States of the Organization for European Economic Cooperation (OEEC) signed the « Statutes of the European Nuclear Energy Agency ».

The aims and functions of the Agency are :

- To coordinate the programmes and projects of the Member States in the fields of research and industrial applications;
- To encourage the establishment of joint enterprises for the production and employment of nuclear energy for peaceful purposes, and to supply the essential materials to these enterprises and to Member countries ;
- To study means of derestricting the international exchange of nuclear products ;
- To work out a system of security control, the organization of which is to be laid down in a special convention ;
- To encourage education and training in nuclear science and allied subjects in Member countries ;
- To provide for legislation and the coordination of legislation in Member States particularly to ensure the protection of public health and the prevention of accidents in nuclear industries and to regulate the question of third-party liability and insurance against nuclear hazards.

The Agency is to establish close relations with other relevant international organizations, especially with Euratom. The Euratom Commission and the European Nuclear Energy Agency are working closely together on the question of establishing basic safety standards to apply to the whole of Western Europe.

The main organ of the Agency is the Executive Committee for Nuclear energy ; representatives of all the Member States and of the Euratom Commission, as well as of the associated states, Canada and the United States, take part in its work.

A subsidiary convention, which is subject to ratification, lays down a system of security control in respect of the Agency's work.

The work which had been going on within the OEEC in connection with the setting up of a « European Company for the Chemical Processing of Irradiated Fuels » *(Eurochemic)* was completed in December, 1957; the Convention on the establishment of the first joint enterprise of the Agency was signed at the same time as the Agency's statutes.

The Convention requires ratification by the following countries : Federal Republic of Germany, Austria, Belgium, Denmark, France, Italy, Norway, the Netherlands, Portugal, Sweden, Switzerland and Turkey. Five Euratom countries have signed this Convention. Any country belonging to or associated with the OEEC can be included at a later date.

The Company has been established for a period of 15 years. It has been entrusted with the task of building and operating a plant and a laboratory for the treatment of irradiated fuels. Work should be completed by 1961.

It has a registered capital of 20 million EPU units, which is divided into 400 shares at 50,000 EPU units each ; 254 shares are held by Members of Euratom alone.

The statutes of *Eurochemic* lay down that a representative of Euratom should take part in an advisory capacity in the work of the Executive Committee and the General Assembly.

4) Another international organization is the *Combined Nuclear Research Institute* at Dubno, in Russia.

The Institute has concentrated on the designing of particle accelerators. One of the most powerful accelerators in the world was put into operation here in April, 1957.

The Institute is administred by an Executive Committee of three persons. The scientific side comes under a group consisting of three representatives from each Member State.

1.5.3. Activities of Existing International Organizations in the Nuclear Field

Various other international organizations are interested in particular aspects of nuclear energy. Mention should be made of the important contribution of the Western European Union (WEU) to the study of protection against radiation. Within the United Nations, the International Labour Organization (ILO) and the World Health Organization (WHO) are also active in this field, while the Food and Agriculture Organization (FAO) is particularly interested in the use of radio-isotopes in agriculture. The World Meteorological Organization (WMO) keeps a check on radioactive fall-out, and the United Nations Scientific Committee for the Study of Ionizing Radiations has incorporated the problem of health protection into its programme of work.

APPENDIX TO CHAPTER 1

It would have been of interest to draw up a complete list of undertakings which have set up common organizations in the various countries to tackle problems of general interest. This, however, was not possible, since the professional organization of industry differs from country to country and because a list of this sort would have been too long for the present Report. Accordingly, only a few particularly representative organizations have been singled out. These organizations do not necessarily represent individual professional interests.

BELGIUM

Groupement professionnel de l'industrie nucléaire

(A professional association which aims at acting on behalf of all the interests in the private sector in order to ensure that they are adequately represented in national and international organizations and given proper support.)

This association comprises about 70 undertakings :

Ateliers de Constructions Electriques de Charleroi
Compagnie Auxiliaire d'Electricité
Belgonucléaire
Bell Telephone Manufacturing Company
Usines Gustave Boël
Société de Bruxelles pour la Finance et l'Industrie « Brufina »
Société Carbochimique
Cimenteries et Briqueteries Réunies
Compagnie Belge de Chemins de Fer et d'Entreprises
Forges de Clabecq
Cockerill Ougrée
Usines à Cuivre et à Zinc
Sociétés Réunies d'Energie du Bassin de l'Escaut
S.A. Eau, Gaz, Electricité et Applications
Compagnie Générale d'Entreprises Electriques et Industrielles « Electrobel »
Compagnies Réunies d'Electricité et de Transports « Electrorail »
Ateliers de Constructions d'Ensival

Centrales Electriques de l'Entre-Sambre-et-Meuse et de la Région de Malmédy
Evence Coppée & Cie
S.A. pour le Commerce et les Fabrications industrielles « Fabricom »
Fabrique de Fer de Charleroi
Fabrique Nationale d'Armes de Guerre
Compagnie Générale de Gaz et d'Electricité « Gazelec »
Société de Gaz et d'Electricité Hainaut-Liège
Société Métallurgique Hainaut-Sambre
Société Générale Métallurgique de Hoboken
Union Intercommunale des Centrales Electriques du Brabant « Interbrabant »
Société Intercommunale Belge d'Electricité
Union des Centrales Electriques de Liège-Namur-Luxembourg « Linalux »
Compagnie Maritime Belge
Compagnie Maritime Congolaise
Société Belge de l'Azote et des Produits Chimiques du Marly
Manufacture Belge de Lampes et de Matériel Electronique
Mercantile Marine Engineering and Graving Docks Company
Compagnie des Métaux d'Overpelt-Lommel et de Corphalie
Papeteries de Belgique
Phenix Works
Poudreries réunies de Belgique
S.A. Métallurgique de Prayon
S.A. Laminoirs, Hauts-Fourneaux, Forges et Usines de la Providence
S.A. Minière et Métallurgique de Rodange
Aciéries et Miniers de la Sambre
Société d'Etudes, de Recherches et d'Applications à l'Industrie
Société d'Electricité et de Mécanique
Société Générale de Belgique
Société Financière de Transports et d'Entreprises Industrielles « Sofina »
Hauts-Fourneaux, Forges et Aciéries de Thy-le-Château et Marcinelle
Société de Traction et d'Electricité
Usines à Tubes de la Meuse
Union des Centrales Electriques du Hainaut
Union Minière du Haut-Katanga
Union des Verreries Mécaniques Belges
Mines et Fonderies de Zinc de la Vieille-Montagne
Visseries et Tréfileries de Haren
S.A. Babcock Smuders

S.A. Bureau d'Etudes Nucléaires B.E.N.
N.V. Gevaert Photo-Nucléaire
S.A. Ateliers Lebrun
S.A. Physique Industrielle
Cie. Générale d'Eau
Société Hamon
S.A. Sobelco
S.A. Philips
Société Sovetreaux
Usines Gilson
Tôleries Delloye-Mathieu
Tôleries Gantoises

FEDERAL REPUBLIC OF GERMANY

An example for a part-public, part-private organization is the *Kernreaktor Bau- und Betriebs-Gesellschaft mbH.*, Karlsruhe, in which industry is represented by the *Kernreaktor-Finanzierungs GmbH.* (Company for the Financing of Nuclear Reactors, GmbH), Frankfurt/Main.

The members of the latter organization are :

Allgemeine Elektricitäts-Gesellschaft
Allianz-Versicherungs-AG.
Aluminium-Hütte Rheinfelden GmbH.
Badenwerk AG.
Badische Anilin- & Soda-Fabrik
Badische Bank
Bayernwerk AG.
Berliner Kraft- und Licht (Bewag)-AG.
Bopp & Reuther GmbH.
Robert Bosch GmbH.
Brown, Boveri & Cie. AG.
Chemische Werke Hüls AG.
Colonia Kölnische Versicherungs-AG.
Commerzbank-Bankverein AG.
Daimler-Benz AG.
DEMAG AG.
Deutsche Continental-Gas-Gesellschaft
Deutsche Edelstahlwerke AG.
Deutsche Gold- und Silber-Scheideanstalt vormals Roessler
Deutsche Shell AG.
Didier-Werke AG.
Dynamit-Aktien-Gesellschaft vormals Alfred Nobel & Co.
Energie-Versorgung Schwaben AG.

Eisenwerk-Gesellschaft Maximilianshütte AG.
Farbenfabriken Bayer AG.
Farbwerke Hoechst AG. vormals Meister Lucius & Brüning
Gebrüder Giulini GmbH.
Gelsenkirchener Bergwerks-AG.
Gerling-Konzern Allgemeine Versicherungs-AG.
Gerling-Konzern Rückversicherungs-AG.
Gesellschaft für Linde's Eismaschinen AG.
Goetzewerke Friedrich Goetze AG.
Gutehoffnungshütte Aktienverein
Hackethal Draht- und Kabel-Werke AG.
Philipp Holzmann AG.
Ilseder Hütte
Kabel- und Metallwerke Neumeyer AG.
Karlsruher Lebensversicherung AG.
Klein, Schanzlin & Becker AG.
Fried. Krupp
Kugelfischer, Georg Schäfer & Co.
Lonza-Werke Elektrochemische Fabriken GmbH.
Lonzona GmbH
Mannesmann AG.
Maschinenfabrik Augsburg-Nürnberg AG.
Maschinenfabrik Esslingen
E. Merck AG.
Metallgesellschaft AG.
Neckarwerke Elektrizitätsversorgungs-AG.
Niederrheinische Hütte AG.
Norddeutsche Affinerie
Nordstern Allgemeine Versicherungs-AG.
Osnabrücker Kupfer- und Drahtwerk
Physikalische Studiengesellschaft Düsseldorf mbH.
Pintsch Bamag AG.
Preussische Elektrizitäts-AG.
Rhein-Main-Bank AG.
Röchling'sche Eisen- und Stahlwerke GmbH.
Salzdetfurth AG.
Schering AG.
Schlesische Feuerversicherungs-Gesellschaft
Siemens-Schuckertwerke AG.
Stadtwerke Karlsruhe
Steinkohlenbergwerke Mathias Stinnes
Steinkohlen-Elektrizität-AG.
L. & C. Steinmüller GmbH.
Stolberger Zink Aktiengesellschaft für Bergbau und Hüttenbetrieb

Süddeutsche Bank AG.
Studiengesellschaft für Verbrauchsnahe Stromerzeugung e.V.
Technische Werke der Stadt Stuttgart
August Thyssen-Hütte AG.
C.G. Trinkaus
Vereinigte Industrie-Unternehmungen AG.
J.M. Volth
Volkswagenwerk GmbH.
Wacker-Chemie GmbH.
Wasag Chemie AG.

In the sector of private enterprise, the following groups have been formed, composed mainly of electricity producers :

1) *Studiengesellschaft für Kernkraftwerke GmbH* (Company for the Study of Nuclear Power Stations) in Hannover. It comprises four enterprises :
   Preussische Elektrizitäts AG.
   Vereinigte Elektrizitätswerke Westfalen AG.
   Hamburgische Elektrizitätswerke AG.
   Nordwestdeutsche Kraftwerke AG.

2) *Arbeitsgemeinschaft deutscher Energieversorgungsunternehmen zur Vorbereitung der Errichtung eines Leistungsversuchsreaktors e.V.* (AVR — Association of German Power Companies for Preparing the Construction of an Experimental Power Reactor) in Düsseldorf. It is made up of nine enterprises :
   Stadtwerke Düsseldorf
   Stadtwerke Hannover
   Stadtwerke Bremen
   Stadtwerke Duisburg
   Stadtwerke Kiel
   Stadtwerke Wuppertal
   Kommunales Elektrizitätswerk Mark AG.
   Elektrizitätswerk Minden-Ravensberg GmbH.
   Elektrizitätswerk Wesertal GmbH.

3) *Arbeitsgemeinschaft Baden-Württemberg zum Studium der Errichtung eines Kernkraftwerkes* (Baden-Württemberg Association for the Study of the Construction of a Nuclear Power Station) in Stuttgart. It comprises six enterprises :
   Badenwerk AG.
   Energieversorgung Schwaben AG.
   Neckarwerke Elektrizitätsversorgung AG.
   Grosskraftwerk Mannheim AG.
   Technische Werke der Stadt Stuttgart
   Stadtwerke Karlsruhe

4) *Gesellschaft für die Entwicklung der Kernkraft in Bayern, mbH.* (Company for the Development of Nuclear Power in Bavaria) in Munich. Its members are :
Freistaat Bayern
Farbwerke Hoechst AG.
Bayernwerke AG.
Grosskraftwerk Franken AG.
Innwerk AG.
Isar-Amperwerk AG.

FRANCE

The function of the *Association technique pour la production et l'utilisation de l'énergie nucléaire* (ATEN — Technical Association for the Production and Utilization of Nuclear Energy) is to further the development of the techniques involved in the production and utilization of nuclear energy.

The following firms and utilities belong to the Association :

Commissariat à l'Energie Atomique
Electricité de France
Air-Equipement
Air-Liquide
Aldocatom (Société Algérienne de Documentation Atomique)
Société Alsacienne de Constructions Mécaniques
Société Générale de Constructions Electriques et Mécaniques Alsthom
Société Anonyme des Ateliers et Chantiers de la Seine-Maritime
Compagnie des Ateliers et Forges de la Loire
Anciens Etablissements Aubert et Duval
Auxi-Atome
Société Française des Constructions Babcock et Wilcox
B.A.C.C.I. (Les Entreprises Le Bomin, Caminade et Cie et Béton Armé, Constructions Civiles et Industrielles Réunies)
Banque Française du Commerce Extérieur
Banque de l'Indochine
Banque de Paris et des Pays-Bas
Société Française Bitumastic
Etablissements Bouchayer et Viallet-Grenoble
Société Industrielle de Produits Chimiques Bozel-Maletra
Bureau Véritas
Société Le Carbone-Lorraine
Chantiers Navals de La Ciotat
Centre d'Etude de Prévention
Compagnie pour la Fabrication des Compteurs et Matériel d'Usines à Gaz

Compagnie Générale de Construction de Fours
Crédit Lyonnais
Crédit National
De Dietrich et Cie
Etablissements Delattre et Frouard Réunis
Compagnie Générale d'Electricité
Electricité et Gaz d'Algérie
Compagnie Electro-Mécanique
Société Esso Standard
Compagnie de Fives-Lille
Société des Forges et Ateliers du Creusot
Compagnie des Forges d'Audincourt et Dépendances
Compagnie des Forges de Châtillon, Commentry et Neuves-Maisons
France-Atome
Gaz de France
Etablissements Geosyl
Société d'Exploitation des Matériels Hispano-Suiza
Société Métallurgique d'Imphy
Indatom
Forces et Ateliers de Constructions Electriques de Jeumont
Laboratoires d'Electronique et de Physique Appliquées
Etablissements Kuhlmann
Société des Chantiers Réunis Loire-Normandie
Société Lorraine-Escaut
Etablissements Merlin et Gérin
Société Mesco
Compagnie Française des Métaux
Compagnie Française des Minerais d'Uranium
Société d'Electricité Mors
Etablissements Neyrpic
O.C.C.R. (Office Central de Chauffe Rationnelle)
Omnium Technique de l'Habitation
Compagnie des Produits Chimiques et Electrométallurgiques Péchiney
Chantiers de l'Atlantique Penhoët-Loire
Société Anonyme des Automobiles Peugeot
Société des Aciéries de Pompey
Société des Fonderies de Pont-à-Mousson
Potasse et Engrais Chimiques
Société Rateau
Manufacture des Glaces et Produits Chimiques de Saint-Gobain, Chauny et Cirey
S.A.M.M. (Société d'Applications des Machines Motrices)

S.A.T.N.U.C. (Société pour les Applications Techniques dans le domaine de l'Energie Nucléaire)
Compagnie de Raffinage Shell-Berre
S.N.E.C.M.A. (Société Nationale d'Etude et de Construction de Moteurs d'Aviation)
Rhône-Poulenc
Ateliers & Chantiers de Bretagne
Appareils Gachot
G. Massiot et Cie
M.E.C.I. (Matériel Electrique de Contrôle et Industriel)
Manufacture Française de Vide-Touries Automatiques
La Métallurgie Française des Poudres
S.O.G.E.I. (Société Générale d'Exploitations Industrielles)
S.O.R.V.A.L. (Sociedade de Representaçoes Vasconcelos, Lda.)
S.R.T.I. (Société de Recherches Techniques et Industrielles)
Société Stein et Roubaix
S.T.R. (Société de Produits Chimiques des Terres Rares)
Compagnie de Construction Mécanique, procédés Sulzer
Le Matériel Electrique. S.-W.
Compagnie Générale de Télégraphie Sans Fil
Compagnie Française Thomson-Houston
Tréfileries et Laminoirs du Havre
Etablissements Tunzini
U.C.L.A.F. (Usines Chimiques des Laboratoires Français)
Société d'Electrochimie, d'Electrométallurgie et des Aciéries Electriques d'Ugine
Union Européenne Industrielle et Financière
Société Centrale de l'Uranium et des Minerais et Métaux Radioactifs (S.C.U.M.R.A.)
Société Vallourec
Société Française des Techniques Lummus
S.O.C.E.T.E.C. (Société d'Etudes Techniques)
Techniques Nucléaires
Société Lyonnaise de Plomberie Industrielle
Saunier Duval
Gamma-Industrie
Nucléa
S.O.D.E.R.N. (Société Anonyme d'Etudes et Réalisations Nucléaires)

ITALY

In Italy, the following companies participate in the work of the *Centro Informazioni Studi Esperienze* (CISE — Information, Research and Experimental Centre) :

Società Edison

Società Cogne
Società Fiat
Società Montecatini
Società Adriatica di Elettricità
Società Pirelli
Acciaierie e Ferriere Lombarde Falck
Società Terni
Azienda Elettrica Municipale di Milano
Ente Nazionale Idrocarburi
Istituto per la Ricostruzione Industriale

NETHERLANDS

The RCN *(Reactor Centrum Nederland)* comprises the following firms :

N.V. Philips' Gloeilampenfabrieken
N.V. De Bataafsche Petroleum Maatschappij
Staatsmijnen in Limburg
Kon. Machinefabriek Gebr. Stork en Co. N.V.
Werkspoor N.V.
N.V. Koninklijke Maatschappij « De Schelde »
Rotterdamsche Droogdok Maatschappij N.V.
Dok- en Werf Mij. Wilton Fijenoord N.V.
Nederlandse Dok- en Scheepsbouw Maatschappij
N.V. Dikkers en Co.
N.V. Bronswerk
Kon. Ned. Stoomboot Mij. N.V.
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N.V. Holland-Amerika Lijn
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Kon. Java-China Pakketvaart Lijnen N.V.
Wm. H. Muller en Co. N.V.
N.V. Kon. Pakketvaart Mij.
Kon. Zwavelzuurfabrieken v/h Ketjen N.V.
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W.A. Scholten's Chemische Fabriek N.V.
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N.V. Electrotechn. Ind. v/h Willem Smit en Co.
N.V. Fabriek van Electr. App. v/h F. Hazemeyer en Co.

N.V. Electrotechn. Mechanische Industrie
Willem Smit en Co's Transformatorenfabriek N.V.
N.V. Ned. Instr. en Electr. App. Fabriek « Nieaf »
Heemaf N.V.
N.V. Nederlandsche Kabelfabriek
N.V. Coq
N.V. Hollandse Draad- en Kabelfabriek
N.V. Electromotorenfabriek « Dordt »
Van der Heem N.V.
Kon. Demka Staalfabrieken N.V.
N.V. Nederlandsche Kabelfabriek
Kon. Ned. Hoogovens en Staalfabrieken N.V.
N.V. Kunstzijdespinnerij NIJMA
Algemene Kunstzijde Unie N.V.
Unilever N.V.
Koninklijke Luchtvaart Maatschappij N.V.
Nederlandsche Spoorwegen
Ir. Escher's Constructie werkplaatsen en Machinefabriek N.V.
N.V. Billiton Mij.

CHAPTER 2

THE PRODUCTION OF URANIUM AND THORIUM

2.1. INTRODUCTION

This chapter gives in addition to a brief survey of the uranium and thorium ore resources in the six Member States of Euratom, a description of the industrial means employed for mining and concentrating these ores and for extracting high purity uranium and thorium in the form of metal or of compounds.

The actual production of the fuel elements (manufacture and canning) is dealt with in the following chapter.

Uranium and thorium are the two basic materials used in the production of nuclear energy.

The most important raw material is undoubtedly uranium, which contains the only fissile element occurring naturally in appreciable quantities, viz., uranium 235. The composition of natural uranium is as follows :

99.3 % uranium 238
0.7 % uranium 235 (1)

Uranium 238 is fertile, i.e., when subjected to neutron bombardment similar to that existing in a reactor, it may be transformed into plutonium 239, which is itself a fissile element.

Thorium 232 is a fertile material like uranium 238 and can be converted by neutron bombardment into fissile uranium 233.

At the present time, the most important achievements in the sphere of nuclear energy are based on uranium. However, a number of types of reactor which are at present in the planning stage or under construction rely on the thorium-uranium 233 cycle. If these reactors function successfully, thorium will one day play an important role as one of the world's sources of energy.

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(1) The scientific and technical concepts employed in this Report are summarized in Appendix 2, « Basic Principles ».

2.2. ORE DEPOSITS — PROSPECTING

Before the last war, the production of uranium ore was very small. The main object was to extract radium, a highly valuable natural radioelement and the uranium itself was only used in very small quantities, e.g., for colouring glassware or ceramics. The chief sources at the time were the Belgian Congo (Shinkolobwe), Canada (the Great Bear Lake) and, to a lesser degree, Bohemia (Joachimstal), Portugal and Turkestan.

The advent of nuclear power, its original utilization for military purposes, and its subsequent development for peaceful uses led to greatly increased activity in existing uranium mines and extensive prospecting in many different countries. Naturally, a quicker start was made in those countries that had taken the lead in the race for nuclear energy, namely the USA, the USSR, Great Britain and Canada.

It very soon became clear that the sites of uranium deposits differ considerably and that the ore may be found in sedimentary formations of all ages and in pegmatite deposits as well as in crystalline rocks. The area available for prospecting was thus considerably extended.

In 1945, no appreciable uranium deposits were known to exist on the territory of the six Euratom powers or in the overseas territories (with the exception of the Belgian Congo). It was at this time that prospecting was begun in France on behalf of the DREM *(Direction des recherches et exploitations minières)*, a branch of the CEA *(Commissariat à l'Energie atomique)*. The success of these endeavours encouraged the other European countries also to prospect for the ores necessary to nuclear industry.

The Situation in Various Euratom Countries

2.2.1. **Belgium**

The rich deposits of uranium in the Belgian Congo were among the first to be developed on large scale. Supplies were and continue to be delivered mainly to the United States and the United Kingdom as a result of agreements concluded with these two countries.

The known reserves definitely established represent about 6,000 metric tons of contained uranium. Although it is not possible to give an estimate of the probable reserves, everything seems to indicate that they are very considerable. Apart from the regular prospecting work of the Shinkolobwe mine itself, prospecting has also been carried out in the whole Shinkolobwe area and the neighbouring regions.

At the present time, four geologists and a staff of about sixty are employed on this work, for which about 0.12 million EPU units are allotted annually.

2.2.2. Federal Republic of Germany

It was not possible to begin uranium prospecting in Germany until 1955. Hence, prospecting and development are still in their initial stages.

The deposits so far discovered are :

	Contained uranium	
	Quantity (in metric tons)	*Uranium content* (°/₀₀)
— Fluorspar lode containing uranite (pitchblende) Wölsendorf (Bavaria)	25	2—4
— Porphyry Ellweiler (Rheinland-Pfalz)	100	1—1.2
— Granite with uranium mica		
Weissenstadt (Bavaria)	50	.8
Flossenbürg (Bavaria)	25	.5
— Uranium adsorbed by lignite Wackersdorf (Bavaria)	50	.4

Thus, the definitely established reserves only represent 250 metric tons of uranium. Prospecting work at present in progress, however, indicates that there are further uranium deposits in Lower-Saxony, the Saar, Rheinland-Pfalz, Oberpfalz and the Black Forest.

Initially, this work was entirely in the hands of private firms. Since 1956, however, considerable support has been forthcoming from the Federal Ministry for Nuclear Energy, and in 1956 financial aid amounting to 0.6 million EPU units was made available to geological institutes and enterprises carrying out prospecting work.

2.2.3. France and the French Union

« Mobile prospecting teams » were set up as early as 1946 throughout the French Union. Two years later, in 1948, large pitchblende deposits were discovered for the first time in France itself. The first shaft was put into operation in July, 1950 near la Crouzille in the area of Limoges.

Numerous other shafts have since been opened up in each of the four mining districts existing at the present time : at Grury (Saône et Loire), la Crouzille (Haute-Vienne), Mortagne (Vendée) and le Forez near Saint-Priest-la-Prugne (Loire). Indications of deposits have been found at various places in the Pyrenees, Britanny, and in the Vosges.

In January, 1958, prospecting was being carried out in the following departments : the Pyrenees, Hérault, Alpes-Maritimes and Var.

It will be remembered that the uranium-ore resources of France itself are estimated at 50,000 or 100,000 metric tons of contained uranium. The definitely established reserves amount to some 15,000 metric tons of uranium. The uranium content of the ores ranges up to several $^{o}/_{oo}$ and is comparable to that of deposits in other parts of the world.

Large-scale prospecting has been undertaken in the French Union.

At Madagascar, where there is a branch of the *Commissariat à l'Energie atomique* (at Tananarive) important deposits of urano-thorianite have been discovered and are now being worked in the south-east of the island. These known reserves are estimated at 2,500 metric tons of urano-thorianite, containing 10—20 % of uranium and 60—70 % of thorium.

On January 1, 1958, the *Groupement des Recherches en Afrique*, situated in Algiers, was directing the following prospecting teams :

- — Hoggar team (Common Organization of the Sahara Territories) in Tamanrasset ;
- — Kayes team (Senegal, Sudan) ;
- — Central Africa team (Gaboon, Oubangui, Cameroons) in Brazzaville.

Research carried out in Gaboon has led to the discovery of a uranium-ore deposit in the Franceville area. A company is being formed as a subsidiary of the CEA and various private firms, to work this deposit.

Finally, in French Guiana, a team associated with the *Bureau Minier Guyanais* at Cayenne is prospecting for radioactive ores.

2.2.4. **Italy**

Although uranium prospecting was begun only a short time ago, the work is going on apace and there is reason to believe that the reserves of ore are considerable. According to an estimate (1) made in January, 1957, these reserves amounted to 3 million metric tons with a content of 2 $^{o}/_{oo}$, i.e., 6,000 tons of uranium metal.

A considerable part of the investigations is being carried out by the National Committee for Nuclear Research (CNRN) through its Geology and Mining Division. At present, the latter is made up of four prospecting teams ; three of these operate in Northern Italy, two have their headquarters at Cuneo and the other in Trent. In each of these three towns the Division has set up a petrographic laboratory. The fourth group operates in Southern Italy and works jointly with the Institute of Applied Geology of the University of Naples.

Funds of 1.1 million EPU units have been earmarked for these purposes by the CNRN.

Private companies have been carrying out investigations in various parts of Italy, especially in the North :

— One company has focussed its attention at Bric Colmé and has set up a small laboratory in Mondovi to study the ores. This company plans to begin mining shortly.

— Another company has established itself at Peveragno (Cuneo) at the foot of Monte Besimareda and is investigating the deposits in the area with a view to undertaking mining operations.

— A company whose head offices are in Milan has conducted large-scale investigations and plans to start working a number of deposits. For the year 1958 this company is allowing for a total expenditure of 1.6 million EPU units.

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(1) Report of the « Ad hoc Committee on Supply » (Kramer Report) - Intergovernmental Conference on the Common Market and Euratom, Brussels, January 4, 1958.

- A Milan company has undertaken investigations in the zone of the S. Bovo Canal, which is rich in deposits, and extended these investigations to include the whole Lagorai range (Trentino).
- Other firms are prospecting in the area of Lurisia, in the Val Maira and in Sardinia.

2.2.5. Luxembourg and the Netherlands

Luxembourg and the Netherlands apparently possess no deposits of uranium ore. However, the Netherlands have undertaken prospecting work in Surinam (Guiana) and New-Guinea, but these investigations have so far met with no success.

2.3. MINES AND PLANTS FOR CONCENTRATING ORES

Because of the low uranium content of uranium ores, it is not an economical proposition to transport them in their natural state over long distances. Generally, the ore goes through a preliminary stage of physical or chemical processing at the mine until the uranium content is such that the concentrate can be transported more economically to a central works, where the pure uranium metal is obtained. This concentrate generally consists of sodium uranate with a uranium content of 30—60 %.

The Situation in Various Euratom Countries

2.3.1. Belgium

On January 1, 1958, the annual output of the mines in the Belgian Congo was 300,000 metric tons of ore with a uranium content of 3 ‰, i.e., 850 tons of pure uranium. The chemical concentration plants are situated near the Shinkolobwe mines and they can handle the 300,000 tons of ore extracted annually. The funds allotted annually for production and concentration amounted to 38 million EPU units by January 1, 1958.

By virtue of an agreement concluded between the USA and Belgium, the Combined Development Agency shall have an option on 75 % of the ores and concentrates produced between 1958 and 1960.

After this period, there will be reserves of about 4,000 metric tons of uranium metal, unless new discoveries are made.

At the present time, no special plan exists for the extraction and concentration of ores. In the next few years, moreover, a noticeable drop in the productivity of the Shinkolobwe mine is to be expected owing to the decreasing uranium content of the ores processed.

2.3.2. Federal Republic of Germany

Production from the German uranium mines will start shortly. The construction of plants for concentrating ores has already been planned on the initiative of various private companies. Two projects are under construction :

— An experimental plant near Ellweiler (Rheinland-Pfalz), which will process about 50 tons of uranium ore per day.
— A pilot plant for the production of concentrates and uranium from fluorspar in the region of Wölsendorf (Bavaria).

In addition, a large company in Frankfurt-am-Main is engaged on research on the transformation of uranium and thorium ores into concentrates and subsequently into nuclear-grade compounds. Its subsidiary companies are working out production methods to be employed industrially in this field and plan to build plant for processing the ores of thorium and uranium.

Altogether, the Federal Ministry for Nuclear Energy has set aside for the year 1958 — as for 1957 — a sum of 0.85 million EPU units for the prospecting and working of uranium deposits in the Federal Republic and for the concentration of uranium ores.

2.3.3. France

In France, there is a plant for concentrating ores in every mining district, i.e., in :

— *Geugnon* (Saône-et-Loire) : This factory belongs to the *Commissariat à l'Energie atomique* (CEA) and is attached to the Grury mining district. It produces sodium uranate from ores with a uranium content of over 5 ‰.
— *Ecarpière 1 in Getigne* (Loire-Inférieure) : This factory belongs to a private firm, a subsidiary company of the *Commissariat à l'Energie atomique* (CEA) and of one of the

largest French chemical firms. It produces magnesium uranate from ores with a uranium content of about 1 $^{0}/_{00}$.

- *Bessines 1* (Haute-Vienne) : This factory also belongs to a private company and has been in operation since May, 1958. (1) It produces magnesium uranate from ores with a uranium content of about 1.5 $^{0}/_{00}$.
- In *le Forez* a plant is being installed for the electronic sorting of ores and a washery for the preliminary concentration of ores with a low uranium content. Both plants will be put into operation in the course of 1958.

On January 1, 1958, only two of these works were in operation, processing ores from the various mines. At the present time, the Ecarpière 1 works can handle 150,000 and the Geugnon works 30,000 metric tons of crude ores per year, i.e., a total of 180,000 metric tons.

Taking into account the content of the ores and the recovery capacity of the factories, the total annual production is 350 metric tons of uranium in the form of uranates.

The extraction of urano-thorianite in Madagascar constitutes the most important feature of production within the French Union at the present time. These resources make France one of the world's chief producers of thorium.

At Ambatomika (in the Fort-Dauphin area), a branch of the CEA has been set up to supervise ore production and run the trade-station where urano-thorianite is purchased from private enterprises.

Mention should also be made of a new subsidiary company of the CEA which has been established to produce monazite containing thorium, zircon and ilmenite. The monazite is treated in France by enterprises, which have agreed to hand back the thorium to the CEA on request.

Madagascar produces an annual total of about 500 tons of urano-thorianite, containing 280 tons of thorium. It is planned to keep production at this level until about 1963, when the present resources will be exhausted.

These 500 tons of urano-thorianite yield approximately 55 tons of uranium, which go to increase the production of France itself, which in 1957 amounted to 350 tons of uranium.

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(1) This Report presents the situation as it was on January 1, 1958, but new information has been added when possible.

Expenditure

As it was not possible to deal with the funds allotted exclusively for prospecting under a separate heading and to list them in the previous chapter, they are given here together with the sums expended on mining equipment and plants for producing concentrates.

By January 1, 1958, more than 35 million EPU units were spent in France on prospecting, investigating ore deposits, and mining and factory equipment. These investments were not calculated merely to reach the present rate of production, but also to prepare the way for higher production in the future.

There is a staff of 2,750 persons employed on prospecting and operating the mines and factories for treating the ores ; these include 250 engineers and prospectors.

Considerable sums have also been allotted for the *French Union.*

The CEA has invested some 3.5 million EPU units in uranothorianite mining in Madagascar.

For preparatory work on developing the Franceville deposit in the Gaboon and for general survey work in Africa (the Sahara, French West Africa, French Equatorial Africa, etc.), sums of over 11.5 million EPU units have been invested.

A staff of 1,375 is currently employed, including 70 engineers and prospectors.

Development Possibilities

Two new factories are scheduled to be put into operation in France by January, 1959.

The Bessines 1 factory is able to treat an average of 200,000 t and the Ecarpière 2 factory will be in a position to process 150,000 t of crude ore each year, i.e., a total of 350,000 metric tons.

This will mean a total capacity of 530,000 t a year, which correspond to an annual output of 800 t of uranium in the form of uranates.

The 26 million EPU units which will be necessary to achieve this objective have already been invested.

In *January, 1961,* it is planned to put two more factories into operation :

The Bessines 2 factory will be able to treat an average of 400,000 t, the Forez factory 250,000 t of crude ore each year, a total of 650,000 metric tons.

This will mean that factories will be able to treat 1,180,000 t annually and thus — if calculations are made based on the average uranium content of these ores — turn out 1,500 t uranium annually in the form of chemical concentrates.

This further increase in capacity would require investments of some 24 million EPU units.

There would be a staff of 3,100 persons in 1959, including 260 engineers and prospectors. In 1961, these figures would be 3,600 and 270, respectively.

The work of private prospectors should not be forgotten. Their role, which has only been of minor importance hitherto, will become increasingly important in the future.

Since 1954, with the active encouragement of the *Commissariat,* a considerable number of private companies and persons has been engaged in the search for uranium in France. A certain number of the preliminary investigations have resulted in the discovery of indications sufficient to justify applications for mining permits, some of which have been approved and others are being examined.

By January 1, 1958, these investigations yielded small quantities of surface ores, which were bought up by the *Commissariat* and fed into its factories. The total amount thus produced was about 6,000 t of ore with varying uranium contents.

In 1958, a certain increase in output is to be expected from this source : some 50,000 t of ores with varying uranium contents will probably be bought up by the *Commissariat,* but it is still too early to draw up a definite production and development programme for this private industry. The same applies to the questions of investments.

Moreover, no plans to construct ore-treatment plants have been drawn up as a result of private initiative. Consequently, the manufacture of various uranates or concentrates from ores extracted from private mines in the course of the next few years will be incorporated into the above-mentioned programmes of the factories managed directly by the *Commissariat* and its subsidiaries. It is estimated that private industry spent some 2.4 million EPU units by January 1, 1958 on prospecting and investigations in France.

2.3.4. **Italy**

As has already been mentioned, a number of companies plan to begin mining for uranium ore in Italy soon. Only very inconsiderable quantities are being extracted at the present time.

On the other hand, for over a year, research on the enrichment of uranium and thorium ores has been going on in the Institute for the Treatment of Ores in Rome on behalf of the *Centro Nazionale per le Ricerche Nucleari* (CNRN).

A number of companies have carried out investigations on the concentration of ores and the manufacture of ammonium uranate. A pilot plant is in operation at Spinetta Marengo (Alessandria). Another pilot plant for concentrating ores is being erected at S. Donato Milanese (Milan).

2.4. THE PREPARATION OF NUCLEAR FUELS

As was mentioned earlier, the production of uranium and thorium concentrates from low-grade ores is generally carried out in treatment plants situated near the mines in order to avoid transporting large quantities of rock. The concentrates with a uranium content of 30—60 % (uranate or uranothorianite) are then shipped to the factories producing the nuclear fuels. Here, the concentrates are subjected to a number of physical and above all chemical processes, by which impurities are removed from uranates until they constitute no more than a fraction of a millionth part and nuclear-grade metals and oxides are produced.

The preparation and treatment of nuclear fuels have been undertaken only in Belgium, Germany, France and Italy.

The Situation in Various Euratom Countries

2.4.1. **Belgium**

The manufacture of pure oxides or pure uranium metal is carried out at the Hoboken works in Belgium. It can produce

425 t of UO_3 oxide and 50 t of uranium metal, the oxide plant feeding the plant producing the metal.

Total investments in this factory amount to some 1.1 million EPU units. There are 8 engineers and 67 other staff.

2.4.2. Federal Republic of Germany

In Germany, research on the preparation of high purity uranium has been conducted primarily by a large Frankfurt firm with over 15 years experience in this field, in the course of which it has produced about 15 t of refined uranium metal. It has recently put into operation an experimental plant, which has produced several tons of pure uranium metal from concentrates for the Karlsruhe research reactor. The plant's capacity, however, is not fully utilized by this order.

The same firm has worked out methods for producing industrially uranium oxide (UO_2) with good sintering properties ; it has also done research on the production of uranium monocarbide (UC) on an industrial scale.

It has further elaborated processes for the manufacture of ductile and nuclear-grade thorium metal and is at present constructing a plant, which, among other things, will be able to produce about 1,000 kg of thorium metal for the Karlsruhe research reactor.

Finally, this same firm has collaborated with another private firm to draw up plans for the erection of a factory, which in all probability will be put into service at the beginning of 1960 and will be able to produce some 100 t of nuclear-grade uranium annually (metal, oxide and carbide) and about 10 t of nuclear-grade thorium.

A part of the concentrates to be treated here is to be imported.

Within the framework of a nuclear power programme for providing 500 MWe of electricity for the period 1958-65, expenditure totalling about 24.4 million EPU units is needed for prospecting, mining equipment, treatment plants for concentrating ores and the construction of a factory to produce uranium. This expenditure will have to be met by funds provided by the State and private enterprise.

2.4.3. France

In France, the concentrates which are produced near the mines are shipped to the le Bouchet factory (Seine-et-Oise) near Paris.

This factory was erected in December, 1946 in the grounds of the le Bouchet Powder-Works, near Corbeil, about 50 kilometres from Paris for the *Commissariat à l'Energie atomique* working in cooperation with various large chemical companies. Less than two years later, in January 1948, production of oxide required by the Fontenay reactor was started, until the regular production of metal slugs became possible in course of 1950.

The chemical treatment of ores, by which uranium is extracted in the form of sodium and ammonium uranates, was practiced in le Bouchet until the end of 1956. But the development of chemical concentration plants near deposits of low-grade ores has made it gradually possible for the factory to receive the uranium in the form of uranate. At the present time, therefore, the le Bouchet factory is engaged chiefly on the purification and manufacture of uranium metal. It is, nevertheless, still in a position to treat minerals, either to increase its own supply of uranate if necessary or to develop a new technique.

The actual process of purification is done by a selective extraction in organic solvents. The uranium at its highest degree of purity then undergoes a number of transformations, the last change of which leads to the winning of the metal (violent reaction in the presence of calcium of nuclear purity in crucibles of fritted calcium fluoride).

A new treatment plant was constructed in le Bouchet and put into operation at the beginning of 1957. Since this date, it has been treating the thorium-rich urano-thorianite ores from Madagascar, so that it has been possible to obtain thorium nitrates of nuclear purity. Research is at present being conducted on the transformation of the nitrate into pure metal, which will soon be produced on a semi-industrial scale (Petit Quevilly).

At the present time, then, the le Bouchet factory is able to produce and supply adequate quantities of nuclear fuel to the reactors at Fontenay, Saclay and Marcoule, which operate on natural uranium. A plan to enlarge and modernize the le Bouchet factory has been drawn up pending the putting into operation of other factories for the refining of uranium.

The present annual production capacity of the le Bouchet factory is 500 t of uranium metal and 300 t of thorium salts of nuclear purity. Total investments amount to 6.4 million EPU units.

The le Bouchet factory employs 415 persons.

A new factory for the manufacture of nuclear fuels is being built at present at Malvézy, near Narbonne. In its first stage, a production of 1,000 t is envisaged, 700 t to be extracted directly from ores and 300 t to be recovered from uranium rods irradiated at Marcoule. In the second phase, its capacity will be increased to 2,000 t.

In conclusion, we add the approximate scheduled development of uranium production as envisaged by the French authorities at the present time :

500 t in 1958
1,000 t in 1961
2,500 t in 1970
3,000 t in 1975

2.4.4. **Italy**

A certain amount of uranium metal of nuclear purity has been manufactured by the CISE of Milan in a pilot plant financed by the CNRN.

At the present time, the CNRN has at its disposal a plant which cost 29,000 EPU units to construct and which is in operation in Milan. At the present time, this works has a daily production capacity of 40 kg of uranium metal. Later on, it will produce 80 kg of uranium metal per day. This plant will be transferred to the Applied Nuclear Research Centre in Ispry (Varese).

2.5. CONCLUDING REMARKS

Uranium prospecting is still far too recent a development in the six Euratom countries to provide anything like a complete picture of the extent of the deposits or of prospects for the future. It is only in the case of the resources of France and the Belgian Congo, where prospecting and the working of deposits was started ten years earlier than in the other Member States, that reliable estimates can be made.

The present Report must thus confine itself to evaluating the French resources and those of the Belgian Congo which might be placed at the disposal of the Euratom Supply Agency. In consequence of the agreement between the United States and Belgium, it is only after 1960 that over a quarter of the ore and concentrates produced by the Belgian Congo can be made available to the Agency.

Thanks to the production based on its Madagascar resources, France is now one of the world's leading manufacturers of thorium. This production is certainly sufficient to meet Europe's needs in the years to come and to allow a certain proportion to be exported.

As has already been mentioned, France's probable reserves of uranium ore amount to 50-100,000 t of contained uranium. This figure can best be appreciated by comparing it to the probable reserves in the United States (1) : 75 million tons of ore, i.e., approximately 170,000 tons of uranium. Canada's reserves are probably greater and may be somewhere in the region of 1 million tons of contained uranium.

The search for new deposits is far from being at an end in the United States and will certainly lead to the discovery of new ore-bearing districts in the future, thus increasing the estimated resources there cited above. The same is true of course for the six Euratom countries, where it is hoped that new deposits will be discovered, especially in Germany and in Italy.

It is already clear that the uranium resources of the six Member States are considerable in the context of the reserves available in other parts of the world. Although the output of uranium metal at the disposal of the six countries at the present time is less than 700 metric tons a year, compared to some 8,000 tons in the United States and an estimated output

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(1) Figures quoted in this Report relating to the United States and the United Kingdom have been published in the following documents :
- — Forum Memo — March 1958
- — A Growth Survey of the Atomic Industry, 1958-1968
- — Atomic Energy Facts Prepared under Contract No. At (30-1) 1782 for the U.S.A.E.C.
- — United Kingdom Atomic Energy Authority Third Annual Report, 1956-1957
- — A Programme of Nuclear Power — February 1955, HMSO
- — Capital Investment in the Coal, Gas and Electricity Industries — April 1958 — HMSO

of 10-15,000 tons in Canada by 1960, it is nevertheless possible to step up this production especially in France without having to fear the prospect of the available resources giving out prematurely. Moreover, a considerable increase in the Belgian contribution is possible after 1960.

In order to give some idea of what these uranium resources mean in relation to future needs, it should be noted that the report, « A Target for Euratom », quoted a figure of 24,000 t as being the amount of natural uranium necessary to put into service and operate a set of reactors of the British type, representing an electric power of 7,500 MWe in 1967. The annual consumption of uranium in 1967 was estimated at 2,500 t merely to feed the power plants which would then be in operation. The same report considered that the production of uranium in France and Belgium would go up from 1,200 to 2,500 t per year between 1958 and 1967, and that the production in those countries would not exceed 15,000 t by this date.

These figures show that, in spite of the size of the uranium deposits available to the six Member States, a deficit in their own resources might easily be produced in a very short time especially if, due to the impulse given by Euratom, they were to increase to any considerable degree the scope of their present plans for producing electricity by nuclear means.

This adverse situation may, however, be affected by a number of factors. In the first place, the figure for natural uranium needs which was used in the above estimates takes no account of the possibility of using the plutonium produced in reactors nor of recovering the depleted uranium in irradiated fuel elements. Moreover, the estimate was based on a programme in which only reactors using natural uranium are provided for. It is already envisaged, however, for a certain number of power plants to be fitted with reactors using enriched uranium, which consume a smaller quantity of nuclear fuel. And finally, the mining programmes, especially in France, have hitherto been drawn up with a view to dovetailing with national programmes for setting up nuclear power plants, and it is likely that the establishment of Euratom and the increased pace of construction in the nuclear field which will result from it will give a new impetus to uranium prospecting and mining in the various Community countries.

There are thus good grounds for hoping that the actual production of uranium will exceed the present estimates.

If it is further considered that a critical situation seems to be developing in the United States, where a certain overproduction of uranium ore is feared, a shortage in this field would seem to be hardly likely and the supply of nuclear fuels ought not to be too difficult a problem for the six countries.

Finally, it should be pointed out that the aim of the present Report is not to draw up a programme for the production of nuclear fuels. It is nevertheless essential to stress that, in spite of the extent of the uranium ore resources of the six countries, any development programme in the nuclear field must be based on a thorough study of the supply of nuclear fuels, irrespective of whether they are obtained by increasing production of indigenous ores or by imports.

Under the present conditions, then, it would appear that when the Euratom Supply Agency begins to operate, it will probably not have to adopt a speculative attitude or lay in large stocks of uranium.

CHAPTER 3

THE FUEL CYCLE

3.1. INTRODUCTION

The preceding chapter gave an account of the present activities of the six Euratom countries in the production of uranium metal and described the whole series of operations from prospecting and mining down to the actual production of the nuclear fuel. The present chapter will deal with the nuclear fuel cycle from the time the fuel is used to its reprocessing after irradiation and the disposal of the unusable effluents.

Uranium is used either in its natural concentration or enriched in uranium 235, depending on the particular type of reactor employed. The first part of this chapter is thus devoted to the processes used in the separation of isotopes for the purpose of enrichment ; the second part will discuss the manufacture of the fuel elements and the utilization of nuclear materials ; the third part will deal with the reprocessing of irradiated fuels, which is carried out to recover the fissile and fertile materials that have not been used up or that have been produced by irradiation in the reactor, and to remove the radioactive fission products that impair the chain reaction. The chapter ends with a short section on the treatment and disposal of effluents.

3.2. THE SEPARATION OF THE URANIUM ISOTOPE 235

3.2.1. The General Situation

For certain nuclear applications it is necessary to separate the two isotopes of uranium or to increase the proportion of uranium 235.

Various processes can be employed to bring about this separation. The method generally used in the United States of America is to pass uranium hexafluoride gas through porous membranes.

Investigations and experiments, some of them very far-reaching, have been carried out with the object of elaborating other separation processes (electromagnetic ; high-speed centrifuge ; separating-nozzle method). All these methods are extremely expensive and it is only by processing large quantities that the cost price can be reduced. The expediency of constructing a uranium isotope separation plant to supply the OEEC or Euratom countries is thus still a matter of controversy.

In most of the Euratom countries (Belgium, Germany, Italy, and the Netherlands) this question has on the whole not got beyond the research stage. In France, however, an experimental plant has been put into operation at Saclay.

3.2.2. The Situation in Various Euratom Countries

Belgium

Belgium has shown a great interest in the negotiations on this project, because the Belgian Congo has considerable resources in water power which would make it possible to produce at low cost the electricity necessary for the running of an isotope separation plant.

Federal Republic of Germany

A German firm has developed in the laboratory a process for isotopic enrichment based on the separating-nozzle method and has begun to construct an experimental industrial plant. In collaboration with another company, the same firm has also constructed a high-speed centrifuge.

France

The CEA has carried out research in the laboratory and has erected semi-industrial plants for the production of uranium 235.

An experimental industrial plant has been put into operation in Saclay. This plant is concerned exclusively with the process of separation by means of hexafluoride diffusion and has no ancillary installations. Such installations are necessary for the running of a large-scale plant but they are based on the use of more conventional processes (e.g., the manufacture and distillation of uranium hexafluoride) and are studied elsewhere.

The materials and apparatus employed in this plant are largely manufactured by French firms. A French company has been entrusted with the construction and running of the plant. Its present production of uranium hexafluoride is 70 metric tons a year.

Another company has developed a prototype electromagnetic mass spectrometer.

Italy

The production of uranium hexafluoride has still not progressed beyond the research stage. However, in view of the discussions on the construction in Europe of a uranium isotope separation plant, the CNRN has commissioned the CISE to implement a programme along the following lines :

a) The study of separating membranes of polymerized material;
b) The erection of a plant for producing uranium hexafluoride;
c) The designing and testing of a separating cascade.

So far, a small plant for producing uranium hexafluoride has been constructed within the framework of this programme, and investigations have been carried out on various types of porous membranes made of teflon, zinc, alumina and fluorite.

The Netherlands

The Netherlands depend on foreign supplies for their fissile materials. Nevertheless, research is being carried out on the problem of uranium enrichment. The construction of an experimental enrichment plant using the high-speed centrifugal method is planned.

3.3. THE MANUFACTURE OF FUEL ELEMENTS

3.3.1. The General Situation

A nuclear reactor fuel element is generally composed of a fuel core (uranium or thorium metal, either pure or alloyed, uranium oxide or carbide in powder form or sintered, etc.) encased in a sealed can designed to prevent the escape of fission products and the contact of the fuel with the coolant.

In choosing a fuel element a compromise has generally to be arrived at to satisfy the conflicting demands of mechanics, thermodynamics and neutronics. From the point of view of neutronics it is imperative to have materials which do not readily absorb neutrons and which can be used in the smallest possible quantities. From the point of view of thermodynamics, materials and shapes allowing the maximum heat exchange between the fuel and the coolant are required. From the mechanical point of view it is essential, in order to prevent the escape of dangerous fission products, to utilize materials which are able to withstand the rigorous conditions of high temperature and intense neutron flux and which can stand up to internal pressure.

These often conflicting demands limit the number of possible solutions and necessitate considerable technical research. The fuel element must be as robust as possible in order to cut down the chances of damage to the cans ; breakages of this sort are extremely troublesome because they generally cause contamination in the cooling circuit and bring the reactor to a temporary stop until the faulty element has been replaced.

Use is made of various types of fuel element, differing in shape and composition, and the following types deserve special mention : Hollow cylinders of uranium metal in finned cans of magnesium or aluminium alloy, sometimes held in graphite jackets ; pellets of sintered, enriched uranium oxide stacked in stainless steel or zirconium tubes ; rolled plates consisting of a core of enriched uranium between two aluminium plates, etc.

3.3.2. The Situation in Various Euratom Countries

Belgium

For some years a number of companies, working in collaboration with the CEN, have been carrying out investigations on the following problems : The rolling of uranium, the manufacture of fuel elements using uranium oxide, uranium metal, their alloys and compounds with metals such as aluminium, magnesium and zirconium.

Advanced experiments have been and are still being carried out to produce fuel pellets from uranium oxide (UO_2).

One of these companies is planning a systematic study of the theoretical and practical aspects of the use of plutonium as a power-reactor fuel ; practical work on this programme has already been started with the collaboration of the CEN.

Federal Republic of Germany

One German firm is operating a plant in which uranium metal — sometimes alloyed — is formed, after melting under high vacuum, into rods and fuel elements. This plant, which supplies elements for the Karlsruhe research reactor, has a production capacity in excess of the present needs of the Federal Republic. A special process which has been worked out here is used whenever a highly efficient heat exchange is essential between the fuel and the canning material. New production and testing methods have been developed and are constantly being improved by this same company. Experiments using uranium oxide and uranium monocarbide as fuel are now being carried out. These experiments are being carried out having regard to the German reactor programme, which provides for the building of reactors with a total capacity of 500 MWe.

France

Exhaustive investigations have been carried out by the *Commissariat à l'Energie atomique (CEA)* on the metallurgy of uranium rods and on the problem of canning them with metals such as aluminium, magnesium, zirconium or beryllium.

The reactors built at Marcoule and those erected under the power production programme are fuelled by natural uranium in its metallic form. The canning of this metallic uranium is carried out in a factory built in Annecy by a private firm. This firm will soon be able to treble its capacity and will then be in a position to meet France's requirements, as far as they can be foreseen at the present time.

Another group of French firms is concerned with the manufacture of fuel elements and may also make use of American technical aid. This group is reported to be showing interest not only in fuel elements containing natural, metallic uranium (to be used for French power reactors) but also in much more highly developed types employing uranium oxide (UO_2), ceramics, etc., and in cans made of special metals which make it possible, either with or without enrichment, for the high temperatures to be reached that are essential for the economic use of nuclear energy.

The fissile uranium isotope, uranium 233, can be obtained from thorium in a reactor. France has, as was pointed out in Chapter 2, considerable thorium resources.

The foundation for a thorium industry in France has been laid by the CEA, working in collaboration with three large French firms ; the various activities include obtaining thorium metal in powder form from thorium oxide, preparing thorium rods by sintering and drawing, and sintering thorium powder.

Italy

The Metallurgical Section of the CNRN Research Centre at Ispra plans to obtain the necessary equipment for producing fuel elements on an experimental scale, especially the fuel plates used in materials testing reactors.

3.4. TREATMENT OF IRRADIATED FUELS

3.4.1. The General Situation

When a nuclear fuel is subjected to neutron radiation and undergoes a certain number of fissions, the original material is transformed. The fissile material yields fission products, the majority of which readily absorb neutrons and thus impair the efficiency of neutron activity in the reactor. Moreover, these fission products, e.g., strontium 90, are highly dangerous to health. The fertile material is transformed partly into fissile material, uranium 238 becoming plutonium 239 and thorium 232 becoming uranium 233, and partly — though to a lesser degree — into heavy isotopes, which are strong absorbers of neutrons, e.g., plutonium 240 and 242. Like the fission products, these heavy isotopes poison the reactors and reduce their efficiency.

In order to recover both the fissile and fertile material remaining in the fuel and the fresh fissile material produced, the fission products have to be removed, which means that the irradiated fuels have to be specially processed.

The usual process adopted for treating irradiated fuels is the following : The irradiated uranium rods are decanned and dissolved in nitric acid ; they are then separated into three parts, plutonium, uranium and fission products, by using a solvent which has a different affinity for each of these elements. Here again, only a large-scale plant can ensure reasonable cost prices.

At the present time, two factories are being built for the processing of irradiated fuels. The main one is situated at Marcoule in France ; the other is to be built at Mol in Belgium and is the result of international initiative in establishing the European Company for the Chemical Processing of Irradiated Fuels *(Eurochemic)*.

The company's statutes provide for an unrestricted programme of industrial research designed to find economical ways and means of processing the fuels used in the production of nuclear energy.

By 1961, it plans to bring into operation a plant for processing fuel elements containing natural or slightly enriched uranium, and also a laboratory. Its other tasks include the elaboration of suitable techniques and the promotion of specialist training in this field. The site chosen for this first plant, which will have an annual capacity of approximately 100 tons (metric), is Mol, Belgium, in the immediate vicinity of the installations of the *Centre d'études nucléaires* (CEN).

The company's capital has been fixed at 20 million EPU units (400 shares at 50,000 EPU units each). The cost for constructing and equipping the plant is estimated at 12 million EPU units. In the plant itself 240 persons will be employed, while 200-250 persons will be engaged on research work.

3.4.2. The Position in Various Euratom Countries

Belgium

The decision of the OEEC Council to set up a plant for the chemical processing of irradiated nuclear fuels in Mol has been approved by the Belgian Government. Belgium holds 44 shares of 50,000 EPU units each, making 2.2 million EPU units in all ; Belgian industry accounts for 1.35 million EPU units of this total.

A company formed recently is interested in the chemical and metallurgical aspects of nuclear energy and its applications. It also deals with the question of utilizing nuclear energy and nuclear by-products, in chemical and metallurgical processes. The reprocessing of irradiated nuclear fuels also falls within its sphere of activity.

Federal Republic of Germany

German interests in the *Eurochemic* Company are represented by the 68 shares, totalling 3.4 million EPU units, subscribed by the Federal Republic.

A radio-chemical laboratory has been fully equipped by a German company to help in research on the reprocessing of irradiated fuel elements.

France

The *Commissariat à l'Energie atomique* was responsible for the research work that made it possible to produce plutonium in France as early as 1949. The CEA later constructed a pilot-plant that provided the data necessary for designing and running the plant for processing irradiated uranium rods at Marcoule.

Marcoule, with its reactors (G1, G2, G3) and its extraction plant, is chiefly concerned with the production of plutonium.

A French chemical firm which had previously built at Fontenay-aux-Roses a semi-industrial plant for extracting and isolating plutonium, using a process developed by the CEA, has been commissioned to build the plant at Marcoule.

From 1959 onwards the factory is expected to have an output of 100 kg of plutonium a year. The depleted uranium from the factory can be recycled in the metal-processing plants.

In Saclay a pilot-plant has been erected for the processing of thorium irradiated in the EL 2 reactor. This plant has gone into operation and has begun work on the separation of uranium 233.

Furthermore the CEA holds 68 shares representing a sum of 3.4 million EPU units, in the *Eurochemic* Company.

Italy

To help in financing the *Eurochemic* plant in Mol, Italy plans to contribute the sum of 2.2 million EPU units to the company's capital via the CNRN.

The Netherlands

The Government of the Netherlands has decided to contribute a sum of 1.5 million EPU units towards the financing of the *Eurochemic* plants.

3.5. EFFLUENT DISPOSAL

To obviate all danger, radioactive effluents from nuclear plants have to be subjected to special treatment. There are no industrial installations of this type in Europe at the present time, with the exception of Marcoule in France. The installations involved are generally small-scale plants attached to laboratories.

In Belgium the problem is being studied on a semi-industrial scale, pending the installation of the *Eurochemic* reprocessing plants.

At Marcoule, the low-activity industrial wastes are passed through an effluent treatment plant before being discharged into the Rhone. In this plant the dangerous components are removed, filled in the form of mud into steel drums, and stored under a layer of concrete.

3.6. CONCLUDING REMARKS

The information given in this chapter shows that the fuel-cycle question is still only in the research and planning stage in the Community countries, with the exception of France, where a factory producing fuel elements is in operation at Annecy and a plant for processing irradiated fuels is to be brought into service on an industrial scale at Marcoule.

In 1956 the six countries of the Community set up a syndicate to study the possibility of erecting a uranium isotope separation plant.

This problem is still unresolved, since a plant of this sort can only be operated at reasonable cost if it is built on a fairly large scale. Approximately 3,000 million dollars were required for the three plants constructed by the United States Atomic Energy Commission (at Oak Ridge, Paducah and Portsmouth). Moreover, electric power of over 5 million kWe is required to run the three plants. They were originally designed for national defence.

The need for planning on a large scale is just as great in the case of plants for processing irradiated fuels. In America five such plants have been built by the Atomic Energy Commission for its entire programme.

Thus, considerable efforts will have to be made in Europe, if complete autonomy is to be achieved in the processing of fuel.

CHAPTER 4

MODERATORS AND SPECIAL MATERIALS

In the foregoing chapters the role of uranium and thorium as basic materials in the production of nuclear energy was examined. In this chapter we shall consider the position in the six Member States of Euratom as regards the production of other materials which are indispensable for the construction and operation of given types of reactors.

4.1. MODERATORS

4.1.1. Introduction

These materials are characterized by their ability to « moderate » or slow down the speed of the neutrons which pass through them. This « moderating » property of certain materials is determined by the energy lost by the neutron on each collision with a nucleus, the number of atoms per unit volume (atomic density), the probability of an elastic collision between the neutron and the nucleus rather than the absorption of the neutron by the nucleus. The lighter the nucleus, the greater the loss of energy. « Moderators » are indispensable in types of reactor using nuclear fuels in which the chain reaction can only be maintained by thermal neutrons. In nuclear fission, fast neutrons are produced, and in order to cause further fissions and sustain the chain reaction, these fast neutrons must be slowed down. The braking action of the neutrons can best be understood by imagining that the fast neutrons are bounced off elastically when they collide with the nuclei of a moderating material. Most of the reactors now in operation or in course of construction employ heavy water, light water, graphite or beryllium as moderators.

Part of the moderator is used as a « reflector », in other words it is placed around the core of the reactor in such a way that the majority of the neutrons are reflected back into this core.

4.1.2. Heavy Water and Light Water

1) *Introduction*

Heavy water is a chemical compound of heavy hydrogen (deuterium) and oxygen. The atomic nucleus of heavy hydrogen contains not only a proton (as in the case of light hydrogen) but also a neutron. The specific gravity of heavy hydrogen is about twice that of ordinary hydrogen. The behaviour of heavy water, when neutrons are passed through it, is different from that of light water in that the elastic collisions have a slighter braking effect on the neutrons and also that less neutrons are absorbed. Light water, which reduces the number of neutrons available owing to its greater absorption, is therefore not suitable for types of reactor employing fuels that contain only small amounts of fissile material (e.g., natural or slightly enriched uranium). With such reactors the advantage of a relatively cheap supply of fuel is outweighed by the expensiveness of heavy water, which must be used as a moderator.

Ordinary water contains only a very small quantity of heavy water (about 1/7,000 on the average). The principal ways in which ordinary water can be enriched in heavy water (up to a level of 99.75 %) are given below. These methods are often combined in order to reduce the cost of operations.

a) The Electrolysis of Water

Principle : Under the effect of an electric current, light water decomposes into its constituent elements of hydrogen and oxygen more quickly than does heavy water. The residual electrolytic liquid thus becomes more and more enriched in heavy water as the process continues.

It is interesting to note that this method is followed on an industrial scale in Norway (Rjukan), where 25 metric tons are produced yearly. The method is also employed, in conjunction with the isotopic exchange of deuterium between water vapour and hydrogen, in the Trail factory in Canada.

The production costs have been estimated at about 120,000 EPU units per metric ton.

b) Distillation of Water or Liquid Hydrogen

Principle : Natural water vaporizes at a lower temperature than heavy water. In the liquid state, light hydrogen is more volatile than heavy hydrogen or deuterium.

c) Isotopic Exchange of Deuterium Between Water and Sulphuretted Hydrogen at Two Different Temperatures

Principle : At low temperatures sulphuretted hydrogen loses deuterium to the water, whereas at higher temperatures it gains deuterium from the water. By means of a continuous process deuterium is extracted from normal water and supplied to the water enriched in deuterium until the required degree of concentration is reached.

d) Isotopic Exchange of Deuterium Between Water and Hydrogen at Two Different Temperatures

Principle : At low temperatures natural hydrogen loses deuterium to water, whereas at higher temperatures it gains deuterium from water. By means of a continuous process deuterium is extracted from normal water and supplied to the water enriched in deuterium until the required degree of concentration is reached.

2) *The Situation in Various Euratom Countries*

Federal Republic of Germany

Since 1954, German industry has been studying the theory and practice of manufacturing heavy water.

At Griesheim near Frankfurt am Main two firms have built an experimental plant for the production of deuterium by rectification of liquid hydrogen. The plant employs a mixture of nitrogen and hydrogen (synthesis gas) obtained from an ammonia factory and will produce six metric tons of heavy water yearly. Construction of this plant, which was started about the middle of 1955, is almost completed. At the present moment, operating trials are being carried out, and normal operation will soon begin.

The double-temperature method of exchanging deuterium between natural water and hydrogen has been perfected in the laboratory. A start has been made with the construction of an industrial test-plant where this process will be investigated.

Research is also being carried out on the process of isotopic exchange of deuterium between water and sulphuretted hydrogen. The plant being used for this work was constructed in 1957, with financial support from the Federal Minister for Nuclear Energy and Waterworks, as a basis for a future industrial installation.

France

France has purchased heavy water in the USA and in Norway, but has not neglected to examine the possibilities of producing for itself.

A pilot factory has been constructed near Toulouse. Its production should reach about two metric tons yearly through liquefication and distillation of hydrogen.

A company has been formed for the study and utilization of the natural gas found at Lacq for the isotopic exchange of deuterium between water and sulphuretted hydrogen ; this gas in extremely rich in sulphuretted hydrogen. A first pilot plant has been constructed at Lacq and it can treat up to 1,000 m^3 of sulphuretted hydrogen hourly. This plant has given excellent results.

Finally, mention should be made of the important plant for water electrolysis in the Pyrenees. Concentrates of heavy water are obtained as by-products from this plant, but only in small quantities.

Italy

In Italy studies have been carried out for the CNRN on various questions relating to the methods of producing heavy water. Two of these methods are employed in small laboratory installations. Using the method of electrolytic concentration, a small installation is producing heavy water (99.8 %) from a mixture containing only 2 %. The possibility of employing this method to treat preconcentrates obtained from the Nera-Montero electrolytic installation has also been examined.

At Merano a plant has been modified so that it can be used for the production of heavy water as a by-product in the manufacture of hydrogen. In addition, consideration has been given to the possibility of utilizing the Apuania installation for the purpose of producing heavy water as a by-product of ammonia.

A study has also been made of the possibility of setting up, in a factory at Ravenna, a department for obtaining heavy water as a by-product in the production of nitrogenous products.

4.1.3. Graphite

1) *Introduction*

Although graphite is inferior to heavy water as a moderator, this form of carbon is the most frequently used for this purpose.

It is only suitable, however, when its density and purity are extremely high. The presence of other materials, even in minute quantities, results in a considerable increase in the absorption of neutrons, so that when the blocks of graphite are being manufactured the greatest care must be taken to avoid all impurities.

In order to permit stacking of the carbon in the core of the reactor, the blocks must be made to the exact shape and size required. In spite of the resulting expense, graphite is very much less costly than heavy water. The cost of graphite in France is from 1.2 to 1.4 EPU units per kg whilst the cost of heavy water is from four to ten times higher.

2) *The Situation in Various Euratom Countries*

Federal Republic of Germany

In Germany, graphite of nuclear purity is obtained from artificial graphite and from natural graphite.

A chemical factory at Meitingen, near Augsburg, has been engaged since 1896 in the manufacture of *artificial graphite* from products obtained in the coal and petroleum industries (cokes from coal, petroleum and bituminous cokes). The investigations so far carried out on the production of nuclear graphite show that there is every reason to hope that graphite can be produced of the same quality as that used in France, the USA and Great Britain.

After years of research, a system has been perfected in the « Bayerischer Wald » area for transforming *natural graphite* into compressed nuclear-grade graphite. In 1956, with the aid of the Federal Minister for Nuclear Energy and Waterworks, a large experimental plant was put into operation ; some of its production samples are now being examined in various foreign countries with a view to their utilization in reactors.

France

Nuclear-grade graphite is produced from a mixture of petroleum coke and pitch in a factory situated near Chedde. This factory is capable of producing 3-6,000 metric tons of graphite yearly, about half of it being sold for nuclear uses ; production could easily be stepped up if market conditions justified this.

It should be remembered that the Marcoule reactors (G1, G2 and G3) each use more than 1,000 metric tons of graphite.

The CEA has given a contract for supplies worth 4.76 million EPU units. It is estimated that the turnover for production of graphite may soon reach nearly 2.38 million EPU units yearly.

The graphite supplied to Marcoule is manufactured on the spot in a workshop that has been in operation since 1954. This workshop, which is equipped with air-conditioning plant and a special dust-proof system, will not only be able to satisfy the demand for graphite of the Marcoule Centre but will in addition be able to supply other users.

Italy

So far, no detailed attention has been given to the question of adapting the present supply of ordinary graphite to meet nuclear needs. However, various groups are interested in this problem and are endeavouring to find a solution. A plant for the production of nuclear-grade graphite is also planned. This project and the possibilities of adapting present production indicate that it will probably not be difficult to produce large quantities of graphite.

4.1.4. **Beryllium**

1) *Introduction*

Beryllium is an extremely expensive metal, being worth about 80 EPU units per kilogramme. From the nuclear point of view it has remarkable qualities since it can be used as moderator, reflector, structural material or sheathing.

To give an idea of the present demand for beryllium, it is sufficient to recall that a contract has just been given in the USA for the supply of 50 metric tons a year over a period of five years. This contract has a value of about 41.7 million EPU units.

2) *The Situation in Various Euratom Countries*

France

Various branches of industry, in collaboration with the CEA, have attempted to produce beryllium, which so far has only been used in small quantities for the manufacture of copper alloys.

At the beginning of 1957, about 1,500 kilogrammes of bricks of beryllium oxyde were sintered and machined for use in particular on the « Proserpine » reactor. With the help of the CEA many improvements have been made in the process of sintering. The CEA has also carried out research on the manufacture of special beryllium products, on the behaviour of glucine (beryllium oxide) under radiation, on corrosion of the latter by pressurized water and by liquid sodium. In addition, equipment has been erected for studying the thermal properties of glucine.

Italy

Purified beryllium oxide can be supplied in small quantities by the *Centro ceramico* of the Institute of Applied Chemistry of the University of Bologna ; this material, however, must be put through further purification processes before it can be used for nuclear purposes.

4.1.5. Organic Substances

In Italy, studies have been carried out on organic moderators (diphenyl and terphenyl).

In France too, the CEA has carried out research on the use of organic substances in reactors.

It is clear that if the decision is taken to build reactors using organic moderators, the chemical industry will be very interested in the matter.

4.2. STRUCTURAL MATERIALS

4.2.1. Steel and Special Steels

Steel is used in the construction of nuclear installations and ancillary laboratories. It may be used for shielding as well as for structural purposes. Great use is made of stainless and refractory steels because they contain no elements capable of becoming radio-active under radiation and also because of their resistance to corrosion.

For the year 1957, the total production of this type of steel within the Community was about 250,000 metric tons.

4.2.2. The Special Alloys of Aluminium and Magnesium

No great difficulties are encountered by the non-ferrous metals industry in the preparation of nuclear-grade aluminium and magnesium ; the industry will probably always be able to supply these metals in the quality required for nuclear purposes. Certain problems have still to be solved, however, in connection with the manufacture of special aluminium and magnesium alloys.

4.2.3. Zirconium

1) *Introduction*

Zirconium, which so far has not been extensively used, possesses satisfactory mechanical properties and a high permeability for neutrons. It may be used as unalloyed zirconium for shielding or structural purposes, but it can also be used in the alloyed form, especially for the fuel elements.

Although the price of zirconium has recently dropped considerably, it is still very high (in the USA about 70 EPU units per kg). The preparation of zirconium is a delicate process, and requires in particular the elimination of hafnium, an element which is extremely greedy of neutrons and which is always present in zirconium ore.

2) *The Situation in Various Euratom Countries*

Federal Republic of Germany

Pure zirconium tetrachloride is being produced in an experimental plant from zirconium chloride after separation of hafnium ; this zirconium tetrachloride contains less than 100 ppm (parts per million) of hafnium (less than 1/100 %). The sponge of hafnium obtained in the process can be melted down by an electric arc to give solid metal. The valuable experience gained from operation of this experimental plant can be used to construct an industrial plant which will supply several tons per month.

A number of undertakings are attempting to produce zirconium and zirconium alloys.

France

A contract for the supply of 75 metric tons of zirconia (zirconium oxide) has been given to one firm ; the process of hafnium-elimination has been entrusted to the same firm after the method had been perfected in collaboration with the CEA. Another company will be responsible for chlorination of the zirconia.

Various methods have been elaborated for the manufacture of nuclear-grade zirconium and they can now be developed on an industrial scale. Present production exceeds 50 metric tons a year.

Industrial efforts in studying the machinability of zirconium have so far not been crowned with success. This work on the properties of zirconium and its workability is still going on. At the moment a process for the electrolytic deposition of zirconium is being studied.

A factory in Le Havre has been entrusted with the work of rolling the zirconium and zirconium alloys required in the Proserpine reactor.

Studies on the mechanical, physical and chemical properties of zirconium are also being carried out on the basis of numerous agreements with the universities.

Italy

In 1954 the CNRN signed a contract with a German firm which is studying the production of hafnium-free zirconium, the manufacture of zirconium tubes and the use of these tubes for sheathing uranium rods. The method of production is to treat zirconium tetrachloride in such a way that its hafnium content is reduced from 1 % to less than 0.01 %, after which the tetrachloride is sublimed and its vapour reduced by liquid magnesium. A sponge of metallic zirconium is obtained in this way and, after removal of the excess magnesium and the magnesium chloride which has been formed, the sponge is melted down in the form of billets, which can be rolled down to a thickness of 3-5 mm. These sheets can then be worked into various shapes.

4.3. NEUTRON ABSORBERS

To reduce the reactivity of a reactor, all that is necessary is to extract neutrons from the chain reaction. Certain metals, like cadmium, boron, and hafnium, have this special property of being able to absorb neutrons. These metals are used in the manufacture of control rods, which are inserted deep into the reactor to achieve the reactivity required. The methods of powder metallurgy are extensively used in the manufacture of these rods, especially for alloying metals whose melting points are widely different.

These control and stop rods are manufactured on a small scale in France and in Germany.

4.4. COOLING AGENTS

Certain cooling agents, like ordinary water, air and carbon dioxide gas, present no difficulties in manufacture.

Reactors using enriched fuel and breeder reactors can be cooled with liquid metals such as potassium, bismuth, and above all sodium. These metals have the advantage of a high coefficient of thermal conductivity and make it possible to transfer the heat at low pressure. This property eliminates one of the major difficulties encountered in the construction of reactors. In addition, it is an easy matter to pump the liquid metal through the circuit. This can be done with the aid of electromagnetic pumps of new design.

These metals, however, have a strong corrosive effect on normal types of material, so that it will be necessary to develop special techniques.

At the moment, liquid metals only form the subject of laboratory research. In the Federal Republic of Germany such work is being carried out by various undertakings, and special attention is being paid to the development of an industrial process for obtaining pure lithium.

In France, too, such studies are being carried out by the CEA.

In Belgium a pilot factory is producing lithium from spodumene.

4.5. MISCELLANEOUS MATERIALS

4.5.1. **Calcium**

Calcium is of importance to the nuclear industry since it is employed in the production of uranium metal through reduction of uranium oxide (UO_2) or uranium tetrafluoride (UF_4). Calcium, the purity and form of which are suitable for use in the production of uranium metal, is being produced industrially in the Federal Republic of Germany. The calcium is obtained by aluminothermic reduction, followed by sublimation under vacuum and crushing.

In France, industry produces the calcium required by the CEA. The contract is for a sum of 1.2 million EPU units. The present production capacity is 450 metric tons a year.

4.5.2. In the six Euratom countries there is an industry for the production of fluorine and hydrofluoric acid, as well as for the fluorous salts used in the preparation of uranium fluorides (UF_4 and UF_6), one of which (UF_4) is used in the production of uranium metal, whilst the other (UF_6) is used for the isotopic enrichment of uranium.

4.5.3. Protective Materials

All six countries now produce considerable quantities of structural materials which can also serve for protection near the reactor and in the associated laboratories ; examples of such materials are concrete and special types of concrete, boral, ordinary and special steels and lead.

4.5.4. Other special materials used in the reactors and ancillary workshops, e.g., zinc bromide, titanium and germanium are also produced by the various industries within the Community.

4.6. CONCLUDING REMARKS

It is clear from what we have said that industry in the Euratom countries is already producing most of the special materials used in the structure and building of reactors. In cases where preliminary work is still being carried out and the manufacturing stage has not yet been reached, this work is in an advanced stage. It is not possible to predict exactly the future demand for these materials since this will depend on the types of reactor chosen.

In the USA and the United Kingdom, the industrial production of special nuclear materials has developed to such a point that the needs of their nuclear programmes can be met. For heavy water, however, the United Kingdom is mainly dependent on imports (particularly from Canada), and this is one of the reasons why England has chosen graphite-moderated reactors.

CHAPTER 5

RESEARCH REACTORS

5.1. INTRODUCTION

Progress in industrial planning and development depends on the results of pure and applied research. The investigations carried out in these two branches of research serve the triple purpose of facilitating new discoveries, improving existing techniques and training specialized personnel.

In order to solve the many problems involved in the exploitation of nuclear energy, the Euratom countries have had to provide themselves with the necessary equipment and train suitable personnel. The countries of the Community possess in varying degrees the facilities needed for a sustained research effort, especially in the field of reactors.

A number of experimental reactors have been built and put into operation. They are used for the following purposes :

- To train engineers and physicists, and the technical personnel needed to operate power reactors;
- To facilitate the study of reactor technology, the choice and adaptation of nuclear fuels and moderators;
- To provide the neutron beams needed for the study of source and structural materials and for the analysis of radiobiological phenomena;
- To provide, if necessary, a rapid means of studying the behaviour of the special materials used in reactors under conditions of high neutron flux;
- To obtain the radioactive isotopes needed in industry and agriculture, in scientific research and for medical and biological purposes.

For these various purposes neutron fluxes (1) of varying intensity are required :

- A neutron flux of O - 10^6 n/cm^2 sec is needed for reactors used in the training of technical personnel;

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(1) The figures quoted here refer to the average flux of thermal neutrons expressed in neutrons per cm^2 per sec.

— A neutron flux of 10^9 - 10^{12} n/cm^2 sec is required for general research purposes;
— A neutron flux of 10^{12} n/cm^2 sec and over is necessary for materials testing and for most biological research;
— A flux of 10^{14} n/cm^2 sec and over is required for carrying out rapid tests on the resistance of structural materials.

These neutron fluxes relate to thermal neutrons. In certain cases, however, and particularly in materials testing, the use of neutron fluxes involving fast neutrons has to be envisaged.

Apart from the neutron flux, research reactors differ in a number of other respects :

— The capacity of the reactor's experimental facilities, in which samples are inserted for exposure to the neutron fluxes listed above;
— The power of the reactor expressed in the amount of heat generated in its core and transferred by the coolant circuits.

It is hardly necessary to elaborate on the scientific and technical value of a research reactor or its usefulness as an instrument of training. It is interesting to note that a medium-sized reactor can produce a quantity of radiation comparable to that of 100 metric tons of radium; this figure is purely imaginary, however, since the total world production of radium up to the present time amounts to no more than 1½ kg.

Apart from the structural materials and shielding devices, every research or power reactor has the following constituents: the fuel, the moderator and the coolant. Reactors can be classified according to the choice of materials used for these three elements. The fuel can be natural uranium or uranium enriched to various degrees; the moderator can be graphite, beryllium, an organic liquid, heavy water or light water; the coolant can be air, carbon dioxide, heavy, water, light water, liquid metals, etc.

All these materials can be combined in different ways to produce various types of reactor which differ in their mode of operation and their suitability for training and research.

In general it can be said that :

— A reactor with a very high neutron flux must use an enriched fuel;
— A reactor fuelled by natural uranium cannot use light water as a moderator, but must employ graphite, beryllium or heavy water for this purpose;

— A homogeneous reator fuelled by natural uranium cannot use graphite as a moderator;
— Reactors with a high thermal capacity require a force-cooling system and cannot operate, like a swimming-pool reactor, on free convective cooling.

5.2. REACTORS PLANNED, BUILT OR UNDER CONSTRUCTION

The following table lists the main features of the reactors which have been or are being built in the Euratom countries. The column « Type of Reactor » gives either the traditional name associated with the type in question or a reference to some well-known reactor.

It will be seen that, generally speaking, research reactors are owned by the State, by universities or by industrial groups ; they are used in the interests of either pure or industrial research.

RESEARCH REACTORS

Planned, Built or Under Construction

Designation	BR-1	BR-2
Site	Mol	Mol
Country	Belgium	Belgium
Type of reactor	Natural uranium-graphite	Uranium-beryllium-light water (U-Be-H_2O) MTR (materials testing reactor)
Thermal Power	At present 4 MW	50 MW (25 MW in first phase)
Maximum thermal neutron flux	2×10^{12} n/cm^2 sec.	8.6×10^{14} n/cm^2 sec
Fuel	24 t of uranium metal	4 kg of uranium metal
Enrichment of fuel in U 235	Natural uranium	Over 90 %
Moderator	Graphite	Beryllium and water
Coolant	Air	Water
Main purpose	Physical research-radioisotopes	Testing of materials
Date of criticality or state at end of 1957	May 11, 1956	Probably beginning of 1960
Owner	Centre d'étude de l'énergie nucléaire (CEN)	Centre d'étude de l'énergie nucléaire (CEN)
Main supplier	Belgian firm	Nuclear Development Associates (NDA) - (USA)

Designation	—	—	—
Site	Munich	Hamburg	Frankfurt/Main
Country	Germany	Germany	Germany
Type of reactor	Swimming pool	Swimming pool	Homogeneous an boiling water
Thermal power	1 MW	1 MW, later 5 MW	50 kW
Maximum thermal neutron flux	6.6 × 10^{12} n/cm^2 sec	2 × 10^{13} n/cm^2 sec	10^{12} n/cm^2 sec
Fuel	Enriched uranium	Enriched uranium	Uranyl sulphate aqueous solutio
Enrichment of fuel in U 235	20 %	20 %	20 %
Moderator	Light water	Light water	Light water
Coolant	Light water	Light water	Light water
Main purpose	Research	Research	Research
Date of criticality or state at end of 1957	In operation	Under construction	Will soon be pu into service
Owner	Bavaria	Gesellschaft für Kernenergieverwertung in Schiffbau und Schiffahrt GmbH Hamburg	Hessen
Main supplier	American Machine & Foundry (USA)	Babcock & Wilcox (USA)	North American Aviation Inc. (USA)

—	—	—	—
erlin	Stetternich near Jülich	Stetternich, Jülich	Karlsruhe
ermany	Germany	Germany	Germany
omogeneous and boiling water	« Merlin »	« Dido »	German design FR 2 (heterogeneous)
50 kW	2 MW, later 5 MW	10 MW	10-12 MW
^{12} n/cm^2 sec	5 $\times$ 10^{13} n/cm^2 sec	10^{14} n/cm^2 sec	3 $\times$ 10^{13} n/cm^2 sec
ranyl sulphate in aqueous solution	Enriched uranium	Enriched uranium	Natural uranium
%	20 %	Approximately 90 %	Natural uranium
ght water	Light water	Heavy water	Heavy water
ght water	Light water	Heavy water	Heavy water
esearch	Research	Research	Research
be put into operation soon	Construction to begin soon	Planned	Under construction
erlin	Nordrhein-Westfalen	—	Kernreaktor Bau- und Betriebs GmbH, Karlsruhe
orth American Aviation Inc (USA)	AEI John Thompson Nuclear Energy Co. (UK)	Head Wrightson Proc. Ltd. (UK)	Kernreaktor Bau- und Betriebs GmbH, Karlsruhe (Federal Germany)

Designation	ZOE	EL 2	EL 3	Aquilon
Site	Fontenay-aux-Roses	Saclay	Saclay	Saclay
Country	France	France	France	France
Type of reactor	Heavy water	Heavy water	Heavy water	—
Thermal power	150 kW	2,500 kW	15 kW	Nil
Maximum thermal neutron flux	10^{12} n/cm^2 sec	10^{13} n/cm^2 sec	10^{14} n/cm^2 sec	10^{7} n/cm^2 se
Fuel	Natural uranium	Natural uranium	Slightly enriched uranium	Natural uranium
Enrichment of fuel in U 235	—	—	—	—
Moderator	Heavy water-graphite reflector	Heavy water-graphite reflector	Heavy water-graphite reflector	Heavy water-graphite reflector
Coolant	Heavy water	Heavy water	Heavy water	Heavy water
Main purpose	Fundamental research	Research and materials testing	Research and materials testing	Study of lattices
Date of criticality or state at end of 1957	December 15, 1948	October 21, 1952	July 4, 1957	August 11, 1956
Owner	Commissariat à l'Energie atomique (CEA)	CEA	CEA	CEA
Main supplier	French firm	French firm	Chantiers de l'Atlantique in collaboration with France-Atome	French fir

Melusine	Triton	Minerve	Proserpine	Alizé
renoble	Fontenay-aux-Roses	Fontenay-aux-Roses	Saclay	Saclay
rance	France	France	France	France
wimming pool	Swimming pool	Swimming pool	Homogeneous	—
,000 kW	1,000 kW	Very low	Low (approximately 1 W)	Very low
0^{13} n/cm^2 sec	10^{13} n/cm^2 sec	10^{11} n/cm^2 sec	5×10^7 n/cm^2 sec	5×10^7 n/cm^2 sec
nriched uranium	Enriched uranium	Enriched uranium	Plutonium in solution in light water	Varies
—	—	—	—	—
ight water (H_2O)	Light water (H_2O)	Light water (H_2O)	Beryllium oxide (BeO) and graphite	Light water
ight water	Light water	Light water	None	Light water
tudy of lattices	Shielding studies	Tests on purity of materials	Research on the use of plutonium	Study of lattices
robably July, 1958	Probably January, 1959	Probably April, 1959	March 17, 1958	February, 1959
EA	CEA	CEA	CEA	CEA
ndatom	Indatom	Seratom and Indatom	French firm	CARA

Designation	Ispra 1	RS 1 Avogadro	—	—
Site	Ispra	Saluggia (Vercelli)	near Livorno	Milan
Country	Italy	Italy	Italy	Italy
Type of reactor	CP-5	Swimming pool	Swimming pool	Homogeneous solution type
Thermal power	5 MW	Initially 1 MW, to be raised later to 5 MW	1 MW	50 kW
Maximum thermal neutron flux	10^{14} n/cm^2 sec	10^{13} n/cm^2 sec	10^{12} n/cm^2 sec	10^{12} n/cm^2 sec
Fuel	Approximately 8 kg U 235 in form of U-Al alloy	U-Al alloy (Al canned) - approximately 3.5 kg	U-Al alloy	Uranyl sulphate solution
Enrichment of fuel in U 235	20 %	20 %	20 %	20 %
Moderator	Heavy water (D_2O)	Light water (H_2O)	Light water (H_2O)	Light water (H_2O)
Coolant	Heavy water (D_2O)	Light water (H_2O)	Light water (H_2O)	Light water (H_2O)
Main purpose	Research	Research	Research	Specialist training and research
Date of criticality or state at end of 1957	Approximately February-March, 1959	End of February, 1959		March, 1959
Owner	CNRN	SORIN	CAMEN	E. Fermi Research Institute, Milan College of Technology
Main supplier	American Car & Foundry (ACF Industries) (USA)	American Machine & Foundry (AMF Atomics) (USA)	USA	Atomics International (North American Aviation (USA)

Designation	HFR	HOR	Suspension
Site	Petten (NH)	Delft	Arnhem
Country	Netherlands	Netherlands	Netherlands
Type of reactor	High-flux reactor, MTR model	Swimming pool	Homogeneous, aqueous suspension
Thermal power	20 MW	100 kW	Nil
Maximum thermal neutron flux	4 × 10^{14} n/cm^2 sec	1.1 × 10^{12} n/cm^2 sec	—
Fuel	4.2 kg of uranium metal	3.5 kg of enriched uranium metal	1 kg of uranium 235, in the form of enriched UO_2 in suspension in light water (H_2O)
Enrichment of fuel in U 235	90 %	20 %	—
Moderator	Light water (H_2O)	Light water (H_2O)	Light water (H_2O)
Coolant	Light water (H_2O)	Light water (H_2O)	Suspension of uranium oxide (UO_2) in light water
Main purpose	Nuclear research and materials testing	Training and research	Research aimed at utilization for power production
Date of criticality, or state at end of 1957	1959	—	—
Owner	Reactor Centrum Nederland (RCN)	Netherlands Government	Reactor Centrum Nederland (RCN) and KEMA
Main supplier	American Car & Foundry (USA)	American Machine & Foundry (AMF Atomics) (USA)	—

5.3. CONCLUDING REMARKS

As the object of the present chapter was to bring out the interconnection between research and the industrial applications of nuclear energy, a more detailed account of nuclear research and research reactors will be reserved for the Report on this subject to be published by the Euratom Commission.

To emphasize the importance of research, however, attention should be drawn to the close ties that exist between research and industry in those countries which are most advanced in the use of nuclear energy, particularly the United States and Great Britain.

In the United States, military needs coupled with a keen interest in nuclear energy generally have resulted in the construction of a large variety of research reactors of all types. About a hundred have been or are being built, or are planned.

Compared to the efforts made by Great Britain in the use of nuclear energy to produce electricity, the number of research reactors so far built there may seen small. Nuclear research in Great Britain does not cover the same wide field as in the United States. Nevertheless, it is an indisputable fact that the fundamental research carried out by the United Kingdom Atomic Energy Authority (UKAEA) has produced remarkable results. In the United States, the large variety of reactor types which the Atomic Energy Commission has been instrumental in constructing form the basis for considerable theoretical and experimental research. In Great Britain, where power reactors belong basically to one of two types, the scope of research-work is naturally much more limited.

One of the consequences of the great interest shown by American industry in nuclear problems is the construction of numerous reactors used for the training of specialists. A number of universities and industrial concerns possess their own reactors, whereas in Great Britain there are no private research reactors. This may be an upshot of the traditional psychological make-up of the American economy; but, whatever the reasons for it are, there can be no doubt that it provides nuclear research and technology with incomparable opportunities for broadening the scope of their experience in the nuclear field.

CHAPTER 6

POWER REACTORS

6.1. INTRODUCTION

As will be pointed out in chapter 9, nuclear power will be able to make a great contribution to power production in Western Europe, especially in the field of electricity production.

The theory of power reactors is based on the release of thermal energy accompanying the process of fission, on the transformation of this thermal energy into mechanical energy, and on the utilization of the latter to drive electric generators. The direct transformation of the energy of fission into electric energy is never accomplished in a reactor.

The heat-transfer fluid may be passed straight to the turbine. but in the majority of nuclear power stations a preliminary exchange of heat takes place. The reactor coolant thus flows in a closed circuit. Limited by the temperature of the heat-transfer fluid at the inlet and outlet of the reactor, the heat energy produces only a relatively small amount of electrical energy. It is impossible, within the scope of this work, to give in detail all the factors involved in efficiently transferring the heat produced in a reactor, but it should be pointed out that the efficiency, expressed as the relation between the electrical energy obtained and the initial heat energy, lies between 20 and 30 percent for nuclear power stations of the types envisaged. This figure is lower than that for modern power stations of conventional type.

In addition, it is possible to employ the heat energy directly for heating rooms or apparatus, or to produce steam for different purposes.

Finally, the use of reactors for ship-propulsion is another sphere of great interest. Five of the six Member States are maritime nations; reactors for ship-propulsion constitute an important field of research and development.

The present stage of development is given below for the different forms of energy production using nuclear reactors.

6.2. TYPES OF NUCLEAR REACTOR

Nuclear power stations for the production of electric power can be classed according to the types of reactor employed.

1) Gas-cooled, graphite-moderated reactors like those at Calder Hall in Great Britain; ,

2) Reactors using light or heavy water under pressure, well known under the abbreviation « PWR » (pressurized-water reactor); a reactor of this type is now in operation at Shippingport in the first American nuclear power station;

3) Boiling water reactors (« BWR ») using light or heavy water; a great deal of experimental work has been carried out in the large American laboratories on these reactors;

4) Graphite-moderated reactors using sodium as heat exchanger, they are known under the abbreviation « SGR » (sodium graphite reactor);

5) Reactors using an organic moderator, for example diphenyl or terphenyl. Such reactors are known by the abbreviation « OMRE » (organic moderator reactor experiment); a reactor of this type has been constructed in America ;

6) Breeder reactors; one of these reactors is being built for industrial purposes at Dounreay (Scotland).

Each type has its own particular advantages and is specially suitable for certain purposes. The graphite-moderated reactor. for example, is heavy and bulky for its energy capacity, but can operate satisfactorily on natural uranium both from the economic and technical point of view, and this is not possible with the other types unless heavy water is used.

For operation of the PWR reactors, enriched uranium must be used, but the reactor is less bulky and lighter. This reactor is apparently more suitable for ship-propulsion than the first type.

The use of water at high temperatures, as in the PWR, implies relatively high pressures, which call for special methods of construction. The construction of a boiling-water reactor, is a more simple matter because of the lower pressures involved. It is not necessary, for example, to employ reservoirs capable of withstanding pressures of 100 atmospheres or more. This type is especially suitable for applications in which the thermal energy is directly utilized.

As far as the moderator is concerned, either light water or heavy water may be utilized with BWR or PWR types. Heavy water is an excellent moderator, but its high price and the difficulty of obtaining it in sufficient quantities sometimes preclude its use. For this reason heavy water has so far been used mainly in fairly small research reactors. At the present time studies are being carried out on the use of heavy water in power reactors. The use of an organic moderator in an OMRE reactor makes it possible to combine a high temperature with a low pressure. The moderators studied in America, diphenyl and terphenyl, are solid at normal temperature and pressure. Under working conditions, they are liquid and possess qualities which are suitable both for use as moderator and for the transfer of heat. As far as industrial uses are concerned, the OMRE has not yet progressed as far as the other types mentioned above.

6.3. THE SITUATION IN VARIOUS EURATOM COUNTRIES

6.3.1. **Belgium**

An experimental nuclear power station is under construction for the CEN at Mol; the Centre is also in charge of the building operations.

This reactor, known as BR-3, is of the PWR high-pressure type (140 kg/cm^2). Its overall electric power will amount to 11,500 kWe, equivalent to a net power of 10,500 kWe. The fuel used will be 4.5 % enriched uranium, distributed over 32 elements and in the form of pellets of uranium oxide. There will be 12 control rods having a cruciform section. The maximum thermal neutron flux within the core will be 8.57 x 10^{13} n/cm^2 sec and the average flux 1.83 x 10^{13} n/cm^2 sec. Other technical data are : inlet pressure at the turbine, 36.6 kg/cm^2; temperature, 244° C; overall efficiency, 26.7 %.

The reactor, including the primary cycle, will be placed in a container of sheet-steel, 28 mm thick. The container has a diameter of 16.5 m and a height of 32 m. This power station will be connected to the Belgian national grid and is intended to go into service at the beginning of 1960.

The Belgian electricity industry has not yet made a definite choice of the types of reactor to be employed in future power installations.

Plans are now being examined for the construction of a reactor with a power of some 150 MWe; this is for the CNI Project (Interescaut Nuclear Power Station), which is to be ready by 1962-63.

The construction of another power station of the same capacity should also be completed by 1962-63.

For 1967, the construction of two more power stations is contemplated. Each of these installations will have a capacity of 120-150 MWe, giving a total of 240-300 MWe. The installed nuclear electric power should then amount to about 550-600 MWe.

In addition, a Belgian company acting in concert with a design and development organization in the USA, has completed the plans for a BWR power station, which will employ high-temperature steam superheated with the aid of fuel oil.

6.3.2. Federal Republic of Germany

Before 1965, four or five nuclear power stations with a total capacity of about 500 MWe will probably be constructed and put into operation in the Federal Republic.

Orders given in connection with the building of these power stations will for the main part be fulfilled by German concerns; they are being drawn up by four groups of electric-power undertakings with headquarters at Hannover, Düsseldorf, Stuttgart and Munich, (1) together with one single undertaking, the Rheinisch-Westfälisches Elektrizitätswerk AG (RWE) at Essen.

The German nuclear industry, in particular the big electrical firms and the steam-engine and boiler manufacturers, who

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(1) The names of members of these four groups are given in the appendix to chapter I.

have formed special departments for nuclear work, is at the moment working out plans for nuclear power stations equipped with the following types of reactor :

N°	Fuels	Moderator	Coolant
1	natural uranium	heavy water	high-pressure gas
2	natural uranium	heavy water (under pessure)	heavy water (under pressure)
3	natural uranium	heavy water	organic substance
4	natural uranium	graphite	gas
5	natural uranium	graphite	liquid sodium
6	slightly enriched uranium	light water (boiling)	light water (boiling)
7	slightly enriched uranium	graphite	high-pressure gas
8	slightly enriched uranium	organic substance	organic substance
9	20 % enriched uranium and thorium	high - temperature breeder reactor	gas

The high-temperature breeder reactor (N° 9), which has spherical fuel elements, has been recently developed by two German companies. The latter have recently submitted a final offer for the construction of a 15 MWe experimental nuclear power station using this type of reactor, to the group of electricity producers at Düsseldorf (see chapter 1). The producers are urging that building should begin at the end of 1958.

As far as work on the other types mentioned above is concerned, preparations have made the most progress in the case of 1, 2 and 6.

In respect of type 4, a special study in collaboration with certain British firms is being made to perfect a reactor of the Calder Hall type.

The construction of the power reactors, which are the subject of negotiations between the electricity producers and distributors on the one hand and the nuclear industry on the other and which will have an installed capacity of about 500 MWe, will involve investments amounting to 150 - 190 million EPU units.

According to an estimate, the overall needs in nuclear raw materials will amount to :

400 t	natural uranium
40 t	slightly enriched uranium (from 1 to 1.5 %)
300 kg	enriched uranium (20 %)
2,000 t	graphite
150 t	heavy water
50—60 t	zirconium
about 50 t	thorium

This list does not include the materials required for the reactor with organic coolant.

It is envisaged that a sum of about 70 million EPU units will be made available to provide the nuclear industry with these raw materials if they are not imported from abroad. This sum must be added to that already mentioned in respect of the cost of construction of the nuclear power stations and the cost of installing safety and radiation-protection equipment. If, moreover, we take into account the expense of materials analysis, of work relating to the choice of sites and to various technical or chemical preparations, as well as the sums payable to certain international organizations (Euratom, CERN, OEEC, etc.), expenditure by 1965 will reach a total of about 500 to 600 million EPU units, which will be partly supplied by the State.

Reactors for Ship-propulsion

The « Gesellschaft für Kernenergieverwertung in Schiffbau und Schiffahrt » (Company for the Exploitation of Nuclear Energy in Ship-building and Sea Transport) in Hamburg has undertaken to study the various types of reactor which are particularly suitable for ship-propulsion, and subsequently to construct with the help of industry an appropriate reactor for this purpose.

To prepare and facilitate its work, the Company has built at Geesthacht-Tesperhude near Hamburg a Babcock & Wilcox « swimming pool » type test reactor. This reactor has a thermal power of 5 MW and will be in operation within a few months.

No decision has yet been made regarding the date of completion and the method of construction of the first power reactor for ship-propulsion.

6.3.3. **France**

In 1953, on the initiative of the *Commissariat à l'Energie atomique,* a French programme for the construction of power reactors was launched and is now nearing completion.

In selecting the type of reactor, account was taken of the fact that France has a considerable supply of uranium but that no factory has yet been established for the separation of isotopes.

The *Commissariat* wishes to develop a policy adapted to the possibilities of French industry, due regard being paid to the present knowledge in the field of nuclear energy. This policy is based on the use of reactors fuelled with natural uranium, moderated by graphite and cooled by gas.

The public authorities have decided to embark on a programme of electricity production using the heat liberated by such gas-cooled reactors. These nuclear power stations, which will go into service before 1965, will have a capacity of 850 MWe.

The full French programme was recently extended to provide 1,200 MWe ; the extra power will be produced by other types of reactor, which will be ready before the same date.

France is at the moment the only one of the six Member States of the Community which has a nuclear power station, although this is only for experimental purposes. It is the G1 reactor, belonging to a group of three reactors (G1, G2 and G3) of the Marcoule Centre in the Department of Gard near the Rhône. Although these reactors, constructed by the *Commissariat à l'Energie atomique,* are intended mainly for the production of plutonium, they are also used under a programme for the production of electric power under the authority of *Electricité de France.*

The G1 reactor, which became critical on January 7, 1956, was started in May, 1954. The first kWh of the associated power station were produced in September, 1956.

This reactor was designed for a thermal power of 40 MW. It contains about 1,200 metric tons of nuclear-grade graphite.

The total load of the fuel elements amounts to some 100 metric tons. The air leaves the reactor at a temperature of about 200° C, and its rate of flow has been fixed at 250 kg per second under normal conditions of operation.

The core of the G1 is a prism of graphite with a horizontal axis contained in a cylinder 8 m long and with a diameter of 8 m. It is pierced by 1,338 horizontal channels, into which the elements of uranium are inserted. The air coolant arrives through a slot 80 mm long which cuts this prism at right-angles to its axis. The control rods and safety rods move in vertical holes in the stack, and in this way the power of the reactor may be regulated and safety ensured.

The uranium elements employed in the G1 are 3.8 m long and contain rods of natural uranium in an envelope of magnesium provided with longitudinal fins. In designing the generating plant associated with the G1 pile, account was taken of the particular characteristics of the coolant.

The power station will produce a net power for continuous normal working of 5.1 MWe. The hot water storage tanks make it possible to produce a net power of 7.2 MWe for peak loading.

The installation was designed for these values under normal and overload conditions.

It should be noted, however, that the power requirements of the auxiliary equipment of the G1 reactor are about 8 MWe, which is considerably more than the capacity of the generating plant.

The G2 and G3 Reactors

These two reactors, which are identical, are similar in design to the G1 except that their coolant system is in the form of a closed circuit using carbon dioxide at a pressure of 15 kg per cm^2, whereas in the G1 there is an open coolant circuit using air at atmospheric pressure. Thanks to this arrangement, it has been possible to bring about a considerable increase in the power of the reactors.

The thermal power of the pile is 150 MW. The core is a prism fitting into a cylinder 8.45 m long and 7.85 m in diameter, whilst the peripheral reflector has a thickness of 1 m. There are 1,200 channels. The total weight of graphite is about 1,000 metric tons. The uranium load is 100 metric tons and is made up of fuel elements 30 cm long. These fuel elements are sheathed in a magnesium alloy and, like the G1, they are provided with fins to improve the heat exchange between the uranium and the coolant. The coolant circuit is divided into two sections and the total flow is 997 kg per second. The maximum outlet temperature is 254° C. Four heat exchangers are used to feed the generating plant, which has a rated output of 45,000 kVA. They also feed the turbo-blowers which are used for cooling the reactor. The power of these turbo-blowers is 9,600 horsepower (metric). Finally, the electric power at the output, taking into account the net electric power absorbed by the auxiliary equipment, is 25 MWe. Under more favourable conditions, this net power could reach about 35 MWe.

Work on the G2 reactor started at the beginning of 1956, and criticality will be reached in the second half of 1958. Criticality of the G3 reactor will be reached about 6 months later.

Taken together, the plant at Marcoule represents a net electric power of about 65 MWe. This power must be included in the 850 MWe programme for gas-cooled reactors drawn up by the French Government to be ready before 1965, as indicated above. To implement this programme, *Electricité de France* has decided, in principle, to start the construction of the new power stations at intervals of 18 months, each station having twice the power of the preceding one. The first installation started by *Electricité de France* is the EDF1 Nuclear Power Station, which is now being built at Chinon on the Loire near the confluence of the rivers Loire and Vienne.

The EDF1 Power Station

The overall design of this station is similar to that of the G2 and G3 installations. Profiting from experience gained on previous projects, attempts have been made to reduce the cost of the station. However, the possibility of introducing new designs has not been excluded. The reactor, for instance, has vertical channels, whereas the G2 and G3 have horizontal channels. The core of the reactor is contained in a steel tank, whereas in the G2 and G3 it is contained in prestressed concrete tanks. The thermal power of this new installation has been raised to 300 MW, which corresponds to a net electric power of 70 MWe. The core of the reactor is contained in a cylinder 9 m long and 8.3 m in diameter.

The reactor is cooled by carbon dioxide at a pressure of 25 kg per cm^2 flowing at a rate of 1,300 kg per sec ; the temperature of the carbon dioxide is 140° C at the inlet and 345° C at the outlet. A set of 120 heat exchangers feeds the generating plant, whose rated electric power is 102.5 MVA. The coolant system employs a single blower, which requires a maximum power of 8,000 kW.

Work on the EDF1 commenced at the beginning of 1957 and the station should be ready to go into industrial service at the end of 1959.

The EDF2 Nuclear Power Station

Electricité de France has decided to include in its full programme a new nuclear plant to be built near the EDF1. In building this power station, use will be made of the experience already gained. The overall design resembles that of the EDF1, but the available power will probably be increased. The general characteristics of these installations have not finally been fixed. However, the thermal power should be about 700 MW, which will give a net electric power of 170 MWe. About 250 metric tons of uranium will be used. The first orders for materials have already been given. It is hoped that these installations will go into service in 1961.

Other Industrial Projects

Several French companies have combined to deal with requests on the part of Dutch and Italian manufacturers to construct nuclear power stations with a net electric power of 150 MWe. These companies have studied in detail a project with a gas-cooled reactor fuelled with natural uranium and moderated with graphite, and they have submitted their proposals and prices for the whole plant within the prescribed time.

The CEA and the Secretary of State for the Merchant Marine have formed a Working Party to study on land a reactor for tankers, and French manufacturers are also cooperating with this group.

More recently a group of engineering firms including shipbuilders was formed with a view to coordinating efforts in the field of ship-propulsion within the various associations. Several reactor projects for tankers are at present being studied.

6.3.4. **Italy**

There are as yet no power reactors in Italy. Various branches of industry, however, have already drawn up programmes in this field. Two projects that have been decided on deserve special note.

A 200 MWe nuclear power station of the Calder Hall type containing 245 metric tons of natural uranium will be built by the *AGIP-Nucleare* with the collaboration of the *Società Italiana Meridionale Energia Atomica* (SIMEA).

The *Società Elettronucleare Italiana* (SELNI) will construct a 135 MWe nuclear power station using reactors of the pressurized water type (PWR). Uranium oxide (UO_2) enriched to 2.6 % will be used as fuel.

The *Società Elettronucleare Nazionale* (SENN) intends to build a nuclear power station with a capacity of 130-150 MWe (ENSI project). Thanks to consultations between foreign designers, who have also been requested to secure the cooperation of Italian designers, it will soon be possible to decide on the type of reactor to be employed.

The following two projects are also being studied :

by the *Società Ricerche Impianti Nucleari* (SORIN) : a 150 MWe reactor of a type not yet fixed ;

by the *AGIP-Nucleare :* a 130-180 MWe power station using pressurized water type reactors.

In addition, the *Comitato Nazionale per le Richerche Nucleari* (CNRN) has carried out a preliminary study of various types of prototype reactors ;

in collaboration with FIAT, which is connected with SORIN :
— a reactor using liquid metal fuel ;

in collaboration with MONTECATINI, a firm connected with SORIN :
— a reactor with organic moderator ;

in collaboration with *AGIP-Nucleare* :
— a gas-cooled reactor of extremely modern type.

In the field of power reactors, the CNRN has undertaken a comparative study of the Calder Hall type of gas-cooled reactor and the pressurized water reactor.

6.3.5. The Netherlands

The Netherlands Ministry for Economic Affairs envisages the construction of nuclear power stations to supply a total electric power of 400 MWe by 1965 and 1,200 MWe by 1970.

Consultations are being held with foreign groups in connection with the first nuclear power station in the Netherlands. This power station will have a capacity of 150 MWe and will be built at the expense of all the electricity producers. It should be completed by 1962.

Several firms of boiler-makers specializing in electric power stations have expressed their intention of forming a limited company to encourage the development of the homogeneous aqueous suspension reactor mentioned in chapter 5 (KEMA-RCN) for the production of electricity. First of all, an experimental 10 MWe power station will be built.

POWER REACTORS

Planned, Built or Under Construction

Designation	BR-3	G1	G2
Site	Mol	Marcoule (Gard)	Marcoule (Gard)
Country	Belgium	France	France
Type of reactor	PWR	Gas-graphite	Gas-graphite
Thermal Power in MW	43 MW	40 MW	150 MW
Electrical Power in MW	10.5 MWe	5.1 MWe	30 MWe
Fuel Charge	2.8 t UO_2	100 t natural uranium	100 t natural uranium
Enrichment in U 235	4.5 %	natural	natural
Moderator	Light water	Graphite	Graphite
Coolant	Light water	Air	Carbon dioxide
Temperature (°C) at reactor outlet	271	200	255
Pressure in reactor in kg/cm^2	140	Atmospheric pressure	15
Steam	In exchanger at full load : 36 kg/cm^2 absol. saturated steam ; at no-load 50 kg/cm^2 absol.	—	—
Criticality at end of 1957	Not critical ; probably 1960	Critical since September, 1956	Not critical ; probably secon half of 1958
Total cost of plant (1)	10 million EPU units	23 million EPU units	30 million EPU units
Cost per kWe	1,000 EPU units	4,500 EPU units	1,000 EPU units
Owner	Centre d'étude de l'énergie nucléaire	Commissariat à l'Energie atomique	CEA
Main Supplier	Westinghouse	—	—
Main consulting engineer	Bureau d'études nucléaires in collaboration with Belgo Nucléaire	SFAC	Alsacienne

(1) Excluding research and investigations, fabricatio

G3	EDF1	EDF2	SIMEA	SELNI
Marcoule (Gard)	Chinon (Indre & Loire)	Chinon (Indre & Loire)	South of Rome	—
France	France	France	Italy	Italy
Gas-graphite	Gas-graphite	Gas-graphite	Gas-graphite	PWR
150 MW	300 MW	700 MW	711 MW	482 MW
30 MWe	70 MWe	170 MWe	200 MWe	134 MWe
100 t natural uranium	140 t natural uranium	250 t natural uranium	245 t natural uranium	27.5 t UO$_2$
Natural	Natural	Natural	Natural	2.6 %
Graphite	Graphite	Graphite	Graphite	Light water
Carbon dioxide	Carbon dioxide	Carbon dioxide	Carbon dioxide	Light water
255	345	345	390	274
15	25	25	13.8	140
—	—	—	52.3 kg/cm^2 13.7 kg/cm^2 (371° C)	35 kg/cm^2 (241° C)
Not critical ; probably first half of 1959	Not critical ; probably end of 1959	Not critical ; probably 1961	Not critical ; probably 1962	Not critical ; probably 1961
30 million EPU units	33 million EPU units	60 million EPU units	80 million EPU units	25 million EPU units
1,000 EPU units	500 EPU units	350 EPU units	400 EPU units	186 EPU units
CEA	Electricité de France	EDF	SIMEA	SELNI
—	—	—	NPPC	Westinghouse
Alsacienne	—	—	—	—

of fuel and waiving of dues for use of fuel.

6.4. CONCLUDING REMARKS

The short account given in this chapter on the power reactors now under construction or being planned in the various countries of the Community shows that European industry is already in a position to play a more or less active part in the work. The contribution of the various undertakings concerned may range from the drawing up of the whole or part of a project to the manufacture of reactor parts or an entire reactor, according to the knowledge or manufacturing capacity of the firm concerned.

The scope and nature of the programmes announced or definitely decided upon by the various countries depends largely on their general policy in the nuclear field. Some countries have decided to avail themselves of their own national resources, whilst others are arranging to get their nuclear fuels from abroad, and will work in close cooperation with countries that have already reached an advanced stage of development in the field of nuclear energy. This is reflected in the choice of reactors and the means required for their construction and operation.

All the six countries of the Community are concentrating on power stations of high capacity in order to obtain an economical supply of electricity. Low-power stations have also been constructed or are in course of construction (e.g., the BR-3 and the G1, G2, and G3), but they must be considered as prototypes for the more economical reactors, i.e., for reactors having a power of 100 MWe or over. The reactors in this power class whose construction has already been started or decided on include both gas-graphite, and pressurized water types. So far, the BWR type has only been used for experimental purposes with a power of about 10 MWe.

France, like Britain, has concentrated its efforts on the gas-cooled, graphite-moderated reactor. In the USA, however, various types are receiving attention, but the PWR and the BWR have reached the most advanced stage of development.

The differences between the American and the European programmes, both for immediate implementation and for future development, can be explained by the fundamental economic differences between the USA and Europe.

Thanks to their existing coal, petroleum and gas reserves, the USA do not need to specialize in the large-scale production of atomic power at the present moment. The programme of the *Atomic Energy Commission* (AEC) is more concerned with the improvement of those reactor types which offer the best prospects of successfully obtaining the cheapest possible supply of electricity at some future date, litte account being taken of present requirements. This does not mean, of course, that the types of reactor specially studied in the USA are not already suitable for operation in Europe under satisfactory economic conditions. It is for the above reason that the various American programmes are based on reactors of very different designs. In the case of prototypes, the reactor power does not exceed 40 MWe.

These reactors will not of course render possible the immediate production of cheap electricity ; they have been developed and designed for research purposes and the knowledge gained will make it possible at some time in the future to construct power reactors offering the optimum economic conditions of operation.

In the six Community countries, the situation in the field of nuclear energy is very much the same as in Great Britain. As has been pointed out in this chapter, however, research and investigation is being carried out on a large number of different reactor types.

Outside the field of high-capacity power stations, close attention is now being paid in the USA to the construction of small reactors (with a power of about 5 MW) which can be used for military purposes or for supplying power in sparsely populated areas. These small reactors are of interest to the Euratom countries in connection with overseas needs.

Another important difference between the British and American research programmes on power reactors is the fact that use is made almost exclusively of enriched uranium in the USA, whereas in European industry preference is given to projects employing natural uranium.

In the field of ship-propulsion, the Community countries, as well as Great Britain, are examining the new possibilities offered by the use of nuclear energy. These possibilities are clearly illustrated by various American shipbuilding achievements and by plans for equipping units of the American Mercantile Marine with nuclear-powered drives. Although in the USA and Great Britain work has already been started on nuclear-powered aircraft and rockets, this field has not yet been entered by the Euratom countries.

CHAPTER 7

RADIO-ISOTOPES - THEIR PRODUCTION AND USE

7.1. INTRODUCTION

From the very beginning, there have been two fundamental peacetime applications of nuclear fission : the production and use of radio-isotopes and the generation of power.

The use of isotopes is no new thing, but now that their production has been facilitated by technical progress they will naturally become increasingly available for use in many different fields, in medicine, science, industry, and agriculture.

The various isotopes of a given element are chemically the same but they differ in their physical properties, e.g., in their mass numbers, one from another. Some are stable, others are not. The latter are called radioactive isotopes or radio-isotopes. Being unstable, they are transformed after definite periods of time into other isotopes, which may or may not be radioactive.

In the course of this process, radiations are emitted (alpha, beta, or gamma), which can be utilized for many different purposes. Some of the known radio-isotopes are encountered in nature (about 50 of them) whilst others (roughly 700) are produced artificially.

Radio-isotopes are characterized by their « half-life », which is the length of time required for half the number of nuclei initially present to disintegrate ; they are also distinguished by the nature and energy of their radiation.

Another property associated with samples of radio-isotopes is their specific activity, that is to say the radioactivity (in disintegrations per second, or curies) per unit weight of the sample.

Production of Radio-isotopes

There are three ways of producing radio-isotopes. The first is to subject certain substances to irradiation in a reactor. The nuclear reactions produced in this way, which may be followed by one or more radioactive disintegrations, form radioactive isotopes of the original element or of some other element. The second method, which consists in reprocessing and separating the fuel used in a reactor, is applied to the radio-isotopes produced by the fission process. The third method consists in subjecting certain elements to radiation with the aid of particle accelerators.

Each of these three processes has its advantages and its drawbacks. The first method is at present the most widely employed, but in future increasing use will be made of the second method. The total number of radio-isotopes is considerable, but for all practical purposes only about one hundred are commercially available.

Uses of Radio-isotopes

Radio-isotopes are finding an increasing number of applications and it would be difficult to list them all. The following classification, although incomplete, is fairly representative and is based on recent developments.

1) *Research*

The use of radio-isotopes in fundamental and applied research is becoming more and more widespread. Some of the main uses are in the study of solid-state diffusion, ionic surface-adsorption, the determination of the thickness of deposits and the measurement of metallic vapour pressure.

2) *Medicine*

A. The study of biological and biochemical processes in the human organism : Thanks to the fact the isotopes of any particular element behave alike chemically and that the radioactive isotopes emit radiation, it is possible, by mixing a certain number of radio-isotopes in a given substance, to follow the latter's path in the body of a human being or of an animal. In particular, use is made of isotopes having the following properties :

   a) Proneness to selective absorption by the organ or systems of organs under investigation ;

   b) Sufficiently short half-life ;

c) Rapid elimination by the organism.

With the aid of radio-isotopes, for example, it is possible to study the behaviour of certain medicines in the living organism.

B. Diagnosis : Diagnosis is possible in some cases thanks to the preferential location of certain elements in certain organs. Examples of current diagnostic applications are : radiography, tests for thyroid activity, localization of brain tumours, the investigation of the up-take of iron in the body metabolism, the study of various aspects of the blood circulation, radiocardiography and testing the functioning of the heart, etc.

C. Therapy : These applications are well known and the first experiments date back to the time when radioactive isotopes were first discovered long before the introduction of nuclear reactors. The isotopes may be applied in different ways : by direct, external contact with the affected part (if this is external), or by internal irradiation (for an internal part), by ingestion or by injection, depending on the circumstances.

D. Genetic research : Positive results have been obtained in this field.

3) *Agriculture and Foodstuffs Industries*

Radio-isotopes are utilized in agriculture to study the biological or biochemical processes of plant organisms by using the methods outlined above. It is possible to study the lymphatic circulation in plants and the processes involved in the assimilation of particular substances. Particularly important research has been carried out on photosynthesis of chlorophyll.

In the foodstuffs industry, methods of preserving foods by subjecting them to powerful radiation from a radioactive source are being studied.

4) *Industry*

The catalogue of uses of radio-isotopes in industry is almost endless. A few of their more important applications are :

A. Measurement of density, thickness, liquid levels. This is done by registering the radiation emitted by a source, the intensity of the radiation being affected by the material under investigation.

B. Industrial radiography (to replace cumbersome and costly X-ray machines), various applications in the petroleum industry (wells and refineries), flow-control of fluids.

C. Checking corrosion of relatively inaccessible parts of plant or machines.

D. Various irradiation processes in the chemical industries to modify the molecular state of material.

7.2. THE SITUATION IN VARIOUS EURATOM COUNTRIES

The situation is much the same in the various Community countries and radio-isotopes are everywhere finding increasing applications.

7.2.1. Belgium

A few radioactive isotopes are produced in the CEN establishments (BR-1 reactor), and they are used almost entirely in scientific research in Belgium, the Belgian Congo and abroad. Certain of them are also used for medical purposes.

When the BR-2 materials testing reactor is put into service, it will be possible to produce isotopes of high specific activity, which so far have had to be imported from Great-Britain, France or the U.S.A.

The production of radio-isotopes may in the future constitute a specialized branch of industry, and companies have already been formed to construct the equipment necessary for the packing and shipment of the products. Belgium's long experience in the handling and treatment of radioactive products will be invaluable to all those engaged in the new industry.

The most important radio-isotopes produced in Belgium are : gold 198 (Au 198), cobalt 60 (Co 60), tritium 3 (H 3), iodine 131 (I 131), iridium 192 (Ir 192) and phosphorus 32 (P 32).

The following table gives an idea of the growing importance of the use of radio-isotopes in Belgium.

Use of Radio-isotopes in Belgium

(in EPU units)

Year	Industry and Agriculture	Medicine	Miscellaneous Including Science	Annual Totals
1955	3,300	10,300	8,700	22,300
1956	2,900	17,200	10,500	30,600
1957	5,700	19,300	12,600	37,600

7.2.2. Federal Republic of Germany

Radio-isotopes are at present being produced in fairly limited quantities by the research reactor in Munich.

Imports have risen from 130,000 EPU units in 1956 to 162,000 EPU units in 1957, but in view of the fall in prices these figures represent 2,214 and 4,444 curies respectively.

Over the same period, the number of users has increased in the following proportion :

	1956	*1957*
Medicine & Research	306	385
Industry	136	160
	442	545

Altogether, about 65 radio-isotopes are used, the most important being : gold 198 (Au 198), cobalt 60 (Co 60), iodine 131 (I 131), iridium 192 (Ir 192), and phosphorus 32 (P 32). Radiation sources with an sctivity of one curie or more have been imported from abroad.

In medicine the applications of radio-isotopes have become more important in diagnosis and research than in actual treatment. For therapeutical purposes various machines with a high-intensity cobalt source are now available, and radioactive, colloidal gold 198 is being increasingly used for the treatment of lung cancer.

In industry the gauging of foil thickness in all types of material (plastic, paper and sheet metal) is becoming increasingly widespread. Altogether, some 200 machines employing sheathed preparations are now in use for gauging thicknesses. Radiation techniques are also of great value in the field of non-destructive testing and for checking the level of filling of containers.

In the electric-lamp industry new uses have been found for radio-isotopes. The phosphorescent coating on the inside of certain lamps is subjected to radiation from krypton 85 (Kr 85). The upkeep of luminous signals on deep-sea buoys is extremely expensive. With the help of radio-isotopes it is hoped that the cost can be considerably lowered by reducing the frequency of inspections.

As a result of the recent drop in the price of cobalt 60 (Co 60), the application of this radio-isotope in industry will naturally become more widespread. New techniques have been evolved in various spheres, particularly in the production of synthetic materials. Tests have also been carried out by the foodstuffs industry on the preservation of food by radiation methods.

7.2.3. **France**

In France, orders are placed with the CEA's « Service des Radio-éléments » (Département de Chimie), which carries out, in the reactors at Fontenay-aux-Roses, Saclay and Marcoule the irradiation of substances to be kept in stock (sulphur, cobalt, etc.). Before distribution, the radioactive substances are sometimes subjected to a complicated and delicate chemical treatment. The greater part of these operations is carried out in a high-intensity laboratory which has been specially equipped for the purpose (special ventilation, remote control tongs, etc.). The « Service » can satisfy 80 % of French requirements. The radio-isotopes are used by hospitals (10 %), university laboratories (30 %) and industrial establishments (60 %).

The demand is greatest for phosphorus 32 (P 32), iodine 131 (I 131), gold 198 (Au 198) and sodium 24 (Na 24) on account of their medical applications. Some of the radio-isotopes used in France (about 20 %) are imported.

Shipments of isotopes to French consumers continue to increase, from about 3,300 in 1954 (65 % of them being made by the CEA) to 6,000 in 1957 (80 % of them made by the CEA). Imported radio-isotopes with a low specific activity come from Great-Britain (e.g., cobalt 60 [Co 60] and iridium 192

[Ir 192]), those with a high specific activity come mainly from Canada and the USA.

The total number of consumers is also on the increase, as can be seen from a comparison of the figures for the end of 1954 and 1957.

	End 1954	*End 1957*
Medicine	27	35
Research	60	120
Industry	57	365
Total number of consumers	144	520

The following table shows the distribution of the various uses of radio-isotopes in industry (end of 1957) :

Radiography	109
Thickness gauging	109
Tracers	48
Control of machines	33
Utilization or study of the effects of radiation	16
Ionization	15
Animal biology	13
Detection of objects	13
Luminous paint	6
Plant biology	3
Total number of industrial uses	365

In 1957 the total value of radio-isotopes sold in France was 95,000 EPU units.

7.2.4. **Italy**

Not having any research or power reactors, Italy is not yet in a position to produce its own radio-isotopes. They are, however, imported and widely used.

The industrial use of cobalt 60 (Co 60) is widespread, mainly for testing the quality of welds and castings. The use of radio-isotopes as irradiation sources and as tracers is fairly common. They are extensively used by most University Institutes of Chemistry, Pharmacology, Biology, etc., even for the study of such delicate problems as the equilibrium of membranes in animal biology.

Radio-isotopes are widely used in radiation therapy institutes, clinics and hospitals, many of which possess their own cobalt units.

They also find application in pharmacy, microbiology, pharmacology, parasitology and in the field of vitamins.

A new establishment will shortly be opened which will undertake research work with radio-isotopes. This is the « Research Centre for the Application of Radio-isotopes in Biology and Agriculture », which was set up on the initiative of the CNRN. It will have an installation for subjecting plants to irradiation from gamma rays and a number of laboratories specializing in the study of agricultural and cattle-rearing problems. It will supplement the work which has already been done by private firms and by a special department of the Ministry of Agriculture.

7.2.5. **Luxembourg**

A cobalt 60 (Co 60) source has been imported for gammagraphy in the metallurgical industry.

It is planned to use radio-isotopes for medical purposes in the future.

7.2.6. **Netherlands**

In the Netherlands, radio-isotopes are used in various branches of scientific research, medicine and industry. The manufacture of radioactive products was started some years ago by the Dutch pharmaceutical industry. Supplies of irradiated substances come partly from the synchro-cyclotron of the *Instituut voor Kernonderzoek* (IKO — Institute for Nuclear Research) in Amsterdam. Most of the reactor-produced radio-isotopes are now bought at Saclay (France) and, to a lesser extent, at Harwell (England), at Kjeller (Norway) and in Canada.

The products regularly manufactured include compounds of phophorus 32 (P 32), sulphur 35 (S 35), antimony 124 (Sb 124), iodine 131 (I 131) and cobalt 60 (Co 60) ; they are made in the form of needles, beads, threads, and radiographic sources.

For purposes of radiography, gold 198 (Au 198) in colloidal solution or as « seeds », iridium 192 (Ir 192) and caesium 137 (Cs 137) are also produced and packed in aluminium containers. In addition, there has been a certain amount of specialization in the manufacture of products for biochemical, medical and therapeutical research, for example Vitamin B 12 labelled with cobalt 58 (Co 58), and insulin containing iodine 131 (I 131).

7.3. CONCLUDING REMARKS

A number of factors suggest that the use of radio-isotopes will become increasingly widespread as time goes on.

The fact that radio-isotopes are being made in increasing quantities from fission products means that production (the total in curies per year) will go up and that more radio-isotopes will become available. They are moreover bound to become increasingly important as new discoveries are made in pure and industrial research.

The increase in the total value of sales does not give an adequate impression of the actual number of radio-isotopes produced, imported or used, since the prices for radio-isotopes have dropped during recent years and are still dropping.

These considerations are just as valid for the United States and the United Kingdom as they are for the Member States of the Community. These two countries are in an extremely favourable position thanks to the relatively large number of nuclear reactors in their possession. They produce, use and export isotopes in large quantities. In the USA, apart from the *Atomic Energy Commission*, there are also private companies which sell radio-isotopes or prepare chemical compounds containing radio-isotopes.

In Great Britain these activities are under the control of the *Atomic Energy Authority.*

CHAPTER 8

NUCLEAR ENERGY AND INDUSTRY

8.1. INTRODUCTION

In order to assess the importance of an industry within a country's economic system, it is essential to have adequate statistical data on all the branches affected. As such information is not yet available on the nuclear industries of the six Euratom countries it is difficult to give exact figures for the volume of the Community's nuclear production and to supply details on manpower, turnover and invested capital.

The industrial application of nuclear power entails the use of special new techniques and the adaptation of existing industries to the new situation. In order to have an overall impression of the present position, it is useful to list the main industrial uses of nuclear energy and some of the trades and products which will be required by the new industry.

8.1.1. Principal Industrial Applications of Nuclear Power

1) *Direct utilization of the heat released by nuclear reactions*

The heat released in a reactor can be used directly for heating or for industrial purposes.

This application is still in its infancy, but it has great potentialities and in time may acquire great economic importance.

2) *The indirect use of heat released by nuclear reactions*

This heat can be transformed into motive force and used for propulsion purposes or for driving alternators to produce electricity.

These two applications, particularly the second, are the most important at the present time. Numerous examples exist to show the progress made in both these fields.

3) *The utilization of radiation*

In the future, considerable economic importance is likely to attach to this application in various processes used in the chemical industries (e.g., the influencing of chemical reactions by nuclear radiation). On the one hand, it makes it possible to improve the properties of various materials already known (e.g., resistance to heat) and to produce new materials with new properties ; in addition, research work carried out by the chemical industries indicates that it will probably become possible in time to reduce the cost of chemical processes, which hitherto have required extremely high temperatures and pressures, or the use of expensive catalysts. By employing radioactive sources, it may well become possible to carry out the same processes at atmospheric pressure, at lower temperatures and without expensive catalysts.

The use of radiation for control and measurement reduces production costs and improves the quality of goods. Measuring instruments and control equipment for many different purposes are already being produced within the Community, and isotopes are being produced as sources of radiation. They are already available to the industries concerned, and their use is not difficult.

8.1.2. **Nuclear Trades and Products**

The most important opportunities offered by the nuclear industry are listed below.

1) *The planning and building of nuclear plants*

The work of a « nuclear architect » is performed by design and development departments and consulting engineers. This work may be carried out either by independent services or by the manufacturers. Their function is :

- To draw up overall and detailed plans ;
- To place orders with industry ;
- To supervise construction and assembly.

2) *The supply of materials*

- Prospecting for ores and the production of nuclear concentrates ;

- The production and reprocessing of nuclear fuels ;
- The production of moderators, structural and other materials.

3) *The supply of finished products, equipment and services*

- Machinery and metal structures ;
- Electro-mechanical equipment ;
- The construction of chemical and metallurgical plant ;
- Electronic equipment ;
- Mechanical precision equipment ;
- Civil engineering work.

4) *Miscellaneous supplies*

Protective clothing, packing and transport of radioactive substances, etc.

It will be seen that all branches of industry can make use of nuclear energy in one form or another and that most branches can supply products or services in connection with nuclear energy.

This makes it difficult to state what precise principles should be adopted in compiling statistics on the position of the nuclear industries within the Community. Some statistical basis will have to be worked out as soon as possible, however, if we are to keep track of developments in the nuclear industries.

8.2. THE SITUATION IN VARIOUS EURATOM COUNTRIES

8.2.1. **Belgium**

It must be remembered that Belgium's nuclear industry goes back to before the war, Belgium being the oldest and most important producer of radium. Belgium is thus in a particularly favourable position, not only in all industries in which work is performed under protection on radioactive materials, but also in the production and processing of uranium.

After the war, the most pressing task of Belgian industry was to train a properly qualified staff of engineers and physicists to study the new problems arising from the use of nuclear energy.

To-day, there are about 150 to 200 university specialists in nuclear physics and engineering. It is not yet possible to say how many engineers and scientists are working in ancillary nuclear industries.

There are three important aspects to the use of nuclear energy in Belgium :

a) Like the other Community countries, Belgium will soon be faced with a shortage of conventional fuels. To avoid mass imports of fuels, electricity companies have drawn up a large-scale programme for the construction of nuclear power stations.

b) Belgium is a country with a long industrial tradition. Because of the loss of some of its older markets and because it has to rely on its exports, Belgium is obliged to adapt its industry to the new situation.

Various Belgian industries now supply products used in the application of nuclear energy. The possibility of expanding these industries to meet the needs of the home and the foreign market is being examined.

c) Finally, mention should be made of the industrial potential of the Congo. The Belgian Congo possesses both hydraulic resources and mineral deposits, so that the founding of a metallurgical and nuclear industry there would seem to offer good prospects of success.

As was mentioned in chapter 2, mineral deposits are being exploited on a large scale and the estimated reserves are sufficient to meet future requirements.

Great progress has been made by those branches of Belgian industry which deal with the mining and preparation of ores and their transformation into uranium metal. It is the same undertakings which deal with the production and preparation of radium.

A large number of undertakings in different branches of industry are concerned in various ways with nuclear developments.

Various companies concerned with financing, planning and operating electric power stations are examining the question of building and operating nuclear power stations. They have research establishments at their disposal with facilities for exhaustive scientific investigations. These companies have also set up a special planning and development department in which a small corps of specialists studies the practical problems involved in producing electricity by nuclear methods.

In the ferrous metals industry, systematic work is being carried out on special steels. The new applications of radioactive isotopes are being closely studied. In the metal working and non-ferrous metals industry, preparations are being made for the manufacture of articles needed to equip nuclear power stations.

Certain companies have investigated the possibility of using special and ordinary concretes as building materials and as shields in nuclear reactors and in plants for the treatment of radioactive waste. These concretes are also used in the workshops and laboratories where highly radioactive materials are handled.

In recent years, one branch of Belgium industry has specialized in the electrical and electronic equipment used in the various applications of nuclear energy.

The chemical industries, which already supply products derived from fluorine, tributyl phosphate and various other substances of interest to the nuclear industry are carrying out extensive research on the manufacture of solvents and chemical products used in the processing of irradiated fuel.

8.2.2. **Federal Republic of Germany**

It is only since May, 1954 that the industry of the Federal Republic of Germany has been legally authorized to carry out work in the field of nuclear energy. In comparison with the other countries, German industry has had only a relatively short time to undertake scientific and technical research in this field.

Research and development work had therefore first to be carried out, and research reactors built. Some of the research reactors are not yet completed and the construction of power reactors is still in a very early stage.

No law on atomic questions has yet been passed by the Bundestag. There are various laws in force within certain « Länder », but they only apply to research reactors.

From the point of view of power-production it is important to note that it has been possible to meet the demand for energy by constructing and enlarging conventional plants so as to make full use of the considerable national energy resources available. It is for this reason that plans for power reactors have not aroused as much interest as in the other industrialized countries of Europe. The big industrial undertakings have been primarily interested in thoroughly examining the possibilities offered by nuclear energy before devoting themselves to the construction of power reactors.

In spite of these difficulties, German industry is quite capable of making its contribution in the nuclear field, especially in the electrotechnical sphere, chemistry, metallurgy and mechanical construction. The necessary installations, if not already in existence, are in course of construction.

Their importance is shown by the information given in other chapters of this Report. If it is considered that this development is founded on large concerns with highly developed technical facilities and a considerable productive capacity, it is obvious that German industry is already capable of constructing nuclear power stations, together with ancillary plant. In chapter 6 it was pointed out that power reactors would be constructed on behalf of the electricity producing concerns. The first important orders will come from these firms.

So far, the firms supplying nuclear research installations and the manufacturers of control and measuring equipment employing radioactive sources have had the best chance of developing their productive capacity.

8.2.3. **France**

France, whose industry has been working on nuclear problems since the end of the war, has forged ahead of the other Community countries.

Public corporations have played an important part in this work. For this reason, a clear account can be given of the nuclear projects implemented in France, since most of the orders are placed on behalf of the *Commissariat à l'Energie atomique* and *Electricité de France* and various ministerial departments, whose budgets are published.

The CEA is responsible for nearly all work in connection with the prospecting and production of ores, in addition to which it plays an important part in the concentration of these ores. It is also responsible for the production of uranium metal at le Bouchet and nearly all the research work at Châtillon, Saclay and Grenoble, and finally for running the plutonium centre at Marcoule.

Similarly, *Electricité de France* is responsible for the programme providing for the installation of nuclear power stations.

These are the two main organizations in the nuclear field.

Their total expenditure, apart from operating costs, was 230 million EPU units in 1957. Of this total 7-8 % has been spent on research.

1) *The CEA*

In spite of the continued increase in the loans made available to the CEA, it is only since 1955 that this organization has received sufficient financial support to enable it to expand.

A sum of about 35 million EPU units was made available to the CEA during its initial period of activity. For the first five-year plan for the development of nuclear energy (1952-57) the *Commissariat* had at its disposal a total sum of 340 million EPU units. For the second five-year plan (1957-61) a sum of not more than 1,200 EPU units will be available. For this latter plan the CEA programme is divided into three sections : a central programme concerned with the production of uranium, research and experimental work and the construction and operation of experimental machines and prototypes ; programmes to be carried out on behalf of various ministerial departments ; certain « subsidiary » programmes involving funds for industrial purposes allotted under the plan for modernization.

The total financial resources of the *Commissariat à l'Energie atomique* for 1958 are about 240 million EPU units, including operating costs.

On December 31, 1957, about 10,000 people were employed by this organization in France. Since the CEA's foundation, the number of its employees has increased continually. On December 31, 1946, shortly after its foundation, the number of CEA employees was 236.

The number of employees in the service of the CEA on December 31, 1957 was 9,096. Of these, 5,225 persons were employed at the headquarters and research centres, and 3,871 in the various mines, the factories at le Bouchet and the

Marcoule Centre. Engineers, scientific personnel and other permanent staff make up about one fifth of the total number of employees.

2) *Electricité de France*

The chapter on power reactors shows the importance of the French programme for gas-cooled reactors, which aims at reaching a total installed power of 850 MWe by 1965. It is planned to raise this target to 1,200 MWe by using other types of reactor to provide the extra power.

About 300 employees of *Electricité de France* are engaged on work in the nuclear field, 100 of them engineers and permanent staff.

in millions of EPU units

	1956	*1957*	*1958*	*1959*	*1960*	*1961*	*Total*
Work already commenced	3	10	17	23	24	23	100
Work not yet commenced (estimate for the remainder of the 850 MWe programme)				2	12	38	52
	3	10	17	25	36	61	152

3) *Private Industries*

The programme of the *Commissariat* and the associated programme of *Electricité de France* will be entirely implemented by French industry, from the extraction of ore and the building of reactors to the processing of irradiated fuels. French industry is, therefore, already in a position to supply all the necessary materials and products. All the various types of work listed at the beginning of this chapter are performed on a large scale, as can be seen from the preceding chapter of this Report.

Taking into account the money made available by other organizations for study, research and nuclear power projects, the turnover of the French nuclear industry can now be evaluated at 250 million EPU units yearly for the next three years.

In particular, inquiries made into the various private undertakings directly engaged in nuclear activities show that in 1957

15 specialized companies out of the 75 investigated had a turnover of approximately 20 million EPU units.

During the year 1957, the total expenditure of seventeen firms exceeded 20 million EPU units.

At twenty-eight of the companies concerned in the inquiry, over 5,000 people, including 600 engineers and other professional staff were employed in the nuclear industry.

This shows that French industry has made great efforts to adapt itself and that it is capable of meeting any demands likely to be made. With the aid of experience already gained, French industry is in a position to be able to intensify its activities and to cope with any expansion in the present programmes.

8.2.4. **Italy**

The problem of power supplies in Italy is a particularly acute one. The public authorities and Italian industrialists have therefore decided to carry out an important programme for the construction of nuclear power stations in the next few years. It is intended, of course, to seek the cooperation of foreign manufacturers who already have considerable experience in the nuclear field, but Italy itself will play an important part in the building and manufacture of these plants.

On the basis of present production in the various branches of Italian industry, it can be predicted with reasonable certainty that the special material and machinery required for this programme can be supplied without difficulty.

Examining Italy's nuclear activities with reference to the list at the beginning of this chapter, it is clear that the greatest progress has been made in the manufacture of finished products and machines, the other spheres of activity also having been developed to varying degrees.

Firms manufacturing conventional and special materials for the mechanical and electrical industry will expand their nuclear departments as soon as the construction of research reactors and nuclear power stations begins.

In overcoming the initial difficulties, particularly important work has been done by the electricity supply companies and other undertakings that are concerned with the general problem of power production. Thus, the companies named in the present

Report and those not mentioned but only referred to in terms of the work they have already performed or are still performing have formed special departments with a total staff of more than 700 people, including about 250 engineers, physicists, chemists and senior staff.

8.2.5. The Netherlands

In the Netherlands, industry has aimed in particular at adapting its existing productive capacity to nuclear requirements. It is already in a position to supply electronic regulating and control equipment used in the construction of reactors. In addition, one firm has perfected special blocking valves and fittings used in nuclear applications. These valves are used not only in the Netherlands, but they are also exported to Sweden.

Of the other products employed in the field of nuclear energy, mention should be made of polyvinyl coverings used as protection against contamination, special safety glasses and containers used in transporting radioactive waste.

One Dutch firm also builds and exports cyclotrons.

Instruments for the measurement of radiation are manufactured for a great many different purposes.

A number of firms have already started to study methods of adapting parts used in conventional power stations for use in nuclear power stations.

Investments

A distinction can be made between investments made internally within the firms themselves and contributions to the funds allotted for common research projects.

The following table gives an idea of the contributions made to the RCN :

Firms affiliated to the RCN	1.8 million EPU units
Electric power stations	1.8 million EPU units
Government	3.6 million EPU units

The contributions to the RCN of the firms affiliated to it (the 50 firms listed in appendix 1) represent the larger part of their investments.

This is not always the case, however, e.g., in the branch of industry devoted to electronic measuring equipment, but it is extremely difficult, if not impossible, to estimate the volume of investments in this particular field, because the manufacture of nuclear measuring apparatus is closely associated with the production of other electronic equipment. The same applies to the mechanical engineering industry. According to an estimate, the latter industry has so far invested between six and eight million EPU units for nuclear applications.

Personnel

Here again, it is impossible to separate purely nuclear from other activities. According to an estimate, 30-40 engineers and other university-trained staff are engaged on nuclear work in mechanical engineering. Altogether, about 100 engineers or university-trained staff are employed in research centres in the Netherlands — reference has already been made to the scientific collaboration between the RCN and industry.

8.3. CONCLUDING REMARKS

The industries of the Member States of Euratom have made great efforts to develop their activities in the nuclear field. It is clear that this expansion will continue.

In the free world, the economic potential of the Community is second only to that of the USA. The fact that nuclear activities play as yet only a relatively minor part in economic life is due to various circumstances.

In certain countries, industry received considerable government subsidies because of the initial, military importance of nuclear energy. The United Kingdom, moreover, has decided to launch a large-scale programme for the building of nuclear power stations in order to meet growing power needs.

European industry has a certain leeway to make up, and for this reason it is absolutely essential to train specialized personnel as quickly as possible. In America 100,000 people, including 10,000 engineers and scientists, are engaged in the private nuclear industry. In the United Kingdom, 27,000 people are in the service of the UKAEA. The knowledge and experience at present lacking in Europe in science, technology and industry must also be obtained without delay.

In spite of the manufacturing orders given in the nuclear field, no really important market has arisen for nuclear materials and products. It should be borne in mind that over 15,000 million dollars have been spent by the American Atomic Energy Commission since it was first established, as compared to the CEA's total expenditure to date of 450 million EPU units.

This, however, has not prevented the six Member States of the Community from continually expanding their nuclear activities during the last ten years.

The experience gained from research and preparatory work already carried out must soon be applied to give a new impulse in the development of research and manufacturing plant. This will probably necessitate collaboration between various firms, both large and small, and important contributions will be made by these firms in encouraging the expansion of nuclear activities. There is no doubt that this in turn will necessitate certain adaptations and changes in industry. An appropriate path of development should be followed, lying somewhere between that followed by American industry and that chosen by British industry. In America, research and development have been favoured by the abundance of the financial resources available. However, enthusiasm seems to have waned somewhat, in spite of the fact that a few years ago many people believed that nuclear energy was off to a flying start. In the United Kingdom, however, efforts have been concentrated almost entirely on a single programme, and use has been made of a single reactor type, namely the gas-cooled, graphite-moderated type. In the six Community countries efforts in the nuclear field will be strengthened by the industrial potential that can be made available, and the coordination of individual efforts, thanks to the birth of Euratom ; in particular, research on reactors will be concentrated on a small number of carefully selected types.

In view of what has been said above, it must be concluded that European industry, reinforced by the probability of cooperation with the industries of America, Great Britain and other countries, will be in a position both industrially and technically to carry out an extensive nuclear programme.

CHAPTER 9

THE ENERGY ECONOMY OF THE COMMUNITY

9.1. INTRODUCTION

One of the purposes of this Report is to examine how far nuclear energy in the form of electricity can be expected to meet the power requirements of the Community.

This chapter, therefore, aims at giving some idea of the future trend in power requirements. Consideration is also given to the relative costs of conventional and nuclear electricity, and also to the projects for building nuclear power stations.

9.2. POWER REQUIREMENTS AND NUCLEAR ENERGY

The questions of future power requirements and power production within the Community have been studied in detail by the Mixed Committee of the Council of Ministers and the High Authority of the European Coal and Steel Community. The first results of this inquiry were embodied in the report prepared at the beginning of 1957 by Messrs. Armand, Etzel and Giordani under the title « A Target for Euratom. » In november, 1957, the subsequent findings of the Mixed Committee were published in an interesting preliminary report entitled « Study on the Structure and Trends of the Energy Economy in the Community Countries ». The work of the Mixed Committee has been continued in order to expand the report and bring it up to date but the latest estimates and forecasts, which largely confirm earlier data, have not yet been published.

The following estimates of future supply and demand sum up the indications given on the probable line of development.

9.2.1. **Energy Needs and Production**

The Mixed Committee has estimated the probable demand for power by relating it to the anticipated gross national product for a period commencing in 1955.

For the six countries of the Community, the gross national product is expected to go up by about 50 % for the period 1955-65, and by 35 % for the period 1965-75, which is almost equivalent to a 100 % increase for the whole period.

The increase in power needs will be slightly less. On the basis of its estimated relationship wilt the gross national product, the increase in the demand for power may be calculated at about 40 % between 1955 and 1965 and 30 % between 1965 and 1975, in other words at about 80 % over a period of 20 years.

Although such long-term forecasts are of necessity uncertain, they are of importance in indicating future trends and as a target to be aimed at in raising the standard of living.

There is an even greater margin of uncertainty about production forecasts because of the impossibility of predicting such important factors as labour conditions, political and industrial policies and production bottlenecks.

In spite of the inherent difficulties, forecasts of the anticipated overall production of conventional energy within the Community were given in the above-mentioned reports. By comparing them with the estimated power requirements, the probable margin of deficit can be estimated. This deficit was no more than 5 % of requirements on the eve of the Second World War, but it had climbed to 20 % by 1955 and is expected to be in the region of 30 % in 1965, and in 1975 it will be in the order of 35-40 %. Up to now, the deficit has been covered by imports, especially of petroleum and coal. If excessive imports are to be avoided in the future, however, it will be essential to utilize nuclear energy, even if power production by conventional methods is developed to the full.

9.2.2. The Role of Nuclear Energy

The various applications of nuclear energy have been described in other chapters of this Report.

For the period under consideration, however, nuclear energy will be used mainly to produce electricity ; production of this form of power is increasing rapidly, and in the Community countries the increase since the Second World War has been so great that production will be doubled in 10 to 12 years.

Even if this rate of growth should slacken, it can be assumed that production will almost be doubled between 1955 and 1965 and trebled by 1975. A proportion of this total production of electricity, however, is supplied from sources of energy which are specially adapted to power production, for example water, geothermal power, lignite, certain types of coal, and in certain places even blast-furnace gas, natural gas, and coke gas.

In meeting the increased demand for electricity, nuclear energy can therefore only be used to supplement or replace the other sources of energy utilized for the production of electric power.

The available documents do not make this distinction quite clear. The report « A Target for Euratom », however, gives an estimate of the production of electric power from the various types of thermal plant, with the exception of those based on lignite and blast-furnace gas. The assessment is thus based mainly on oil and coal, including low-grade coal. What is important in this estimate is not so much the individual numerical values, but their trend after 1960, since it is only after this date that nuclear power can be made available on a large scale. The table below will help to make this clear.

Increase in Production of Electricity from Thermal Stations (other than those based on lignite and blast-furnace gas)

(in millions of MWh)

	Net Production	Increase compared with 1960
1955	90	—
1960	141	—
1965	208	+ 67
1970	302	+ 161
1975	410	+ 269

On the basis of these figures, an attempt can be made to determine what nuclear power station capacity should be installed to cover the entire increase in production, but without taking into account replacements.

This capacity depends on the anticipated annual operating period, in other words on the « load factor » adopted.

In the absence of sufficient experience, it is difficult to determine this factor for nuclear power stations.

From the economic point of view, it is considered essential that under present conditions and in the immediate future nuclear power stations should have a high annual operating period. Because of the installation costs, the fixed charges make up a large proportion of the cost of nuclear electricity, so that production must be as high as possible in order that these charges can be spread.

A load factor equivalent to 7,000 hrs per year is economically desirable. In this case the installed nuclear power station capacity which would be necessary in 1965 to meet the entire increase in production after 1960 would be about 10 million kWe.

But the normal load factors are related to production costs, so that if these costs are reduced a lower load factor may be permitted for the nuclear power stations, for example 6,500 hrs/year in 1970 and 6,000 hrs/year in 1975.

This would mean the following installed capacities :

1965 — 10 million kWe
1970 — 25 million kWe
1975 — 44 million kWe

However, for technical and financial reasons, it will not be possible to meet the entire increase with the aid of nuclear power stations.

The part which nuclear power stations can be expected to play in providing the increased capacity depends not only on the magnitude of the requirements but also on their nature, especially in terms of the difference between the peak and base load. (1)

Since the nuclear power stations must have a high annual operating period, they will be run mainly to produce base-load electricity. In fitting nuclear power stations into existing networks, it will be necessary to consider the proportion of this base load in the total daily production. The other types of plant will also need to have an annual operating period sufficiently high to enable them to operate under satisfactory technical and economic conditions.

In the year 1975, therefore, it will not be possible to produce in power stations with a load factor of 7,000 hours an amount

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(1) The base load is the electricity produced round the clock.

of power equal to the increase anticipated after 1960, in other words 269,000 million kWh or about 65 % of the total production. Since the average load factor for all thermal power stations at the moment is only 4,250 hours per year, it is not even certain that nuclear power stations will be able to reach 6,000 hrs per year, if they are to make the above contribution to the total power production.

These various factors, of course, will only make themselves felt when the production of nuclear electricity represents a higher proportion of the total, say a fifth or a quarter. The problem of the operating period will therefore not be of great importance in the initial period. But this problem will have to be examined and studies prepared for future needs.

It is clear that, as far as the near future is concerned, the further development of nuclear energy for the production of electricity will not be held up by the anticipated power requirements. These requirements, indeed, continue to increase at a pace which will necessitate a considerable expansion to the existing power network.

Nuclear power stations should take an increasing share in providing the additional power required, but it is unlikely that they will be in a position to bear the whole of the extra burden by 1975.

It is not so much power requirements as the technical and financial possibilities that might eventually set an upper limit to nuclear development.

9.3. THE RELATIVE COSTS OF NUCLEAR AND CONVENTIONAL ELECTRICITY

There has been little modification in the data available for assessing the relative costs of nuclear and conventional electricity since the publication of the report « A Target for Euratom ».

However, the preliminary work carried out on various projects both within the Community and abroad, as well as the offers and guarantees now available to electricity companies supply concrete evidence to back up the estimates made in the report. In other words, the forecasts of a year ago now seem to be borne out by economic facts.

As far as conventional electricity is concerned, the report mentioned above is based on the probable cost of electricity from modern power stations employing imported fuel, coal or fuel-oil, because it is these that will probably be replaced, at least at the beginning, by nuclear power stations.

On the basis of the present prices of different types of coal for long-term import contracts, there would seem to be a case for assessing the cost somewhat lower than the 10 to 12 mills (1) per kWh allowed for in the above-mentioned report. These prices could be reduced, for example, to about 9 to 11 mills per kWh, depending on installation costs and the investment required. The first of these figures, however, applies only to power stations operating on base load under extremely favourable conditions of supply. Moreover, it must not be overlooked that the data relating to coal prices are influenced by the prevailing economic situation.

As regards the cost of nuclear electricity, however, the agreement signed with the USA providing for the installation of a power of one million kW suggests that the total fuel costs (fuel-cycle) will be about 4 or 5 mills per kWh, while the fixed charges may well be somewhat less than those contemplated in the report « A Target for Euratom », which gave a figure of 11 to 14 mills. The cost per kWh would thus be reduced to between 10 and 14 mills.

The argument contained in the report that the cost of nuclear electricity would gradually be reduced seems to have been borne out by subsequent developments. In the first place, the operating costs of nuclear power stations now being built will be less than was expected a few months ago, and, thanks to technical improvements in the fabrication and utilization of fuel, the situation will continue to improve in the future. Unlike the situation in conventional generating stations, in which only slight improvements can be made in a station's heat economy once it has been built, any new developments made in the nuclear fuel cycle can be very quickly applied to the nuclear power stations that are already in operation. Moreover, and this is equally true of the power stations now being planned as it is of those to be constructed at a later date, there is considerable scope for improvement in the nuclear fuel cycle, whilst the possibility of making further improvements in the conventional combustion process becomes smaller and smaller. Finally, the information obtained in recent months on the costs

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(1) 1 mill = 1/1000th of a dollar, or 1/1000th EPU unit.

of building nuclear power stations shows that it will be possible in future to reduce their costs and increase their efficiency.

On the other hand, it is probable that, provided there are no great economic changes, the cost of conventional fuels must be expected to rise slowly but steadily in relation to the general level of prices and thus gradually raise the cost of conventional electricity.

According to the latest information, it appears that there is already some overlapping of the price zones for conventional and nuclear power. This means that in certain parts of the world and in certain circumstances electricity produced by nuclear reactors can already compete with electricity produced by conventional power stations. The trend in cost prices for the next few years, even for power stations now envisaged, will further improve the competitive position of nuclear energy. The comparison of prices lends support to the hope that the new source of energy will soon be playing an important part in the economic development of Europe.

9.4. THE NUCLEAR ELECTRICITY PROGRAMMES

Most of the Member States of Euratom have now drawn up plans for the building of nuclear power stations. The present projects do not generally extend beyond 1965, but various countries have nevertheless drawn up long-term programmes.

Belgium

The following units will be put into operation :

1960	BR-3	10 MWe
1962-63	2 stations of 150 MWe, totalling	300 MWe
1967	2 stations of 120-150 MWe, totalling	240-300 MWe

In 1967, therefore, there will be a nuclear installed capacity of about 550 to 600 MWe.

It seems likely that, starting in 1967, one power station of 150 to 200 MWe will be put into operation every two years, so that by 1975 the total installed capacity will amount to at least 1,200 MWe.

Federal Republic of Germany

Projects are already in existence for the building before 1965 of four or five nuclear power stations with a total capacity of about 500 MWe.

Furthermore, according to the latest estimates, as published by the OEEC with the authorization of the Government of the Federal Republic of Germany, the nuclear installed capacity will amount to 6,000 MWe in 1975.

France

Existing projects can be summed up as follows :

End 1958 — beginning 1959 — 3 reactors at Marcoule 65 MWe
End 1959 — EDF1 70 MWe
End 1961 — EDF2 170 MWe

totalling about 300 MWe for 1961.

These projects form part of a programme for the production of nuclear electricity adopted by the French Government and aiming at the installation of a total capacity of 850 MWe by 1965, using gas-cooled reactors; in addition to this power, another 350 MWe will be obtained from reactors of another type, which has not yet been decided on, making a total of about 1,200 MWe.

Italy

Projects have been definitely accepted for two power stations having a total power of about 320 MWe, which will be put into operation by 1962.

In addition, projects are being studied for plants to be in operation around 1963 and which would have an installed capacity of about 650 MWe. It is difficult to foresee the rate at which nuclear power stations will go into service in the future, but, in view of Italy's power situation, it will probably be fairly rapid and will probably raise the nuclear installed capacity to about 1,500 MWe in 1965.

The Netherlands

A project is now being studied for the building of a nuclear power station for 150 MWe, which should be completed by 1962. The Ministry for Economic Affairs has published a programme for nuclear electricity covering the period until 1975, with the aim of giving some indication of the current plans of the electricity producers.

According to this programme the following nuclear installed capacities should be reached :

In 1965 : 400 MWe
In 1970 : 1,200 MWe
In 1975 : 3,000 MWe

The Overall Situation

It would be difficult to combine all these data into an overall plan for the whole Community.

By 1965, however, the total installed capacity of the Community's nuclear power stations may be expected to be at most in the region of 3,500-4,000 MWe.

This is about two thirds of the British programme (5,000 to 6,000 MWe) for the same date.

9.5. CONCLUDING REMARKS

The development of nuclear power production within the Community is linked to the increasing demands for power and to the necessity for covering part of the increasing power deficit of the six countries by home production.

The contribution of nuclear electricity to the total electric power of the Community is in no way limited, as far as the immediate future is concerned, by the extent or nature of foreseeable requirements. The potential demands exceed the number of kWh that can be expected from nuclear power stations in the near future.

With regard to the cost of production, we have seen that under certain conditions nuclear electricity can already compete with conventional electricity and that it will become even more competitive as time goes on. From this point of view, too, there is therefore no obstacle to the immediate implementation of a large-scale nuclear programme in the Community.

The existing projects represent a first step in this direction, although they are fairly small compared with the actual possibilities and with various foreign programmes.

It seems unlikely, however, that these projects will suffice to reach 15 million kWe by 1967, the figure quoted as necessary in the report « A Target for Euratom » in order to stabilize the net power imports of the Community at the 1963 level.

It is absolutely essential, however, to stabilize imports. Euratom must encourage the necessary enterprise and initiative and make every effort to ensure that the target is reached, if not by 1967, at least as quickly as possible.

GENERAL CONCLUSIONS

As has already been emphasized in the introduction, the Commission views the present Report as a first attempt to evaluate the state of the Community's nuclear industry and to assess its importance for the economies of the six countries concerned.

In spite of the shortcomings inherent in this first short Report, a few general tentative conclusions nevertheless emerge from it.

In the immediate future, nuclear energy will be particularly important for producing electric power. Obviously, the six Euratom countries cannot afford to ignore this opportunity of covering the energy deficits that threaten their economies and of reducing their imports of conventional fuels, which are such a burden to their balance of payments and are, moreover, at the mercy of political circumstances. Furthermore, the prospects offered by nuclear energy of developing new industries and creating employment are of particular interest to densely-populated areas.

However — and this is a first conclusion which can be drawn — the possible applications offered by nuclear fission are by no means confined to the production of electricity. Motive power for vehicles, domestic and industrial heating offer large possibilities. Radioisotopes, too, have a wide variety of uses, from medical science to industrial and agricultural research. Thus, there is hardly any branch of economic activity which is not affected by the production or use of nuclear energy or radioisotopes.

A second conclusion is that nuclear activities, whether in the field of energy production or radioisotopes, will gradually extend to a growing number of firms. While the planning, installation and operation of reactors will certainly require the scientific, technical and financial resources of large-scale firms, the very multiplicity of nuclear activities offers smaller firms possibilities for specialization. It must be emphasized, therefore, that the exploitation of nuclear energy in all its forms will not therefore necessarily be the sole prerogative of a few large consortiums. Medium-sized and even small firms will also be able to play their part, if they seize their opportunities.

A third conclusion is that nuclear activities will not necessarily be restricted to entirely new enterprises. In spite of the revolutionary nature of nuclear techniques, one of their main effects will be to bring about radical changes in existing industries and direct industrial effort along new paths. The advent of nuclear energy will involve the expansion and development of existing industries just as much as it implies the creation of new industries.

These first conclusions seem te show that the technological needs of nuclear activities are capable of creating a fresh climate which will benefit the whole of the industries of the Community by increasing the scope of their activities and by modernizing their equipment.

This first Report ought to encourage all those who are already engaged in the new field. Furthermore, by showing what vast possibilities the applications of nuclear energy offer, it should also help to overcome inertia and stimulate further contributions to the nuclear effort of the Euratom countries.

Nevertheless, however justifiable it is to place great hopes in the results of the application of nuclear energy, especially in raising the standard of living of the population, it is essential to realize that all this will require a considerable educational and financial effort and will entail making full use of available scientific nd technical talent.

These problems can be solved within the framework of the Community. Moreover, the six Euratom countries possess a number of natural advantages, which will facilitate the solution of these problems and make it possible to achieve effective and relatively rapid progress in the nuclear field. It is worth while recalling what some of these advantages are.

Continental Europe is already suffering from a deficit of conventional fuels. It would be a great help if its production of conventional energy could be supplemented by nuclear fuels, even if this meant importing them. It seems likely, however, that the Community has access to considerable uranium reserves, which will reduce import needs once they are put into production.

As for isotopes, special metals and alloys, measuring and control apparatus, dependence on imports will be both limited and temporary. It is even not too ambitious to hope that the Community will be in a position to export these products itself within a relatively short period.

All this, however, is largely anticipating events. As far as the actual situation at the moment is concerned, it is interesting to see how nuclear developments in the Community compare with what has been done in the rest of the world.

One preliminary point must be made : our nuclear industry is only just beginning and, furthermore, progress varies from country to country within the Community. Generally speaking, France leads the rest of the Community in nuclear progress, but it must be stressed that this has only been made possible thanks to a considerable financial effort.

The United Kingdom's nuclear effort is mainly devoted to developing economic methods of producing electric power. A first nuclear power station, built for this purpose, was put into operation in 1956. A well-organized ancillary industry is constantly being developed. The expenditure of the Atomic Energy Authority — approximately 200 million EPU units for the year 1956-57 — gives some idea of the efforts made to develop nuclear industry and research.

In the United States, too, great progress has been made since 1945 in the field of nuclear research and in the nuclear industries. Here the problem of producing electricity based on nuclear power is less urgent thanks to the plentiful supplies and low costs of conventional fuels. Nevertheless annual expenditure on the development of power reactors for civilian use amounts to approximately 160 million EPU units. Moreover, this expenditure is devoted solely to power reactors — unlike the figure quoted for the United Kingdom — and takes no account of the considerable funds allotted to other items in the budget covering the peaceful uses of nuclear energy.

It is often pointed out that, as compared to the United States, Great Britain and the USSR, the Community as a whole has considerable leeway to make up in the development of the peaceful uses of nuclear energy. This is, of course, an undeniable fact. The danger is that it might give rise to the superficial and erroneous view that little has been accomplished and that all the preliminary work still remains to be done before the Community can embark on large-scale achievements. It is hoped that the present Report will contradict this view and help towards a proper assessment of the work done so far and of the prospects henceforth open to research and industry. It should also contribute to a better understanding of the importance of the role to be played by industry generally in the

Community in the development of nuclear power in Europe. Furthermore, it should help to account for the great interest displayed in this new form of energy by wide and influential sections of the population.

The Commission has been entrusted with the task of doing its utmost to exploit these natural advantages. It has in no sense the intention of pursuing a policy of systematic intervention which might hamper spontaneous initiative or lead the policy of the six countries into isolationist or autarchic paths. On the contrary, the nuclear industry will have the best chance of development in a climate of collaboration and mutual contact leading to frank and healthy competition. In line with the provisions of the Euratom Treaty and with existing international agreements, such competition will not be limited to the industries of the six countries, but must be extended equally to the industries of other countries, in particular the United States and the United Kingdom. Contacts with these countries are extremely valuable and the Commission welcomes the fact that these two nations should have been the first to establish systematic relations with it.

A final point made by the present Report is that there is little likelihood of the development of the nuclear industry being curbed by insufficient power requirements, especially requirements for electrical power. In the next few years, there is a much greater risk of this development being held up by the technological potentialities of the Community's industries and by financial considerations.

While excessive optimism must be guarded against, the Commission believes that, in so far as the present Report enables conclusions to be made, it can affirm its confidence in the future of the European nuclear industry. In spite of the great efforts which still remain to be made, there is good reason to be satisfied with the task already been accomplished and with the manifest determination of those concerned to persist in their endeavours. The substantial achievements described in the present survey should silence the sceptics and encourage those who believe that, with the help of nuclear energy, it will be possible to create employment, raise the standard of living and open up new sources of prosperity.

If the harvest is far from ripe, at least the crop is springing up.

APPENDIX I

THE SITES OF THE MAIN INSTALLATIONS

(See map on inside cover)

APPENDIX II

BASIC PRINCIPLES

The aim of this section is neither to present an overall picture nor even to give a résumé of the present state of knowledge in the nuclear field but merely to explain in simple language some of the scientific and technical terms which have been used in this Report.

Matter is discontinuous, i.e., every substance is made up of a finite, generally enormous, number of *molecules* of chemical substances of the same or different sorts. The molecule is the smallest existing particle of a chemical substance having all the chemical properties of this substance. Thus, there are as many types of molecule as there are distinct chemical substances. The various types of molecule are different combinations of even smaller particles, the *atoms*.

There are about a hundred different types of atom, each corresponding to an element, e.g., hydrogen, carbon, copper, lead, uranium, etc.

A molecule can be made up of atoms of the same type, in which case it is a *simple substance.*

A molecule can also be a combination of atoms of different types ; and in this case it is a *compound* (water, acetic acid, polystyrene, etc.).

Composition of the atom

Although the atom — as its name indicates — was long considered to be indivisible, it is actually composed of a *nucleus* around which *electrons* revolve.

The best way to imagine the structure of an atom is to compare it to a miniature solar system, in which the planetary electrons move around a central sun, the nucleus. This comparison, which is qualitatively exact, brings out the fact that the nucleus is the centre of gravity of the atomic structure and that it is separated from the electrons by a vast space, comparable to the space between the stars. It is to these electrons, moving at an enormous speed a round the nucleus, that the chemical activity of the atoms is due, i.e., they are responsible for the « ease » with which one element (e.g., iron) combines with another (e.g., sulphur) to form a compound, in our case ferrous sulphide. These electrons do not play a direct part in nuclear reactions, and it is sufficient to state that the presence around the nucleus of this outer « cloud » of negative electric charges (the electrons) impedes the approach of electrically charged particles because of the interplay of the forces of repulsion and attraction.

The nucleus itself is made up of a certain number of particles, called *nucleons,* of which there are two sorts : the *neutrons,* which are approximately 1,800 times heavier than the electrons and have no electric charge, and the *protons,* which have about the same mass as the neutrons and are positively charged. The electrons carry an electric charge equal in magnitude to that of the protons, but it is negative. Since the number of electrons is equal to the number of protons, the electric charges cancel each other out and the atom is electrically neutral.

The mass of an atom (atomic weight) is practically equal to the mass of the nucleus. The mass of the nucleus is approximately equal to the sum of the masses of its nucleons.

Characteristics of the Atom

The chemical nature of an atom is determined by the number of protons contained in its nucleus and thus also by the number of electrons which it possesses in its neutral state.

An atom, however, is not always neutral. In certain circumstances, it can lose or gain one or more electrons. It is then said to be ionized. Since the number of electrons is no longer equal to the number of protons, the atom has a positive or negative electric charge.

All atoms, neutral or ionized, having the same number of protons in their nucleus belong to the same element.

There are nevertheless certain differences in the properties of atoms of the same element, depending on the number of electrons or neutrons and on the distribution of the electrons.

Characteristics of the Nucleus

In the nucleus the number of neutrons is approximately equal to or slightly higher than the number of protons. But atoms possessing the same number of protons and thus belonging to the same element can differ in the number of neutrons they contain. Thus, for each element there are several types of atom, each having a different number of neutrons and consequently a different weight.

Each element possesses several *isotopes* or *nuclides* which have the same chemical nature and possess identical chemical properties but not necessarily the same physical properties. In order to distinguish the isotopes of a given chemical element, the total number of nucleons in its nucleus is usually written after the name of the element or its symbol. For example, hydrogen, with one proton in its nucleus, has three isotopes : hydrogen 1 (symbol H 1 - 1 proton and 0 neutrons - the most abundant natural variety) ; hydrogen 2 or deuterium (symbol H 2 or D - 1 proton and 1 neutron) ; hydrogen 3 or tritium (symbol H 3 or T - 1 proton and 2 neutrons).

Another example is the element uranium, of which 14 varieties are known at the present time, although only two occur naturally :

Uranium 238 (symbol U 238 : 92 protons, 146 neutrons),

Uranium 235 (symbol U 235 : 92 protons, 143 neutrons).

Within the nucleus, in spite of the mutual electrical repulsion between the equal positive charges of the protons, the nucleons are held together by a binding energy which is greater than the forces of repulsion. The forces contained in this nucleus (nuclear energy) have been harnessed for many peaceful purposes, as we shall see later.

If the number of neutrons and protons is such that these particles form a stable system within the very small space of the nucleus of an atom, the nucleus is said to be stable. This implies that its composition and its energy state can only be modified by influences that are capable of exercising a powerful effect on the nucleus itself. These different nuclei are the basis of stable isotopes.

In the case of certain, so-called, radioactive isotopes (radioisotopes), however, the binding energy is less and the nucleus is unstable.

At the present time approximately 1000 isotopes are known, just over one quarter of them stable. In their natural state, elements are composed of a mixture of *isotopes* in a practically constant proportion. Although these isotopes have the same chemical properties, they can have different physical properties. These differences come out particularly clearly in the case of physical phenomena in which the nucleus is involved (phenomena occurring within the nucleus). Thus, the element uranium, whose nucleus contains 92 protons, occurs naturally in the form of a mixture of 99.3 % of uranium 238 and 0.7 % of uranium 235. Of these two isotopes, only the second is capable of undergoing the phenomenon of fission, which will be dealt with below. In the case of physical phenomena involving the atom (phenomena in which the whole atom whether neutral or ionized is affected) the differences in physical properties between the isotopes come out less clearly, but they are nevertheless sharp enough to be utilized, especially for the separation of isotopes. Because of the definite number of neutrons it contains, the nucleus of every isotope of the same element has a definite number of nucleons, and thus a definite mass, which results in a definite inertia. It is this difference in inertia that provides the basis of the various processes for separating the isotopes of a given element, either in pure form (the separation of light hydrogen H 1 from heavy hydrogen D), or in a compound (the separation of light water H_2O from heavy water D_2O).

This is also the principle used in the plants for *enriching* uranium ; these plants separate uranium 238 from uranium 235 and thus produce uranium containing a greater proportion of uranium 235, an isotope which is subject to fission when exposed to free thermal neutrons.

Radioactivity

The nucleus of a radioactive isotope can change its internal construction or its energy state spontaneously. Such an isotope can be transformed either into the same isotope with a lower energy state or into an isotope of some other element, and in this process the original nucleus disintegrates. This phenomenon is accompanied by the *primary emission* of one or more types of radiation including :

1) Alpha rays, a corpuscular radiation consisting of nuclei of one of the isotopes of the element helium and containing 2 protons and 2 neutrons, thus having a positive electric charge ;
2) Beta rays, a corpuscular radiation consisting of lighter particles ; electrons with a positive or negative charge ;
3) Gamma rays, a very powerful, electro-magnetic radiation of short wavelength.

This primary radiation emitted by the nucleus can produce in the electron shells of the surrounding atoms phenomena which are accompanied by the *secondary emission* of electrons, of gamma rays and X-rays. As it disintegrates, the nucleus tends to become stable. This process can take place in one or more stages, producing a *series* of radioactive isotopes, the last member of which is stable.

This disintegration, moreover, can take place either rapidly or slowly. The number of radioactive atoms in a sample thus tends to decrease at varying rates. The rate of radioactive decay is generally expressed by the *half-life.* This term indicates the period of time necessary for the number of radioactive nuclei to be reduced to one half of the original quantity.

The *curie* is the standard unit for the measurement of radioactivity ; it is the quantity of a radioactive isotope giving 3.70×10^{10} disintegrations per second.

All these various rays are also called *ionizing rays* because one of their effects is to ionize directly or indirectly the atoms which they encounter in their path. It is because of this phenomenon that the question of providing protection against ionizing radiation arises.

Natural Radioactivity

Certain isotopes are naturally unstable and tend to change spontaneously into stable isotopes by emitting the particles and rays mentioned above.

Nuclear Reactions — Artificial Radioactivity

Apart from these alpha, beta and gamma rays, it is possible to produce artificially a number of other corpuscular radiations made up of neutrons, protons or other particles.

All these radiations can, if they possess sufficient energy, modify the composition or the energy state of the stable nuclei which are bombarded. The first result of this is to produce a different nucleus, generally unstable, which then initiates the process ending in stability by emitting one of the radiations mentioned above. All these phenomena together constitute a *nuclear reaction.*

As the nucleus resulting from this nuclear reaction is not yet stable, it will try to regain its stability by emitting the above mentioned radiation at a much slower rate : the nucleus exhibits a certain radioactivity with a varying half-life.

This has made it possible to produce artificial isotopes, i.e., isotopes not occurring naturally.

Of all the particles with which atoms can be bombarded, the neutron is the most efficient because, having no electric charge itself, it is not deflected by the charges on the electrons and the nucleus of the bombarded atom, and can thus reach this nucleus much more easily.

The energy of a neutron can vary : a neutron of high energy, moving at great speed is called a *fast neutron* ; a neutron of low energy, moving at low speeds (which may nevertheless be as much as 2,200 metres per second) is called a *thermal neutron.* Between the two extremes there are a number of other energies and speeds; here, the term *intermediate neutrons* is applied.

When a neutron comes into contact with a nucleus, three phenomena are possible : *collision, absorption,* or *fission.*

The *collision* between a neutron and a nucleus can best be illustrated by the impact made when a cue-ball hits a stationary billard ball. On impact, the latter ball is given some of the energy of the cue-ball. This is what happens when a neutron collides with a nucleus. After bouncing off a number of nuclei in turn, the neutron is slowed down and becomes a thermal neutron. Such collisons are most effective in reducing the speed of the neutron when the weight of the nuclei which the neutron hits is comparable to that of the neutron itself. This is why, in nuclear reactors, use is made of materials called *moderators,* whose atomic weight is low, like *carbon, light* and *heavy water* and *beryllium.*

The neutron can also penetrate the nucleus and be *absorbed* by it. This is how a radioactive isotope is obtained. In the case of certain heavy nuclei, the isotope thus obtained is so unstable that it breaks down spontaneously : this is the phenomenon called *fission.*

Fission

Fission is the name given to the reaction that takes place in certain cases, when a neutron, striking a nucleus, causes it to split into two large fragments.

This fission, which can generally be more easily obtained with heavy nuclei, can be produced by neutrons of any energy. However, fission can be carried out easiest by subjecting nuclei with an odd number of nucleons, such as those of uranium 235, plutonium 239 and uranium 233 to the action of thermal neutrons. Fission can also be brought about by directing fast neutrons against nuclei with an even number of nucleons, such as the nuclei of uranium 238, plutonium 240, etc., but here it occurs to a much lesser degree.

This process of fission has three effects :

1) The nucleus divides into two large pieces, fission fragments, which constitute the nuclei of two new atoms. The isotopes thus formed, called fission products, are always radioactive, because newly created nuclei are unstable. Furthermore, these nuclei generally absorb neutrons very readily.
2) A certain number (from 1 to 3) of neutrons are released. Under certain conditions, these neutrons can cause further fissions and thus start a chain reaction.
3) A certain amount of energy is released. Einstein's famous equation relating mass to energy (energy is equal to mass multiplied by the velocity of light squared : $E = mc^2$) shows what enormous energy is released by fission. The sum of the mass of the fission fragments and the mass of the neutrons released is less than the mass of the original heavy nucleus which has absorbed a neutron. This difference in mass is converted into energy. The energy is released in the form of radiation and as kinetic energy imparted to the fission fragments and the liberated neutrons, which in turn is transformed into thermal energy (heat).

The fact that the fission of one gramme of uranium 235 releases approximately 20,000,000 kilogramme calories gives some idea of the amount of this energy : it corresponds to the energy released by the complete combustion of three tons of coal.

Fissile and Fertile Materials

A *fissile material* is the name given to any material the nuclei of which can be caused to undergo fission and to sustain a nuclear chain reaction by means of the neutrons liberated by these fissions.

A *fertile material* is one which, by absorbing thermal neutrons, can form a new material which is fissile. These materials can sometimes undergo fission when exposed to fast neutrons, but to an extent which is insufficient to sustain a chain reaction.

Uranium 235 is the only natural isotope which is fissile. Uranium 238 and thorium 232, however, which are also natural isotopes but are not fissile, are partially converted, when exposed to thermal neutrons in a reactor, into two artificial isotopes : plutonium 239 and uranium 233, which are fissile. Hence, uranium 238 and thorium 232 are called fertile materials.

The Principle of Reactors

A *nuclear reactor* is the name given to an apparatus containing a certain quantity of fissile and fertile material or a certain quantity of fissile material alone (nuclear fuel) and designed in such a way that the fission reaction, once initiated in a certain number of nuclei, can propagate itself by means of a part of the neutrons liberated by fission and can be kept perfectly under control. This nuclear fuel is found in the reactor in a *homogeneous* form (in solution or in suspension), or in a *heterogeneous* form, divided into what are generally called *fuel elements.*

The *neutron flux* is the number of neutrons which, at any point in a reactor, pass through an imaginary plane of 1 cm^2 at rightangles to the direction of incidence in one second. The value of the neutron flux is in proportion to the number of fissions per second.

A large part of the average number of neutrons released by each fission (approximately 2.5) is absorbed by the fuel itself, by the moderator and the reflector during the slowing down of the neutrons, by the fission products and by the structural materials, while another part escapes from the reactor altogether. In spite of these losses in the neutron *economy,* an average of one neutron per fission must be kept in order to sustain the chain reaction. The reactor is then said to have reached *criticality.* A reactor can only become critical when it contains a minimum quantity of nuclear fuel, called the critical mass. (1) Below this minimum the leakage of neutrons from the reactor makes it impossible for criticality to be reached. In order to keep this critical mass as low as possible for reasons of economy, some suitable arrangement of the fuel in space must be worked out and the amount of neutrons absorbed by materials not susceptible of fission cut down. This latter factor makes it imperative to exclude from the reactor any material greedy of neutrons, especially those which, like boron and cadmium, are particularly strong absorbers of neutrons. This is why reactors must be constructed of materials of *nuclear purity,* a degree of purity much greater than that denoted by the conventional concept of « chemical purity ». Materials which readily absorb neutrons are, however, used intentionally to control the reactor by limiting the rate of multiplication of the neutrons.

Types of Reactor

A *research reactor* is the name given to a reactor designed primarily to measure certain physical quantities, or a reactor the potentialities of which have to be tested (also called a prototype reactor), or a reactor with a very high neutron flux for testing the behaviour of certain materials (materials testing reactor).

A power reactor is one which supplies energy for industrial use to operate an electric power plant, to propel a ship (or other vehicle) or for industrial heating.

Finally, the term *breeder* reactor is used to denote reactors which use fertile materials to produce more fissile material in the nuclear fuel than they destroy.

The study and design of all these types of reactor is the province of the nuclear engineer, just as naval construction is the province of the marine engineer.

Treatment of Irradiated Fuels

The longer fission reactions go on in a reactor, the greater is the quantity of fission products accumulated.

As these fission products and also certain transuranic elements (some isotopes of plutonium) are strong absorbers

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(1) This critical mass varies with the type of reactor.

of neutrons, they naturally lead to a decrease in the neutron flux (reactor poisoning).

On the other hand, under the influences of the heat and the intense flux of the neutrons, the fuel elements (in the case of a heterogeneous reactor) gradually become deformed. This modifies the structural geometry of the reactor and can lead to burst fuel elements with all the serious economic consequences and safety hazards which this implies.

This change in the structural geometry of the reactor, and the presence of isotopes which absorb the neutrons, modify the distribution of the neutron flux in the reactor and tend to diminish it. This means that the neutron economy becomes deficient since a time comes when there are no longer sufficient neutrons to sustain the chain reaction ; thus, the reactor is no longer critical.

It is, therefore, necessary to remove the fuel (then called irradiated fuel) long before all the fissile material contained in it has been disintegrated.

By subjecting this irradiated fuel to physical, chemical, or metallurgical processes, it can be separated into three parts. In the case of uranium, they would be :

1) The remaining uranium, in which the uranium 235 is largely spent ;
2) The plutonium produced by nuclear fission from uranium 238 ;
3) The fission products.

The remaining plutonium and uranium, the latter possibly enriched, can be re-employed in a reactor after the fuel has been converted to suit the particular type of reactor.

Radioactive fission products have up to now been largely considered as waste. How to dispose of this radioactive waste, without endangering the future health of the population, is one of the problems facing industry in the reprocessing of nuclear fuels.

The recovery of further fission products may perhaps be developed, depending on the future demand for radio-isotopes. It seems likely that this method of preparing isotopes will partly replace the method of exposing stable isotopes to intense neutron radiation in a reactor, which has been used hitherto to manufacture nearly all the artificial *radio-isotopes* used in medicine, biology, industry, technology, agriculture, cattle-breeding and pure research.

Fusion

Fission — the splitting of a heavy nucleus, i.e., a nucleus containing a large number of nucleons, in order to form 2 medium-sized nuclei — is not the only nuclear reaction capable of releasing large quantities of energy. A considerable amount of energy is also released by fusion, i.e., the combination of two very light nuclei to form a heavier nucleus.

The mass of the heavier nucleus formed by the fusion of two light nuclei is less than the sum of their masses. According to the Einstein equation, $E = mc^2$, already quoted in the section on fission, this difference in mass is converted into thermal energy.

It is almost certain that the energy radiated by the sun comes from a reaction of this sort.

The problem of using this reaction for industrial purposes, however, is still unsolved. Nevertheless, research carried out hitherto in this field suggests that a practical solution to this problem will be found at some future date.

APPENDIX 3

UNITS AND CONVENTIONAL SIGNS USED IN THE REPORT

Linear Measure

Centimetre	cm
Metre (10^2 cm)	m
Kilometre (10^5 cm)	km

Square Measure

Square centimetre	cm^2
Square metre (10^4 cm^2)	m^2
Square kilometre ((10^{10} cm^2)	km^2

Cubic Measure

Cubic centimetre	cm^3
Cubic metre (10^6 cm^3)	m^3

Weight

Gramme	g
Kilogramme (10^3 g)	kg
Metric ton (tonne) (10^6 g)	t

Time

Second	s
Minute (60 s)	m
Hour (3,600 s)	h
Day (86,400 s)	d

Pressure

Kilogramme per square centimetre	kg/cm^2
Kilogramme per square metre (10^{-4} kg/cm^2)	kg/m^2

Temperature

Degree Centigrade	°C

Electric Current Intensity

Ampere	A

Energy

Erg	erg
Joule (10^7 erg)	j
Watt-second (10^7 erg)	Ws
Watt-hour (3.6×10^{10} erg)	Wh
Kilowatt-hour (3.6×10^{13} erg)	kWh
Megawatt-hour (3.6×10^{16} erg)	MWh
Electron volt (1.6×10^{-12} erg)	eV
Mega electron volt (1.6×10^{-6} erg)	MeV
Giga electron volt (1.6×10^{-3} erg)	GeV

Power (1)

Watt (joule per second)	W
Kilowatt (10^3 W)	kW
Megawatt (10^6 W)	MW

Apparent Electric Power

Volt-ampere	VA
Kilovolt-ampere	kVA
Megavolt-ampere	MVA

Heat

Calorie	cal
Kilocalorie (10^3 cal)	Kcal

Radioactivity

Curie (3.7×10^{10} disintegrations per sec)	c
Millicurie (3.7×10^7 disintegrations per sec)	mc
Microcurie (3.7×10^4 disintegrations per sec)	μc

Monetary Unit

European Payments Union $ unit of account	EPU unit
1/1000 EPU unit	1 mill

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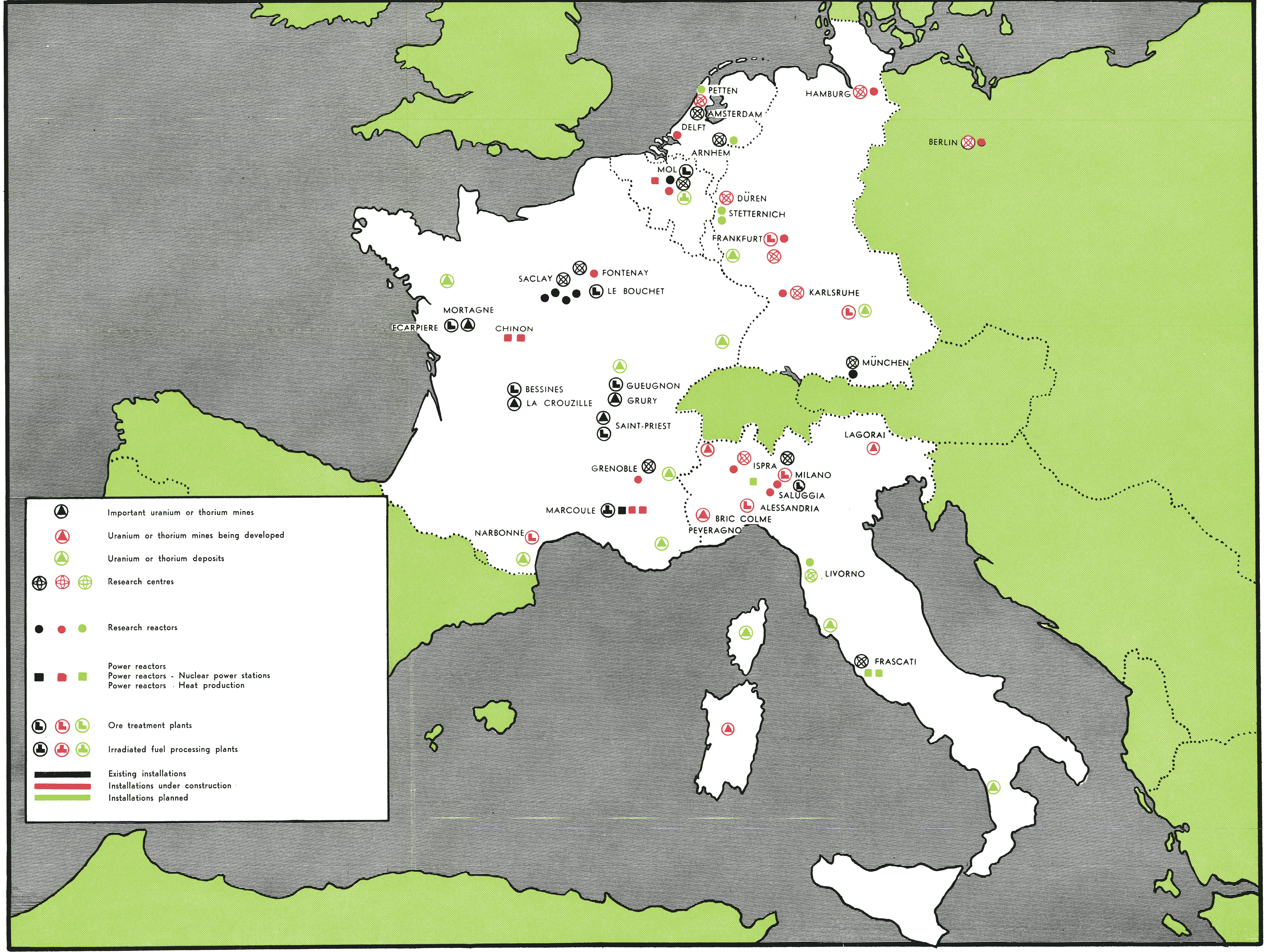
(1) When the word power is used in a general sense, the abbreviation W, kW, etc., is used. On the other hand, if electric power is referred to (to distinguish it, for example, from the thermal power of a nuclear reactor), a small e is added : We, kWe, etc.

EURATOM

SITES OF THE MAIN INSTALLATIONS


PETTEN
HAMBURG
AMSTERDAM
DELFT
BERLIN
ARNHEM
MOL
DÜREN
STETTERNICH
FRANKFURT
FONTENAY
SACLAY
LE BOUCHET
KARLSRUHE
MORTAGNE
ECARPIERE
CHINON
MÜNCHEN
BESSINES
LA CROUZILLE
GUEUGNON
GRURY
SAINT-PRIEST
LAGORAI
ISPRA
GRENOBLE
MILANO
SALUGGIA
ALESSANDRIA
MARCOULE
BRIC COLME
PEVERAGNO
NARBONNE
LIVORNO
FRASCATI
Important uranium or thorium mines
Uranium or thorium mines being developed
Uranium or thorium deposits
Research centres
Research reactors
Power reactors
Power reactors - Nuclear power stations
Power reactors · Heat production
Ore treatment plants
Irradiated fuel processing plants
Existing installations
Installations under construction
Installations planned