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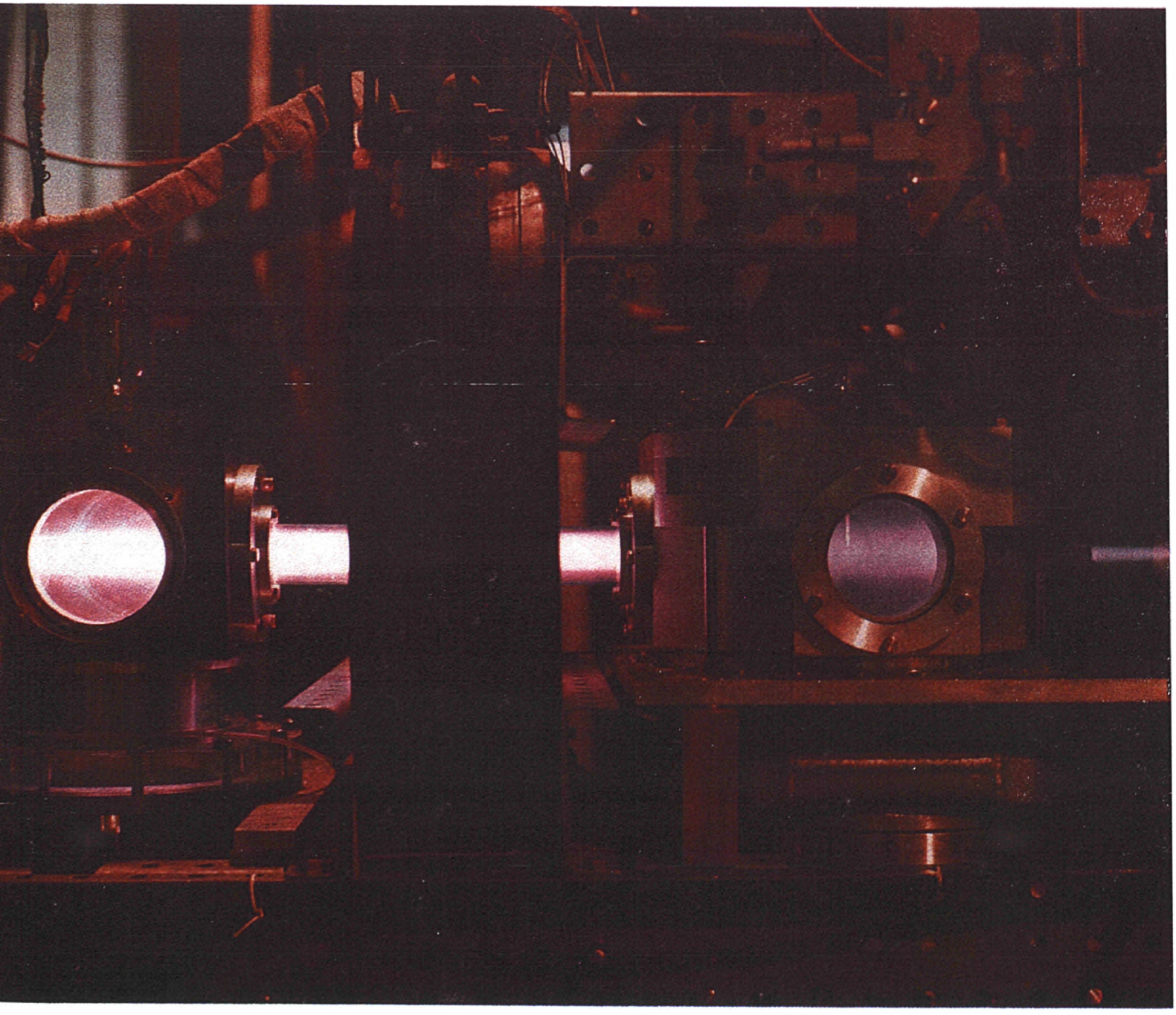

Accelerated plasma beam (CIRCE *experiment at Saclay, France*)

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Quarterly Review of the European Atomic Energy Community (Euratom)

1968-3

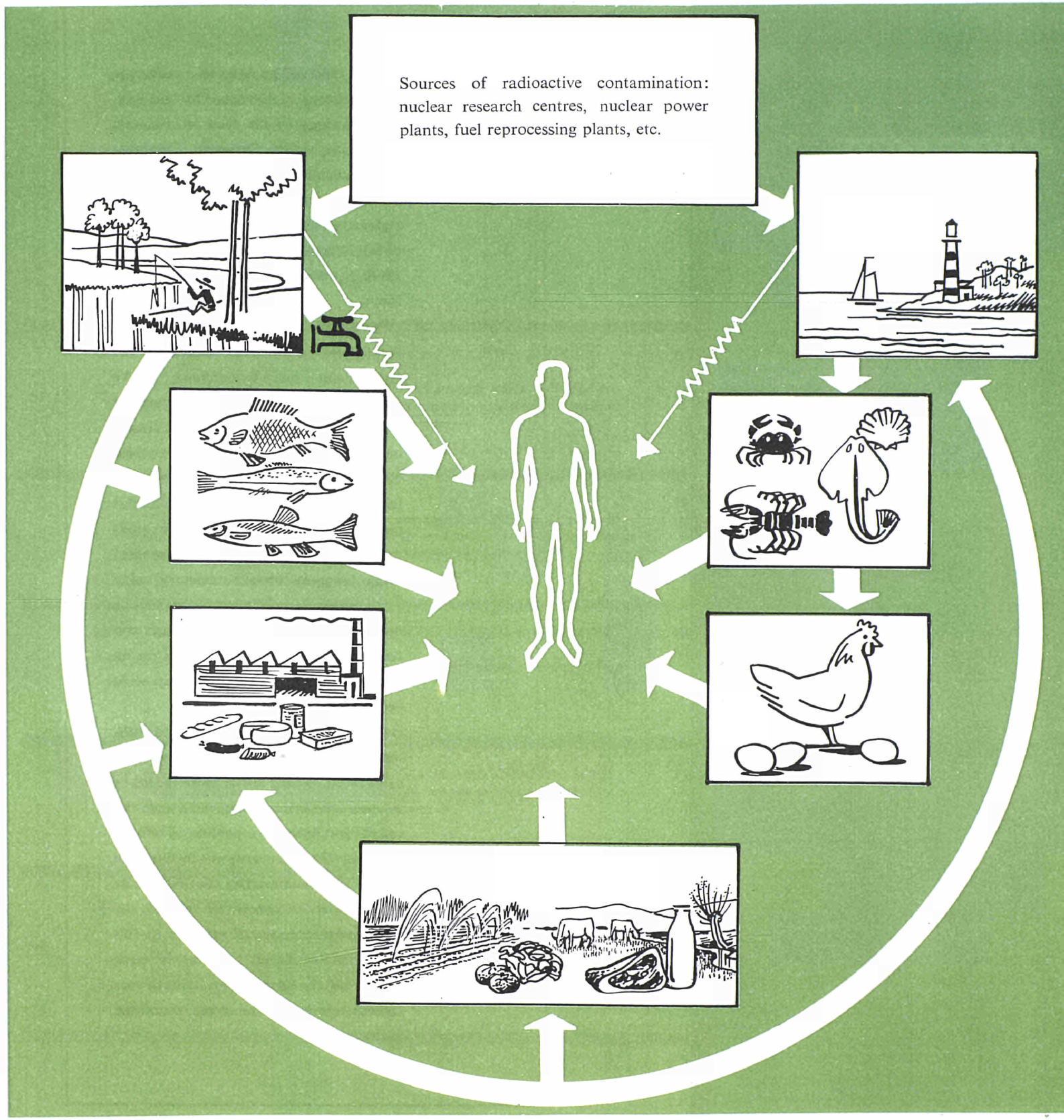
The Community's mission is to create the conditions necessary for the speedy establishment and growth of nuclear industries in the Member States and thereby contribute to the raising of living standards and the development of exchanges with other countries (Article 1 of the Treaty instituting the European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

"1 July 1968 will go down as a milestone in the history of Europe. On that day, the first stage on the road to economic unification of the European Continent will be complete".

These are the opening sentences in the statement published by the Commission of the European Communities on 1 July 1968. A subsequent passage runs as follows:

"Now that the customs union is complete, work on the achievement of economic union must be continued . . . We must gradually replace the old national policies with Community policies, changing the European area into an organised European society . . . Three of these policies deserve special mention. In the first place, . . . tax frontiers must be gradually eliminated . . . In addition, we must make progress towards monetary union . . . Lastly, Europe must be induced to make decisive progress in research and technology, so that it can stand on an equal footing with the other great world economic areas".

Such progress is scarcely possible without co-operation, but while all concerned are agreed on that point, there is less of a consensus among them as regards the exact procedure for a pooling of efforts. On page 93 of this issue will be found an article which summarises the present situation and endeavours to set out the appropriate courses of action to be followed in the future, backing its arguments with the lessons from both the successes achieved and the errors committed in the past.


Sources of radioactive contamination: nuclear research centres, nuclear power plants, fuel reprocessing plants, etc.

Radioactive contamination of water - a new approach needed

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WITH THE CONSTANTLY spreading use of nuclear energy, the contamination of our water resources by the radioactive substances poured into them raises an ever-growing problem of how to safeguard the health of the general public.

Fresh water is considered as a fundamental natural resource, essential to the modern world, but limited as to the quantity available. The demand for water increases with technical progress and social changes, the result frequently being a higher rate of pollution.

As to the sea, it is an immense potential source of substances, and more especially food, useful to man. It is only common sense to assume that radioactive contamination of its waters will sooner or later constitute a danger.

Where does radioactive contamination come from?

There are two major sources of radioactive contamination of water[1]:

— radioactive fallout due to nuclear tests;

— the controlled disposal, or escape, of radioactive waste from nuclear installations.

Since 1963, nuclear tests in the atmosphere have been restricted. But we must expect an extensive growth of facilities that use or study nuclear energy, and this will necessarily increase the quantities of radio-active waste and raise ever greater problems as to their disposal and dispersal in the environment.

At present the levels of surface water contamination by radionuclides from fallout are dropping steadily: the content is now less than 1 pCi/litre[2] for Sr^{90} and 0.5 pCi/litre for Cs^{137}, which is between about a hundred and ten thousand times lower than the maximum permissible concentrations for drinking water (see Table 1).

Discharges of radioactive substances may occur in two ways, namely as a result of an accident or through deliberate controlled disposal.

— *Accidental release:* In this case it seems unlikely that uncontrolled contamination of the environment would seriously affect the health of the population as a whole. Contamination will in most cases be limited to the zones in the vicinity of the accident, so it will be possible to take effective action to limit its spread.

— *Deliberate controlled disposal:* This is disposal effected under the control of the bodies responsible for protecting public health, i.e. in accordance with the official radioprotection standards. Such radioactive waste may come from several kinds of installation:

— mines and industrial plants that process uranium and thorium ores;

— fuel-element manufacturing plants;

— nuclear research centres;

— laboratories, hospitals and industries that use radioelements;

— nuclear power plants;

— irradiated-fuel processing plants.

The characteristics of such waste depend on the type of installation but also on the type of process used to decontaminate them.

As a general rule, the effluents discharged by *reactors and nuclear research establishments* contain only minimal amounts of fission products or other radioelements. The radioactivity in the waste produced by reactor operation stems essentially from activation of the cooling liquid (and of the impurities or corrosion products contained therein) and the structural materials of the reactor. Depending on the type of reactor, the formation of tritium and radioisotopes of such elements as sodium, cobalt, iron and manganese may occur.

Of the small users, i.e. *hospitals, research laboratories, industries that make use of radioelements*, it can be said that each individual installation releases only small quantities of radioactive waste, usually containing radionuclides with fairly short half-lives. Nevertheless, since there are thousands of these users in the Community and their number is constantly growing, the question arises whether in the long run there may not be a cumulative effect.

Figure 1: Radioactive pollution of surface waters and the various routes followed by the radionuclides which may be dangerous to man. ◀

1. Though natural radioactivity (K^{40}, uranium, thorium, etc.) cannot be disregarded in certain cases, e.g. when low contamination levels have to be measured.

2. A picocurie: 10^{-12} curies = quantity of a radioelement corresponding to a rate of 2.2 disintegrations a minute.

Radionuclide	MPC μCi/ml
^{89}Sr	1×10^{-5}
^{90}Sr	4×10^{-7}
^{137}Cs	2×10^{-5}
^{95}Zr	6×10^{-5}
^{144}Ce	10^{-5}
^{140}Ba	3×10^{-5}
^{103}Ru	8×10^{-5}
^{106}Ru	10^{-5}
^{65}Zn	10^{-4}
^{60}Ce	5×10^{-5}
^{54}Mn	10^{-4}
^{51}Cr	2×10^{-3}
^{3}H	3×10^{-3}

Table I: *Maximum permissible concentration* (MPC) *in drinking water for members of the public outside the controlled areas**

The biggest source of radioactive waste is the reactor fuel cycle. This starts at the *mines and industrial facilities* where the uranium and thorium ores are extracted and processed; next come the *fuel-element manufacturing plants*. The effluents discharged by these installations chiefly contain elements of the actinide series and their decay products.
It is the *irradiated-fuel reprocessing plants*, however, that produce the largest quantities of radioactive residues (99% of all wastes). All these residues go through a series of treatments to convert them into solid (glass, ceramic, concrete) or semi-solid (chemical slurry) low level radioactive compounds, which are disposed of with all the necessary precautions. Slightly radioactive liquid wastes only are discharged into the environment, but in large quantities. This deliberate contamination caused by monitored waste is the most significant.

Behaviour of radionuclides in the hydrosphere

The concentration of radioactive substances in the hydrosphere and the distribution of the radioelements may be altered by various diluting and concentrating processes such as the following: dispersion by currents, diffusion, sedimentation, sorption (by sediments, matter in suspension, organisms), precipitation, ion exchange, isotope exchange, ingestion of contaminated food by animals at the various trophic levels of the food chain.
The importance of these processes varies appreciably according to the nature of the radionuclide, its physicochemical state (ion, particle, complex), the composition of the aquatic environment and the selectivity of certain biological or non-biological fixing agents.
For human beings, the resultant irradiation hazard is twofold—external irradiation, which may be due to the water, sediments, fishing gear, etc. and internal

Table II: *Statistics on the trend of nuclear installations in the European Community in the period 1961-167*

	P	D	C	T	P	D	C	T
Mines for the extraction of uranium or thorium ores	–	–	–	26	–	–	–	13
Ore concentration plants	–	–	–	6	–	–	–	6
Chemical processing and concentrate refining plants	–	–	–	4	–	–	–	4
Facilities for the preparation of nuclear fuels in any form	1	–	–	5	–	–	–	8
Fuel-element fabrication facilities	1	1	1	5	1	1	1	5
Uranium hexafluoride production plants	–	–	–	1	–	–	–	2
Uranium enrichment plants	–	–	1	–	–	–	–	2
Irradiated fuel reprocessing plants	–	1	1	1	–	–	3	4
Critical assemblies and mock-ups	1	1	–	10	–	–	1	17
Research and materials testing reactors	1	3	12	19	1	1	6	56
Power reactors or prototype test reactors	4	4	7	4	8	2	10	16
Marine propulsion reactors	(9)	–	–	–	–	1	1	1
Industrial facilities for the treatment of radioactive waste	1	–	–	2	–	–	–	4
Totals	18	10	22	83	10	5	22	138
Grand totals on dates shown	133				175			

T = construction completed
C = under construction
D = firm project
P = under serious consideration

* Euratom Basic Standards

contamination via food, including drinking water.

Protection of public health: present measures and birth of a new philosophy

The safeguarding of public health against the dangers of ionising radiations due to radionuclides is based on standards concerning irradiation doses; these standards are drawn up by international bodies (*International Commission on Radiological Protection*, *OECD*, Vienna Agency, Euratom etc.) to whose directives the national laws generally refer. The Member States of the Community base their regulations on the Euratom basic standards. These standards vary according to the people or population groups concerned—occupationally exposed individuals, members of the public, or the population as a whole. From these basic standards are derived maximum permissible concentrations (MPC) for each radionuclide in drinking water (Table I).
At present, the effluent radioactivity levels are defined by discharge formulas, based essentially on the drinking-water MPCs. Their general expression is as follows:

$$\frac{Q_i}{D} \leqslant (MPC)_i$$

where Q_i is the quantity of radioactivity due to the presence of the radionuclide i, discharged during a time t, D is the average throughput of the receiving network during time t, and $(MPC)_i$ is the maximum permissible concentration of radioelement i in drinking water.
These discharge formulas have to receive the prior approval of the public health authorities, who likewise effect supervisory monitoring to ensure that they are properly applied.
This type of formula takes account only of the radioactive concentration in water, regarded as drinking water, for the purposes of evaluating human irradiation. Yet is has been established that drinking water is not the only route by which radioactivity is transmitted to man (Fig. 1). As was already mentioned, a number of processes alter the concentrations and distribution of radionuclides in the aquatic ecosystems and change the distribution of radioelements. This means that new principles must be adopted in risk evaluation, which must be based on consideration of the routes that carry radioactivity to man, and determination of the rates of transfer of each nuclide via each route.
The most important of these routes are:
— the use of water for drinking purposes;
— the consumption of fish, crustaceans and molluscs;
— the consumption of foods that have been contaminated as a result of irrigation of the soil on which they were grown with radioactively contaminated water (Fig. 2), or of cultivation on contaminated sediments obtained by dredging or spread by flood water;
— the consumption of foods of animal origin (milk, meat) obtained from livestock that have ingested contaminated water or fodder (grass, fishmeal, etc).
As for external irradiation, its only real importance is in certain special cases (e.g. irradiation resulting from the handling of fishing tackle).
The selection of radionuclides for study depends on their abundance in the nuclear waste, their physical half-life and their radiotoxicity. Table III lists some of the important radionuclides in residual liquids from a plant where irradiated fuels are reprocessed; they are Ru^{106}, Sr^{90}, Ce^{144}, Cs^{137}, which are all uranium fission products.
This new philosophy is today being actively developed for both water and seawater. It has led to the formulation of the following basic concepts:
— The *concept of the radiological threshold capacity* of a waterway system. This

Radionuclide	Decay period (half-life) in years	Concentration (microcuries per ml)	Nuisance coefficient (concentration/MPC)	Relative nuisance coefficient (Sr^{90}: 1)	
				Before decontamination	After decontamination (chem. processing)
^{89}Sr	0,148	$1,6\times10^{4}$	$1,6\times10^{9}$	0,028	0,0028
^{90}Sr	28	$2,3\times10^{4}$	$5,75\times10^{10}$	1	1
^{91}Y	0,159	$2,3\times10^{5}$	$7,7\times10^{7}$	0,0013	
^{95}Zr	0,178	$2,7\times10^{5}$	$4,5\times10^{9}$	0,078	0,0015
^{103}Ru	0,110	$3,5\times10^{4}$	$4,4\times10^{8}$	0,0077	
^{106}Ru	1,0	$7,2\times10^{2}$	$7,2\times10^{7}$	0,125	1,24
^{129}Te	0,090	$3,1\times10^{3}$	3×10^{8}	0,0052	
^{137}Cs	28	$2,1\times10^{4}$	10^{9}	0,0172	0,0069
^{140}Ba	0,035	$5,8\times10^{3}$	$1,7\times10^{8}$	0,003	
^{141}Ce	0,088	$9,0\times10^{4}$	$2,1\times10^{8}$	0,0037	
^{143}Pr	0,038	$5,5\times10^{3}$	$1,1\times10^{8}$	0,0012	
^{144}Ce	0,78	$6,9\times10^{5}$	$6,9\times10^{10}$	1,2	0,24
^{147}Md	0,032	$1,6\times10^{3}$	$2,7\times10^{7}$	0,00047	
^{147}Pu	2,6	$9,6\times10^{4}$	$4,5\times10^{8}$	0,008	
^{147}Sm	80	$5,6\times10^{2}$	$1,4\times10^{6}$	0,000025	

Table III: *Concentration of certain radionuclides in the liquid waste at a reprocessing facility, three months after withdrawal of the fuel from the reactor. Figures based on 1 tonne of natural uranium, having reached a burn-up of 2,500 MWd/t at 5 MW/t, dissolved in 400 litres of solution.*

represents the maximum amount of radioactivity that can be allowed in a waterway system without exposing human beings to a level of irradiation higher than the basic standards. For a given waterway system it entails consideration of all discharges, i.e. the cumulative risks and all the routes by which the radioactivity can be transmitted to man.

— *The concept of critical transfer routes* which expose a "critical population group" to a substantial risk of irradiation by a particular "critical nuclide". It should be remarked that the term "critical" does not necessarily imply the existence of a danger; it simply conveys the notion of criteria for decisions at the health and safety level.

The fight against radioactive contamination. . .

Such, then, are the problems inherent in the discharge of radioactive effluents and radioactive contamination of the environment. How can they best be solved? By way of example, we give an outline of the steps taken by the European Atomic Energy Community, which are embodied in both research and regulations.

. . . by means of a scientific and technical research programme

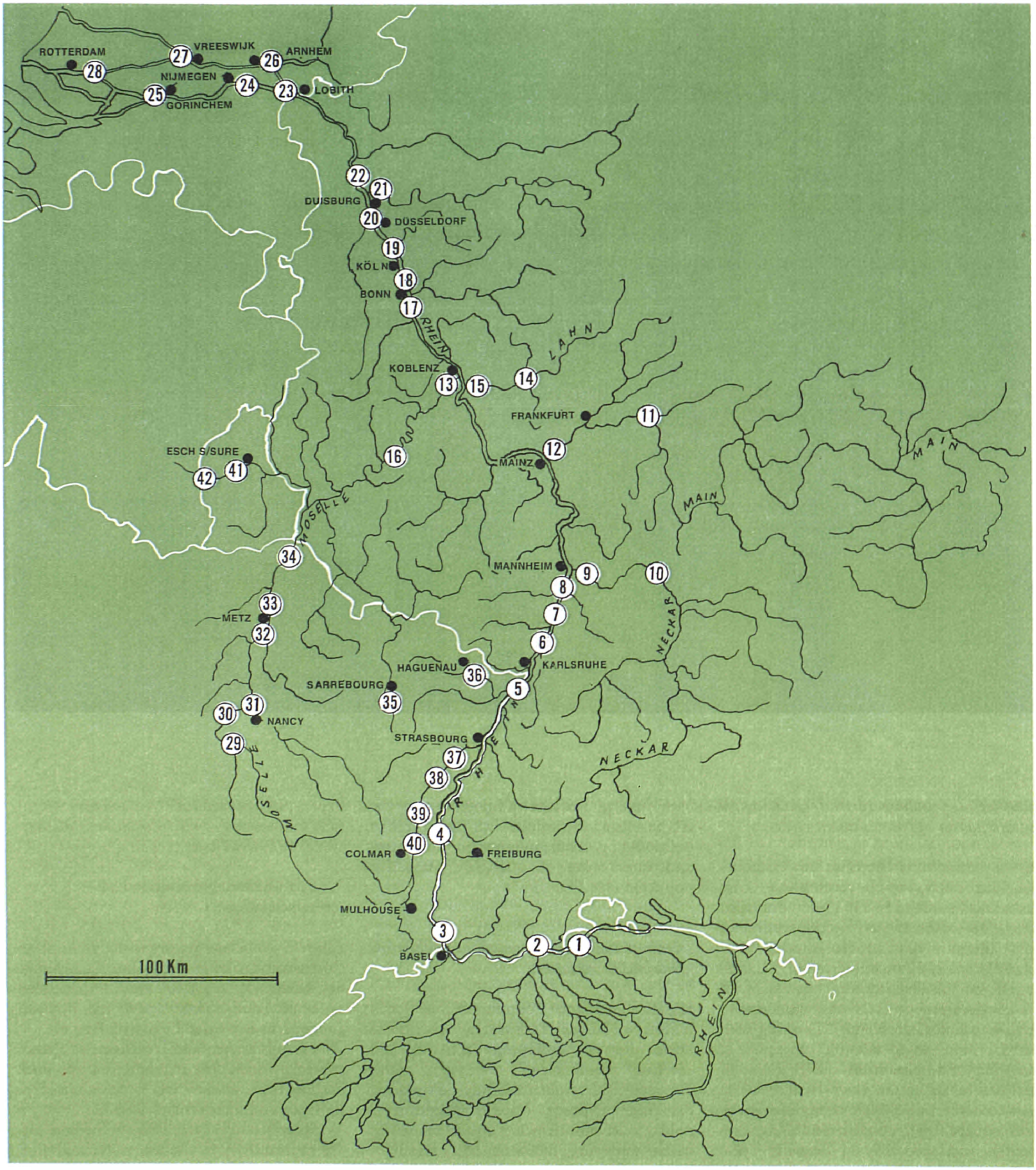
In the research field, the Commission of the European Communities is pursuing a number of specific lines:

Purification and storage of radioactive effluents

For practically all the work connected with this side of the programme, Euratom has signed contracts with Community bodies or enterprises. The work consists mainly in developing new methods of processing, packaging and disposing of effluents (for further details of these activities, see the articles by G. Grison on "Radioactive waste", *Euratom Bulletin*, Vol. VI (1967) No. 1, pp. 22-26 and "The problem of radioactive waste storage in the Community", *Euratom Bulletin*, Vol. VI (1967) No. 3, pp. 84-88).

Figure 2: Crops being watered not far from Koblenz, in Germany. Water is taken directly from the Rhine for watering purposes.

Figure 3: Map of the Rhine basin. A systematic study of the radioactive pollution of this basin was launched by the Euratom Commission and continued over nearly four years. The map shows the forty-two points selected for the sampling of water and sediments, nineteen of them on the Rhine, four in the Moselle basin and twelve on the six other main tributaries of the Rhine. ▶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RHEIN
LAHN
KOBLENZ
FRANKFURT
ESCH S/SURE
MOSELLE
MAINZ
MAIN
MANNHEIM
METZ
NECKAR
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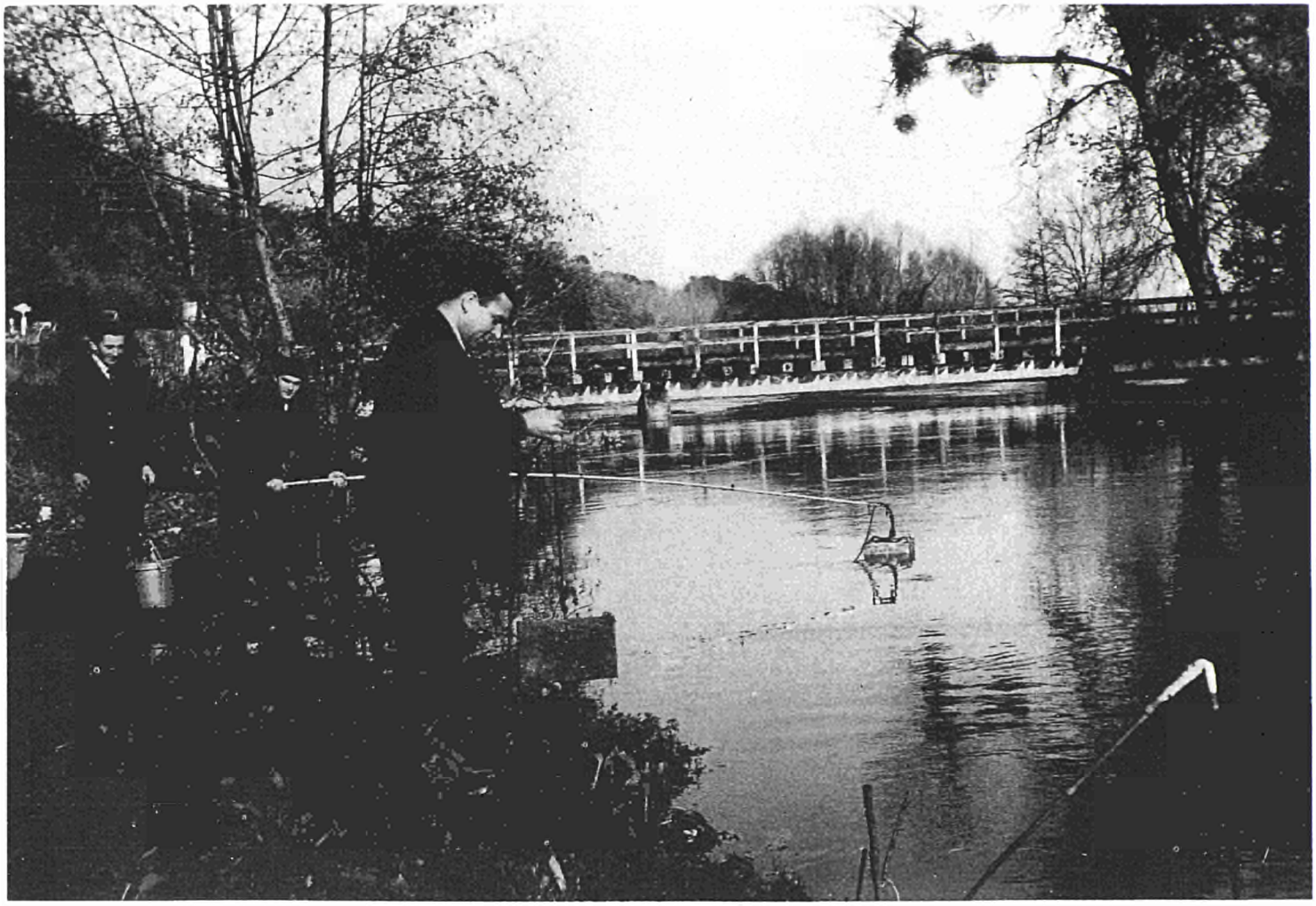


Study of the problems raised by radioactive contamination of international rivers

On the initiative of the Euratom Commission, one such study concerning the Rhine basin was launched in 1962 and continued into 1966, with the active cooperation of the Community countries directly concerned, namely France, Germany, Luxembourg and the Netherlands, but also with the cooperation of Italy and Belgium on certain technical problems. The study consisted, first, in developing methods of sampling and measuring different radionuclides in an actual river basin, with a view to determining their behaviour in the hydrosphere (e.g. concentration on sediments), and secondly, in drawing up a real map of present radioactivity in the Rhine basin; the whole with the object of obtaining practical guidance on the control and monitoring of possible radioactive pollution (see Fig. 3).

Decontamination of water that may be used for drinking purposes

In this field the Community has let a number of research contracts, all with the basic aim of developing economic and efficient methods of removing radioisotopes from water that may be used for drinking purposes. Special attention is paid to certain elements which resist the usual purifying methods by reason of their physicochemical behaviour (e.g., radioruthenium – see *Euratom Bulletin*, Vol. VI (1967) No 1, p. 31).

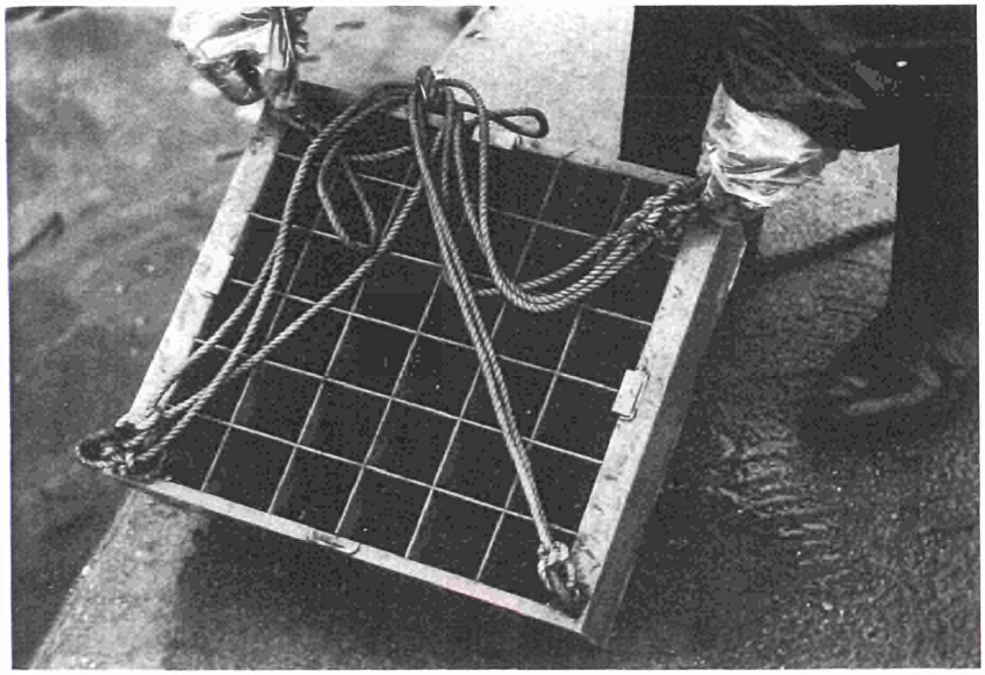
. . . by formulating directives and recommendations

Apart from these research activities, the Commission of the European Communities takes action as follows in questions of health and safety under the powers assigned to it by the Treaty of Rome:

— establishment and revision of basic standards, including irradiation doses and permissible radioactivity concentrations in water and air (Articles 30-33);

— inspection of the facilities for monitoring the radioactivity in the air, water and soil

Figures 4 and 5: For the Rhine Basin radioactivity study (see Fig. 3), various sampling devices had to be developed. Here a team (left) is immersing a rack (shown below) designed to accumulate the sediments deposited on the river-bed over a given period.



in the Member States (Article 35);
— access to the data obtained by the Member States on the levels of environmental radioactivity (Article 36);
— delivery of opinion on every plan for the disposal of radioactive waste in any of the Member States, after inquiry to determine whether its implementation is likely to lead to radioactive contamination of the water, soil or atmosphere of another Member State (Article 37).

In addition, within the context of these activities, numerous groups of experts meet regularly to discuss the questions of pollution of the environment, organisation of control and monitoring of environmental contamination, and the fixing of practical standards for discharges of radioactive matter into the hydrosphere.

Conclusions

Water supplies and their conservation are one of the most anxious problems facing the modern world, particularly in densely populated regions like Western Europe. Radioactive pollution is only one side of the problem, of course, but increasing public awareness of it demands an objective investigation of all the consequences that may stem from the discharge of radioactive substances; the vigorously expanding exploitation of nuclear power makes this all the more pressing.
There can be no question of simplifying this investigation by basing it solely on a study of drinking waters, for instance. On the contrary, it must be conducted in a spirit of analysis, by recourse to concepts such a those of critical groups, critical routes and radiological capacity, so as to obtain a more comprehensive view of the problems. The task is therefore of more than national scope and necessitates regional and international cooperation.
The use of nuclear power implies acceptance of a certain degree of public hazard. It is necessary to find out everything about this hazard, so that we can assess it at its true value and combat it more effectively. To achieve this with efficacy and economy is the ideal answer desired by true health specialists. (EREA-A 7-10)

PROTACTINIUM

PROTACTINIUM, the element with the atomic number 91, occupies the place between thorium and uranium in the periodic system. Two of its isotopes, Pa^{231} and Pa^{234}, occur in nature as members of the radioactive decay series starting with the two main isotopes of uranium. Pa^{234}, which exists in the form of two short-lived isomeric nuclei[1], "UX2" (half-life 1.2 minutes) and "UZ" (half-life 6.6 hours), was the first Pa-isotope to be discovered, being shown up radiochemically in 1913 by Fajans and Göhring as a decay product of uranium. The other and only long-lived isotope Pa^{231} (half-life 32,500 years) and also its position within the radioactive decay series were not discovered until five years later (by Hahn and Meitner, and independently by Soddy and Cranston).

At this time the "actinium decay series" was already known as one of three natural radioactive series. The parent substance, however, was not yet known. Possibilities on the basis of the radioactive displacement laws were either a beta-emitting radium isotope or an alpha-emitting isotope of the element 91[2], of which up to that time only the above-mentioned short-lived Pa^{234}, called for that reason "brevium", was known.

1. Isomeric nuclei are taken to mean isotopes of an element with the same mass number but different nucleonic properties (e.g. half-life, type of emission and energy) due to differing energy contents (different nucleon binding states). This phenomenon was first demonstrated on Pa^{234} (O.Hahn-1921).
2. The radioactive displacement laws state, for example, that the atomic number of an isotope changes during beta decay by +1 and during alpha decay by —2. Actinium has the atomic number 89.

Systematic investigations then led to the discovery of a long-lived, alpha-emitting isotope of the element 91 with mass number 231. On account of its position in the actinium decay series as the parent substance of actinium it was called "protactinium". Later studies showed that protactinium was not the actual parent substance of this series either, but was itself formed by decay of U^{235}, which for this reason is sometimes referred to as "actino-uranium".

As can be calculated from its half-life and the known concentration of its parent substance U^{235} in natural uranium, measurable quantities of the protactinium isotope 231 are contained in natural uranium ores. These quantities, however, are very small (about 0.3 g per 1,000 kg uranium), i.e. about the same as radium.

Therefore, immediately after the discovery of Pa^{231} attempts were made to isolate small quantities in pure form from uranium ore residues. This proved to be less simple than the isolation of radium at the turn of the century by Madame Curie. Since the chemical behaviour of protactinium is very complex in comparison with radium and was at that time still unknown, it was not possible until ten years later (von Grosse 1928) to obtain a few milligrams of pure protactinium, and until very recently only about 0.5 g were available in pure or highly enriched form for chemical studies in the entire world.

It was not until the end of the fifties that Harwell succeeded in obtaining about 100 g from residues of the Springfield uranium factory, thus making it possible

to study the chemistry of this rare radioelement on a broader basis. The great importance attached to these studies both for scientific and nuclear reasons was shown inter alia by the fact that two international symposia were specially devoted to protactinium chemistry (Gatlinburg 1963 and Paris 1965).

More than just a curiosity

Apart from its curiosity value, what is the importance of this rather and rather inaccessible element? The main scientific interest is in obtaining as accurate a knowledge as possible of its electronic structure, which ultimately determines its chemical properties. This is primarily because protactinium (which is tetravalent) and uranium (which is hexavalent); this originally cast doubts on the existence of an actinide series similar to the rare earths. These contradictions were cleared up only by more thorough physical studies which threw direct light on the electron structure. Of course, this stimulated a desire to include in these studies the element protactinium, which had only recently become available in sufficient quantities.

In addition, however, there is also a considerable nuclear interest in obtaining exact knowledge of the chemical and physical properties of protactinium—especially in the condensed phase, i.e. in solid compounds—in connection with the *thorium breeding cycle*, and the following remarks will therefore concentrate on these problems.

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is one of the initial members of the *actinide* series, a group of elements in the periodic system beginning with actinium (atomic number 89) and extending via thorium, uranium, plutonium and the transuranic elements to the heaviest element at present known, lawrencium (atomic number 103). The electronic structure of this group corresponds to that of the rare earths, elements distinguished by their close chemical resemblance to one another, which makes it very difficult to separate them. All rare earths, for example, are chemically trivalent (this is the most stable valency). The higher transuranic elements, beginning with americium, behave similarly. The first members of the actinide series, however, show departures from this rule which are particularly marked in the case of thorium

Protactinium as an intermediate stage in the thorium breeder cycle

In the chain reactions which normally occur in a nuclear reactor, all the neutrons liberated by the fission of a fissile nucleus (their number η varies, according to the type of fissile nucleus and the energy of the reactor neutrons, between about 1.5 and 4 per fissioned nucleus) are used to trigger off further nuclear fissions, one fissile neutron per fissioned nucleus being sufficient to maintain the chain reaction. Disregarding unavoidable neutron losses through absorption (e.g. in structural materials, moderator, etc.) and leakage from the reactor core, there remains an excess of fissile neutrons which could be used for other purposes, e.g. for "breeding" new fissile material. In this way it is theoretically possible in a nuclear reactor of suitable design to produce more fissile material than is consumed to maintain operation. Two nuclear reactions, sketched briefly below, can be used for this breeding process:

Thorium cycle:

$$Th^{232}\,(n,\gamma)\,Th^{233} \xrightarrow{\beta} Pa^{233} \xrightarrow{\beta} U^{233}$$

Uranium-plutonium cycle:

$$U^{238}\,(n,\gamma)\,U^{239} \xrightarrow{\beta} Np^{239} \xrightarrow{\beta} Pu^{239}$$

Both reactions start with isotopes (Th^{232} or U^{238}) which are not themselves capable of sustaining a chain reaction. On the other hand they are available in large quantities in nature. According to geochemical estimates, Th^{232} is the only isotope of naturally-occurring thorium whose reserves far exceed those of uranium. As for U^{238}, it accounts for 99.3% of natural uranium.

The most important physical quantity for the description of a breeding cycle is the conversion factor K. This factor gives the yields of the above nuclear reactions, i.e. the number of new fissile atoms (U^{233}, Pu^{239}) produced per used atom of the original fissile material. Only when $K > 1$ is there a breeding gain, i.e. more new fissile nuclei are produced than are consumed. The upper theoretical limit of K is set by the number of neutrons η liberated per fission (see above).

Since one neutron per fission is required to maintain the chain reaction, the theoretical conversion factor is given by the simple equation:

$$K_{theor.} = \eta - 1$$

Fig. 1 shows a graph of the quantity $\eta - 1$ for various fissile nuclei (U^{235}, U^{233}, Pu^{239}). It can be seen that the curve for the U^{233} formed in the thorium cycle is the only one which lies above the limit value 1 over the whole range of neutron energies. With U^{235} and plutonium this value is exceeded only for neutron energies above 10 keV, i.e. for so-called *fast neutrons*. This means that the last-mentioned breeding cycle can be carried out only in fast reactors, whereas the thorium cycle is possible both in fast and in thermal reactors.

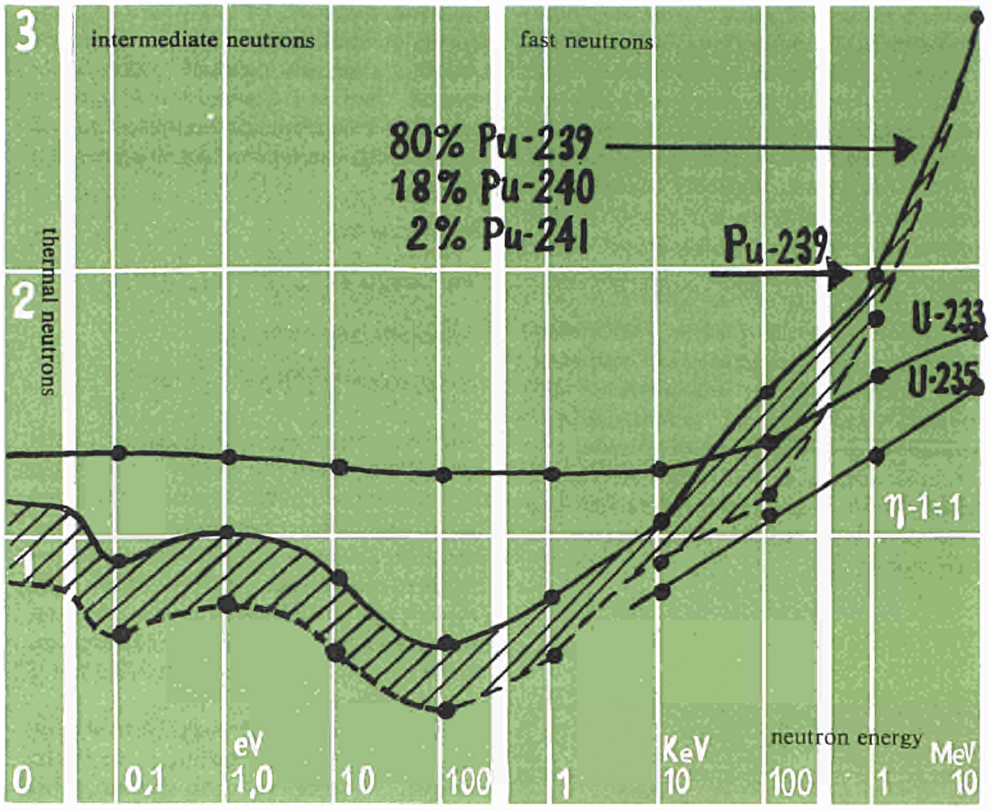


Figure 1: The theoretical conversion factor (= η - 1) as a function of neutron energy.

If we now return to the above equation of the nuclear reaction underlying the thorium breeder cycle, it will be seen that a protactinium isotope, Pa^{233}, plays a central part in it. This isotope differs from those which occur in nature. It is a beta emitter with a half-life of 27 days. In the uranium-plutonium cycle also there is a beta-emitting intermediate product between the starting and the end product, namely a neptunium isotope (Np^{239}). Its half-life, however, is less than 10% of that of Pa^{233} (2.1 days). There is thus a big difference between the significance of these intermediate products. Firstly, the concentration built up in the fuel element of a breeder reactor during operation is approximately proportional to the half-life. This means that in the thorium cycle about ten times more protactinium is formed within the thorium matrix than the neptunium formed in the uranium cycle. Secondly, the half-life of the intermediate product also determines how long it is necessary to wait after the removal of the fuel element from the reactor before the required end product (U^{233} or Pu^{239}) can be extracted by chemical reprocessing. While this period of time is only a matter of days in the uranium cycle and therefore raises no problems, with a thorium fuel element it is necessary to wait several months for all the protactinium to decay into U^{233}. Long waiting times, however, raise the cost of the fuel cycle.

As was already mentioned, the relatively long half-life of the intermediate product Pa^{233} causes higher concentrations of it to be formed in the thorium matrix. Under normal reactor conditions these are in the order of magnitude of 0.2-2%, depending on the neutron flux (see also Fig. 3).

This has an unfortunate consequence from the nuclear physics standpoint. Pa^{233} is itself capable of capturing neutrons, leading to the formation of the non-fissile uranium isotope, U^{234}, via the short-lived Pa^{234} (which is identical with the initially mentioned natural isotope). The neutrons captured through this reaction are lost to the overall neutron balance, since they serve neither to trigger off new fissions nor to breed fissile material. They thus reduce the conversion factor. Fig. 2 shows all the nuclear reactions and related nuclear physics data within the thorium cycle—including the undesired secondary reactions[3].

Protactinium poisoning

Owing to neutron capture in Pa^{233}, a process which can also be called "protactinium poisoning", about 10% of available neutrons are lost per 1% Pa^{233} present in the thorium matrix. This reduces the conversion factor by 0.1, which is a great deal, bearing in mind that the maximum value of this factor in a thermal reactor is only 1.3 (see Fig. 1) and that only the fraction in excess of 1 represents the actual breeding gain.

How can protactinium poisoning be combated? It cannot be completely prevented, since the formation of the desired end product, U^{233}, is possible only by way of Pa^{233}. The only means of combating it is to keep the protactinium concentration in the thorium as small as possible. There are two methods of doing this, which can easily be deduced from Fig. 3. This shows the protactinium concentration in reactor-irradiated thorium as a function of time for various neutron fluxes. A steep increase can clearly be discerned at the beginning of the irradiation period until a practically constant concentration is attained—the so-called *equilibrium concentration.*

If the curves for various neutron fluxes are compared, it can be seen that these equilibrium concentrations are also roughly proportional to the neutron flux. This means that theoretically a limitation of the neutron flux provides a means of limiting the protactinium concentration too and hence also the extent of the protactinium poisoning. On the other hand, a diminished

3. As can be seen from this, there is also a production, although on a smaller scale, of the long-lived Pa^{231}, which also turns, through further neutron capture, into a short-lived isotope of protactinium (Pa^{232}) and finally into a non-fissile uranium isotope (U^{232}).

neutron flux leads to a reduction in the reactor power density and hence ultimately to a drop in profitability, since a larger reactor will be required to produce a given output.

A radically different method is based on the typical time function of the formation of Pa^{233}. At the beginning of irradiation ($t = 0$) the Pa^{233} concentration in the thorium is equal to 0, and then increases with time, at first rapidly and then more slowly. This might suggest the possibility of not leaving the thorium fuel elements too long in the reactor, but of taking them out again after short irradiation times, replacing them by new ones and meanwhile chemically processing the old elements (i.e. separating out their protactinium and uranium).

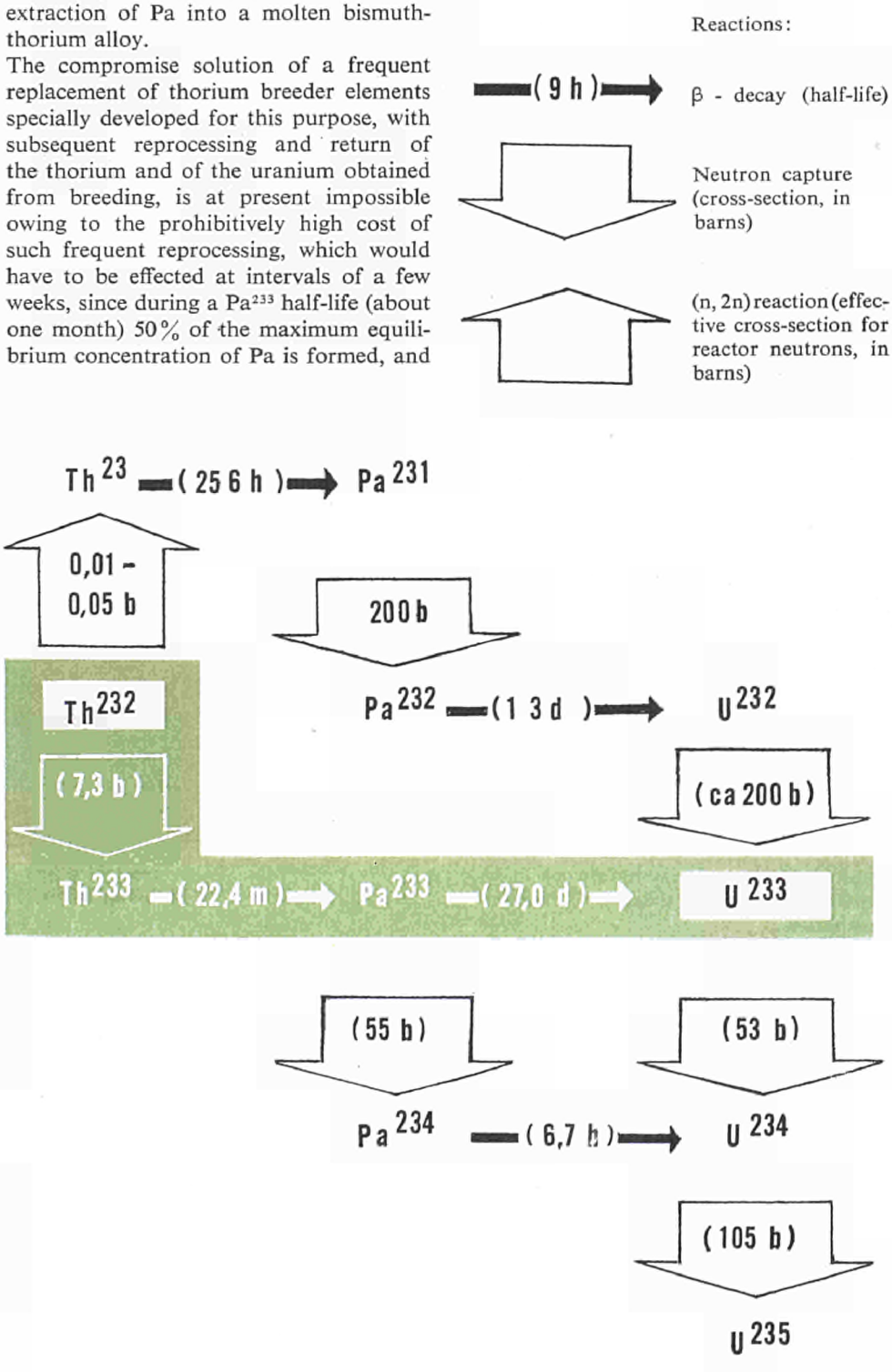
Ideally the thorium should be contained in a suitable fluid, which would circulate continuously through the reactor, and an annexed unit for continuous protactinium separation. This would make it possible to keep the protactinium concentration within the reactor core extremely low. The Pa^{233} accumulating in the separation unit could be stored outside the reactor until it decayed into U^{233}, a fraction of which would be returned into the circuit to maintain the chain reaction. Such a technique would be theoretically feasible in molten salt and suspension *(SUSPOP)* reactors[4].

Very exotic systems, such as reactors containing the fuel and breeder substances dissolved or suspended in molten metal have also been proposed. However, they are still far from large-scale technical realisation, since they raise other problems such as corrosion, homogeneous distribution of fissile and breeder material in the core, etc.

Moreover, owing to inadequate knowledge of protactinium chemistry, the fundamental problem of fast and efficient protactinium separation from such fluid melts or suspensions on a large scale is still for the most part unsolved. Only quite recently *ORNL* succeeded in developing a continuous separation method for Pa from molten salts, which works quite well on a laboratory scale. It is based on continuous extraction of Pa into a molten bismuth-thorium alloy.

The compromise solution of a frequent replacement of thorium breeder elements specially developed for this purpose, with subsequent reprocessing and return of the thorium and of the uranium obtained from breeding, is at present impossible owing to the prohibitively high cost of such frequent reprocessing, which would have to be effected at intervals of a few weeks, since during a Pa^{233} half-life (about one month) 50% of the maximum equilibrium concentration of Pa is formed, and

Figure 2: The most important nuclear reactions in the thorium cycle.



4. Both reactors use a liquid nuclear fuel which circulates between the core and the heat exchanger. In the first case the fissile material is dissolved in a molten salt consisting of the fluorides of lithium, beryllium and zirconium. A 7.5 MW test reactor of this type has been in operation in the *Oak Ridge National Laboratory* for some years; in the second case (*SUSPOP*) the nuclear fuel is in the form of small oxide particles in aqueous suspension. This project is being developed in the Netherlands (see *Euratom Bulletin*, Vol. IV (1965) no. 3, p. 71).

it would therefore not be economic to wait much longer.

Influence of protactinium on the material properties of the thorium nuclear fuel

As we saw above, protactinium concentrations of about 1% are to be expected in a thorium fuel element under in-pile irradiation. The nuclear fuel itself usually consists of a suitable thorium compound to which a few percent enriched uranium (U^{235}, U^{233}) are added as fissile material. During operation this initially Pa-free basic material is contaminated by a protactinium "impurity" which is quantitatively by no means negligible.
Its influence on the material properties depends upon the chemical form in which the nuclear fuel is present, e.g. as metal, oxide, carbide, etc. Metal alloys seem to be particularly promising for water-cooled thorium reactors owing to their favourable neutron and thermal properties (maximum density and thermal conductivity, giving a high power density). Thorium alloys are superior to uranium alloys owing to better mechanical properties, above all at high temperatures. Thorium does not undergo any phase transformations in the temperature range concerned and has a higher melting point than uranium (1,850 as against 1,130°C). But it is well known that the slightest traces of foreign metals can appreciably affect the mechanical properties of metal alloys, especially at high temperatures. Particular caution is therefore indicated here as regards protactinium. On the other hand, up to the present, nothing is known of the alloying behaviour of this element, so that it is not possible to make a definite analysis of the property changes observed during the irradiation of thorium alloys, i.e. to separate the irradiation damage from the effects of the protactinium. The problem is further complicated by the fact that pure protactinium metal, which was produced and studied for the first time only three years ago, has a lattice structure at temperatures below about 1,100°C which differs from that of all other known metals.
Alternatively, the thorium can, of course, also be used in the form of a sufficiently stable chemical compound, e.g. as oxide or carbide, as is already customary with uranium ceramic fuels. In an oxide fuel the influence of the protactinium formed during reactor operations should be negligible, since it has been found that protactinium oxide is soluble in thorium oxide and slight concentrations leave its structure almost unaffected.
Carbides are also considered as ceramic fuels. They occupy approximately an intermediate place between the metals and the oxides, since they combine high thermal conductivity with high temperature stability (high melting point).
Their main disadvantage consists in their low resistance to corrosion by oxidising media such as air and water, and thorium carbide is particularly sensitive in this respect. If, however, by means of suitable cladding and special coolants (e.g. organic or helium) all contact with corrosive media is prevented, the carbides are also efficient nuclear fuels. The best known examples are the *high-temperature gas-cooled reactors*, in which the nuclear fuel is in the form of small particles covered with a high-density graphite coat (coated particles —see *Euratom Review*, Vol. VII (1968) no. 2, pp. 46-51). Carbide is often used here as a chemical form of the nuclear fuel kernel owing to its good compatibility with the graphite coating. Here, too, as with the metal alloys, owing to lack of knowledge of the protactinium carbide it is not possible to predict its influence on the material properties.

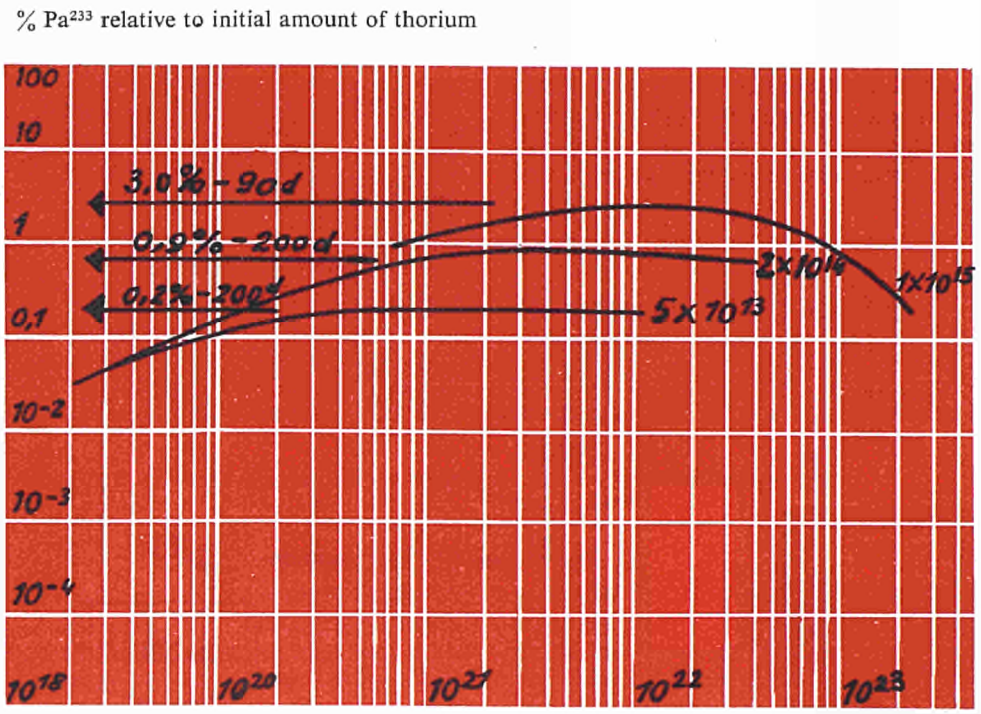


Figure 3: Pa-concentration as function of integrated flux (neutron dose) for three different fluxes.

Apart from the direct effects of the protactinium on the fuel properties, consideration must be given to another important factor independent of the chemical form of the fuel and the design of the element. This is *diffusion*, to which the atoms of any solid are subject at high temperatures. It is due to the fact that the atoms in the lattice of a solid are not rigidly fixed, but vibrate about their position at rest with an intensity which increases with temperature. As a result the atoms may leave their original position, either changing places with adjacent atoms or jumping into nearby vacant positions in the lattice and thereby leaving a similar vacancy behind them. Such vacancies are among the so-called *lattice defects*—deviations from the ideal solid lattice structure, i.e. the spatial arrangement of the atoms among themselves. From the macroscopic standpoint the diffusion process has the following effects:

— at constant temperature it causes an impurity which originally has an inhomogeneous distribution (e.g. punctiform) in a solid body gradually to assume an even distribution;
— in a temperature gradient, e.g. in a rod whose ends are at different temperatures, so-called *thermal diffusion* can result in an impurity with an originally homogeneous distribution becoming enriched at one end, thus resulting in an inhomogeneous distribution.

The velocity of these processes is determined by the size of the *diffusion constant*. In a given solid this differs for each type of atom and is also temperature-dependent. Temperature gradients are always present in a nuclear fuel element under operating conditions and are the more pronounced the lower the heat conductivity of the fuel. For example, in the simple case of a rod-shaped fuel element, the temperature at the axis of the rod is higher than at its surface, where the heat is continuously removed by the circulating coolant. With poorly conducting oxide fuels this temperature gradient is considerably steeper than for example with a metal alloy, and may have values of up to 1,000°C/cm. As a result marked thermal diffusion occurs, leading to an inhomogeneous distribution of all fuel components, including the substances produced during the irradiation by nuclear reactions, among which are the fission products.

What does this signify in the special case of protactinium in a thorium fuel? Since the protactinium is an intermediate product of the nuclear reaction leading from non-fissile thorium to fissile U^{233}, which latter comes into being with a delay of about one month through decay of Pa^{233}, an inhomogeneous distribution of the protactinium must lead to an inhomogeneous distribution of the U^{233} in the fuel element. An alteration in the distribution of fissile material in a fuel element during operations is, however, undesirable. It changes the nature of the fuel, e.g. the temperature distribution, and may also affect the reactivity of the core.

The diffusion is naturally not restricted to nuclear fuels, but occurs in every solid, including the can material, the task of which is to seal hermetically the nuclear fuel and the fission products generated within it from contact with the coolant. A penetration of the can by fissile material and fission products as a result of diffusion would make the fuel element worthless. If the protactinium were to penetrate through the can in a thorium fuel element, fissile U^{233} would subsequently be formed inside and outside the can through decay, leading to complete contamination of the coolant circuit by fission products.

It follows that it is of great importance to have exact knowledge of the diffusion parameters of protactinium in comparison with uranuima nd thorium in all reactor materials (nuclear fuel and can material), since the above effects are particularly strongly marked in the temperature gradient if the diffusion coefficients of the individual components differ greatly from one another. In this field, too, very little is as yet known and intensive studies are therefore in progress.

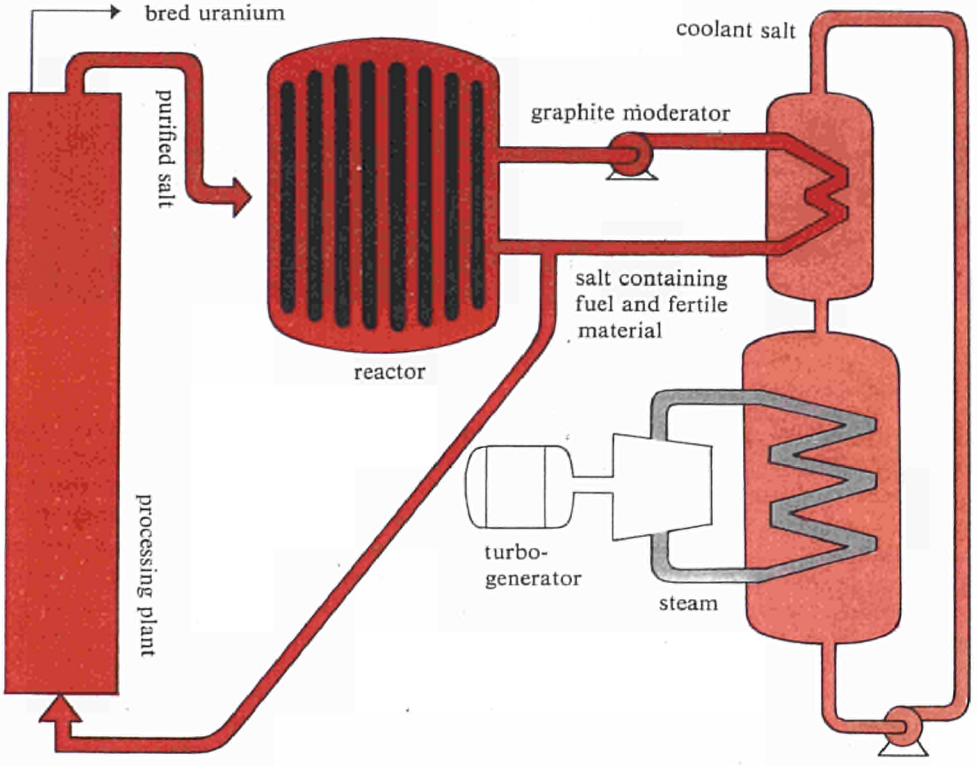
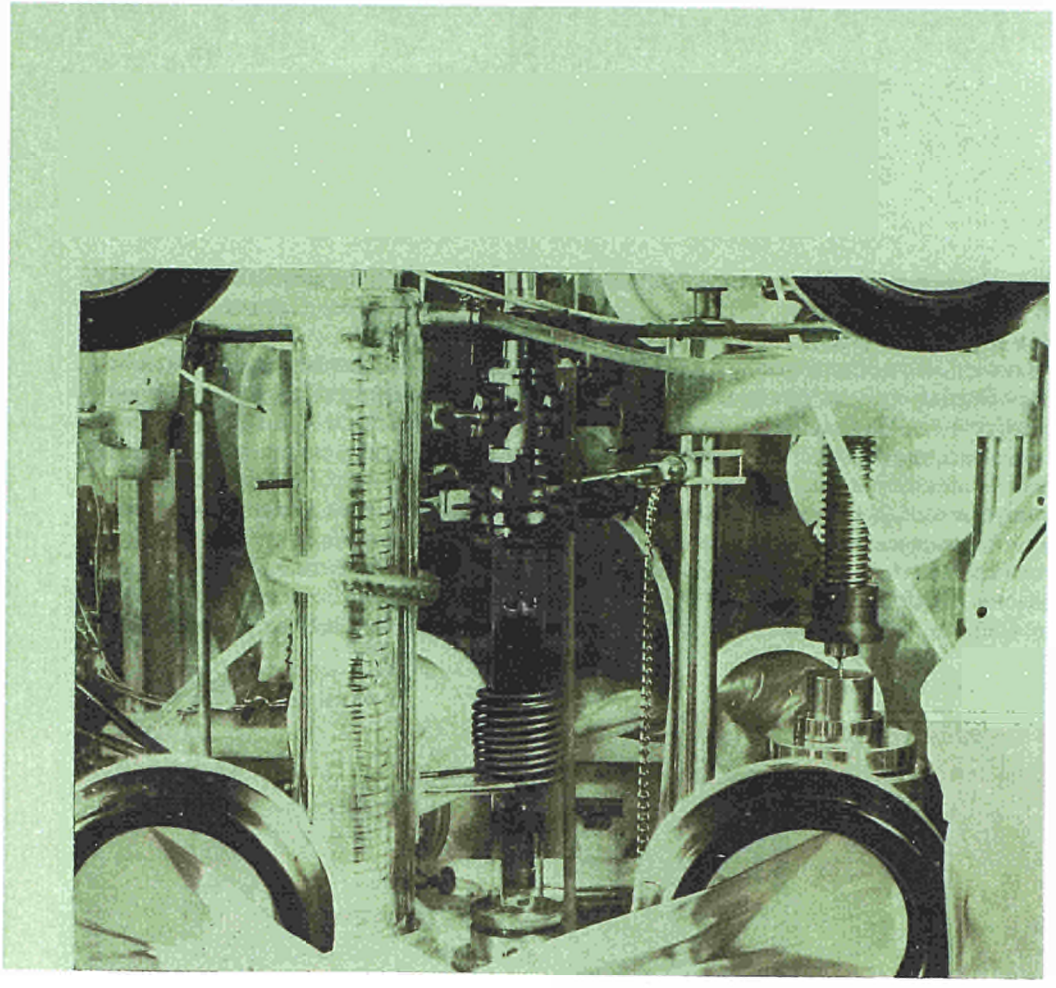


Figure 4: One-fluid, two-region molten salt breeder reactor (after the paper "The status and potential of molten salt reactors", presented by M. W. Rosenthal to the IAEA *pannel on the utilisation of thorium in powers reactors, June 1968).*

Allowing for protactinium in the reprocessing of thorium nuclear fuels

As already mentioned, before reprocessing a thorium nuclear fuel it is necessary to

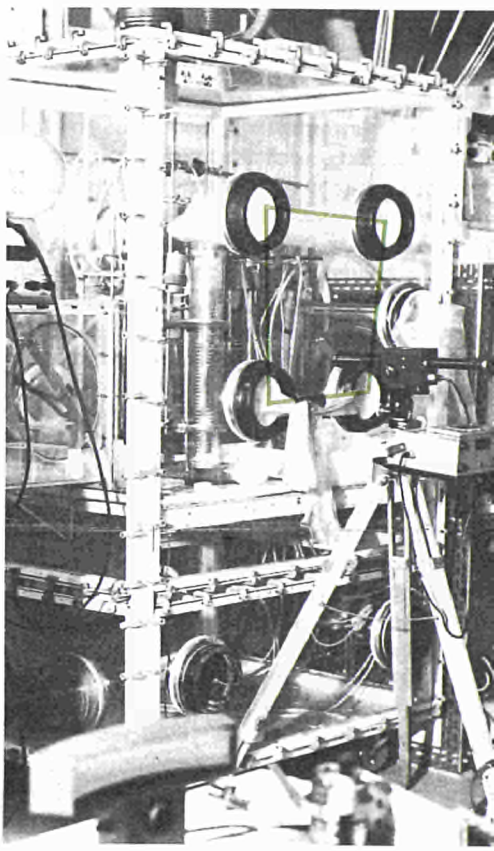


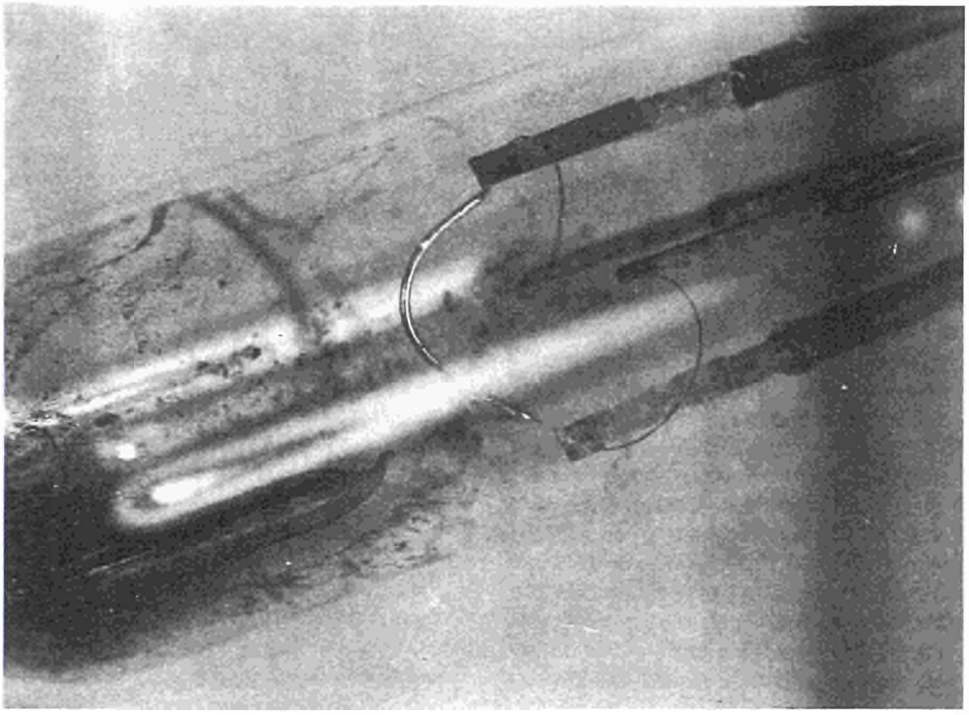
Figures 5, 6 and 7: Fabrication of Th-Pa alloys.
Fig. 5 (left) shows the inside of the glove-box (below) with the essential apparatus (1. furnace for the Van Arckel *bulb; 2. high-frequency heated vacuum furnace for fabrication of the carbide mixture; 3. hydraulic pellet press for compacting the raw materials). Fig. 7 (right) shows a section taken from the* Van Arckel *bulb. In the centre can be seen the hot wire with the Th-Pa alloy deposit. The thin wires are used as potential taps. Below left is the opened iodine capsule.*

wait until all its contained Pa^{233} has decayed to U^{233}, the desired end product of the breeder cycle. This entails waiting times of some months. Alternatively reprocessing can, of course, be carried out more quickly, but one must then either separate the protactinium specially (and store it to allow it to decay into uranium) or ensure through a suitable chemical process that all the protactinium is separated together with the uranium, since any protactinium loss is ultimately identical with a loss of U^{233} obtained from breeding. This again calls for as exact a knowledge as possible of the chemical behaviour of protactinium, in order to allow for it in processing nuclear fuel. This applies especially to recent "dry" reprocessing techniques, which involve chemical separations in molten salts or metals as reaction media (pyrometallurgy), or fluoride volatilisation techniques, which make use of the volatility of uranium fluoride in contrast to most other fluorides, including those of fission products.
These techniques, which are at present still being developed, in theory make it possible to process a nuclear fuel immediately after removal from the reactor, since the selected reaction media, in contrast to the acqueous and organic solutions in the traditional nuclear fuel processing techniques, are not radiation-sensitive. Here again, unfortunately, our knowledge of the chemistry of protactinium is still completely inadequate to allow us to predict its behaviour in these processes. Almost the entire previous basic research on protactinium has been concentrated on its behaviour in aqueous solutions and to a certain extent in organic solvents. Practically nothing is known of its chemistry in molten salts or metals.

Main lines of nuclear research into protactinium chemistry

As will be seen from the above, the nuclear interest in the further study of the physico-chemical properties of protactinium is mainly concentrated on condensed phases, i.e. on solid compounds such as oxides, carbides and intermetallic compounds, together with fused systems (e.g. molten salts and metals). The main effort in studying the pure protactinium compounds is directed to obtaining an exact knowledge





of the structural parameters together with the most important thermodynamic data affecting the stability of these compounds. In addition, the behaviour of dissolved protactinium in condensed phases is studied, i.e. both in solid solution and in molten systems. Up to the present little has been known in these fields, apart from a few structural studies on protactinium oxides and protactinium metal. This is due to the extreme difficulty of such investigations.

In the first place protactinium, as mentioned above, is extremely difficult to obtain, since the only long-lived isotope suitable for such studies—Pa^{231}—is as rare as radium. The Pa^{233} formed in the thorium cycle can scarcely be handled in weighable quantities owing to its short half-life and consequent high specific activity. In addition, Pa^{231} is an alpha emitter with a radiotoxicity comparable to plutonium. Hence even milligram quantities can only be worked and studied under appropriate safety precautions, e.g. in glove-boxes. The inaccessibility and rarity of protactinium also mean that all the material used during a test, including the waste (even if greatly diluted), must be reprocessed and recovered in a pure form. This is a very complex process. The tests themselves can only be performed on a very small scale, i.e. with quantities from a few milligrams up to a few tenths of a gram. Measurements must therefore be made on minute samples, using special techniques.

For example, in the tests on the production of Th-Pa alloys at present in progress at Ispra, the total quantities available are only a few tens of milligrams; the total quantity of a 1 % Pa-Th alloy, for instance, which can be fabricated in this way is only a few grams. Since the density of the metal is > 10 g/cm^3, the volume of such a sample is < 1 cm^3. The main problem in working with such small quantities is to avoid picking up impurities, e.g. by reaction with the material of a crucible, which could seriously falsify the properties to be measured. A metal fabrication technique was therefore chosen which completely eliminates such impurities—the *Van Arckel* process—also used for fabricating high-purity metals.

In this technique the iodide of the required metal is decomposed in a high vacuum on a hot wire (e.g. tungsten), and the metal is deposited on the wire. We use a thin wire of thorium metal, in order to avoid even the slight contamination by a tungsten core in the Th-Pa alloy wire made in this way. The original material is a mixed thorium-protactinium carbide, fabricated previously from a mixture of the oxides through reaction with carbon at 1,500-2,000°C in vacuo. This is placed in an evacuated glass bulb containing the hot wire together with a small quantity of iodine, which reacts with the carbide to form the volatile iodides of Th and Pa. Both metals are then simultaneously deposited on the electrically heated wire in the form of the desired alloy without any foreign impurity. Figs. 5 and 6 show the whole apparatus mounted in a glove-box, which is necessary for performing all the above operations. Fig. 7 shows a *Van Arckel* bulb with the alloy deposited on the hot wire.

For further study of the alloy the bulb must be broken and the wire extracted. The tests performed on the alloy include metallography (i.e. microscopic study of the alloy structure), X-ray structure analysis (*Debye-Scherrer* method) and microprobe studies (*Castaing* method). In the microprobe studies a fine electron beam (diameter a few microns) is focussed on a few selected zones of a ground section of the alloy, thus triggering off the characteristic X-ray emissions of the individual elements present in the irradiated zone. From the intensity and the wavelength of this X-ray emission it is possible to determine directly the type and concentration of the elements present. With this method it is also possible to make non-destructive chemical analyses of microzones of only a few square microns in area.

This is however only an example of the large number of investigations which are still necessary before we can arrive at a complete insight into the behaviour of this rare element in the systems which are of interest from the point of view of the thorium cycle.

this rare element in the systems which are of interest from the point of view of the thorium cycle. (EREA-A 7-11)

Bibliography: (1) D. BROWN, A.G. MADDOCK: Protactinium. *Quarterly Reviews*, Vol. 17 (1963) pp. 289-341. (2) C. KELLER: Die Chemie des Protaktiniums. *Angewandte Chemie*, Vol. 78 (1966) pp. 85-98.

Readers' views and comments, collated by Michel Gibb, Editor

Would you like to help us to improve

SOME 200 READERS replied to the questionnaire we sent last year with issues 3 and 4 of *Euratom Bulletin* (as it was still called at the time). Our first duty is to thank them for giving us their views, some of which came rather as a shock to us, although criticisms were invariably constructive. A few of our readers found the space available in the questionnaire for general comments insufficient and took the trouble to write us a letter. We are particularly grateful to them.

Our second duty is to present in some detail the results of this opinion poll.

The substance of the replies to questions 1, 2, 3, 5 and 6 is best given in tabular form (see tables I to V; replies to question 4 have not been dealt with as they in most cases merely confirm replies to question 3). It should be noted that the figures do not always add up to the same total; this is just because a number of questionnaires were not filled in completely.

Some of these statistical results call for a few comments. *Table II* confirms that *Euratom Review* is read by people from a wide range of professions, which is extremely gratifying, because we have in fact tried hard to keep our journal from slipping into the rut of overspecialisation. *Table III* presents the "scores" obtained by each of the broad subject fields covered by *Euratom Review*, account being taken firstly of "A"-markings only (A = of regular interest), secondly of "B"-markings (B = of occasional interest), thirdly of "A" and "B"-markings combined and finally of "C"-markings (of no interest). The lesson to be derived from the results of this part of our survey are quite clear.

The subjects which attract most interest are physics, reactor technology, industrial applications of radioisotopes, documentation and health protection; they take the first five places not only under "A", but also under "A + B", although not in the same order. We will of course take account of these preferences in future.

Most significant however are the "B"-markings. Waste treatment and storage, almost rock bottom under the "A"-listing, shoots to first place under "B". We find health protection next, then geology (retrieved from the very bottom of the "A"-listing), medical uses of nuclear energy and industrial applications of radioisotopes. Waste treatment problems, health protection and medical uses of nuclear energy being the direct concern of only a few specialists at the professional level, but of everybody at the human level, these results are not entirely surprising. The only surprise is that the uses of nuclear energy in agriculture should not have scored better.

Table I: Breakdown according to country of residence (based on replies to question No. 1: "What is your name and address?).

Belgium	55
Germany	17
France	28
Italy	22
Luxembourg	2
Netherlands	31
United Kingdom	16
United States	12
Switzerland	4
Australia	2
Canada	2
Norway	2
Spain	2
Other countries	10

This is what four of our readers have to say in this connection:

"*Medical, biological and agricultural topics are of interest to everyone if they are presented in an appropriate manner. The same holds good of health protection problems. I think it is desirable that each issue should include, apart from technical articles, a contribution on one of these topics.*"
J. R., biologist, 92 Châtillon-sous-Bagneux, France

"*I would like to see more on biology and agriculture but I find* Euratom Review *a very fine publication as it is.*"
Y.G., biologist, Oran, Algerian Republic

"*The review is heavily oriented towards reactor technology. I would like to see more information and articles on biological and chemical effects of radiation. Comparatively few organisations operate reactors, but many have radiation sources, and are concerned with industrial or research applications.*"
C.G.C., chemist, Skärhamn, Sweden

"*In my opinion your journal is too technical: out of 20 articles published in 1967, I only find one dealing with a biological subject. It seems to me that if you published one per issue it would not be too much and your journal would extend its readership.*"
J.J., biologist, Polleur, Belgium

All we can say in conclusion is that we are absolutely convinced on this point. We will endeavour, in future, to fulfill these wishes to the best of our ability.

Table IV summarises the replies to the question: "When articles in *Euratom Review* cover a field with which you are acquainted, do you feel they are: a) of no interest, or b) lacking in detail but nonetheless interesting, or c) sufficiently detailed?". We are very sensitive to the courtesy of our readers, none of whom ticked the box facing the words "of no interest". We suspect that it may also be courtesy which made so many (a little more than half) of them tick the third rather than the second box.

Table V presents a synopsis of the replies to a slightly different question: "When articles in *Euratom Review* cover a field with which you are not well acquainted, do you feel they are generally: a) too difficult, or b) of a suitable level, or c) too simple?" The readers' verdict is extremely clear in this case: an overwhelming majority of 87% voted for "of a suitable level" and only about 9% for "too difficult" and about 4% for "too simple".
It could be objected here that the result could hardly be different inasmuch as no one would read *Euratom Review*, let alone

Table II: Replies to question No 2: "What is your profession?"

Engineers	45
Teaching profession	24
Students	15
Laboratory technicians and draughtsmen	14
Publishers and journalists	13
Information officers	11
Physicians	7
Physicists	7
Chemists	5
Biologists	5
Members of Parliament	4
Business executives	4
Veterinary surgeons	2
Economists	2
Diplomats	2
Trade unionists	2
Other professions	11

EURATOM REVIEW?

	A of regular interest		B of occasional interest		Total A + B		C of no interest
Physics	80	1	48	11	128	3	22
Reactor technology	79	2	46	12	125	4	33
Industrial applications of radioisotopes and radiations	77	3	62	5	139	1	19
Documentation	72	4	52	8	124	5	28
Health protection	67	5	70	2	137	2	25
Biology	62	6	44	14	106	10	46
Medical uses of nuclear energy	59	7	63	4	122	6	35
Chemistry	58	8	58	6	116	8	40
Legal and economic aspects	58	9	45	13	103	11	51
Mathematics and computers	56	10	58	6	114	9	38
Metals, ceramics and other materials	52	11	49	10	101	12	55
Agricultural uses of nuclear energy	49	12	52	8	101	12	52
Waste treatment and storage	47	13	75	1	122	6	36
Geology	31	14	64	3	95	14	56

Table III: Grading of subject fields according to interest. (Replies to question No 3: "Please mark a letter A against those subjects to which you regularly devote attention in Euratom Review, *a letter B against those which occasionally attract your interest and a letter C against those which are of no interest to you). The first three columns each give two figures, the first of which shows the number of "votes" received by a subject and the second (in white) the placing of that subject, respectively according to criteria A, B and A + B.*

Table IV: Replies to question No 5: "When articles in Euratom Review *cover a field with which you are acquainted, do you feel they are generally: a) of no interest, or b) lacking in detail but nonetheless interesting, or c) sufficiently detailed?"*

Of no interest	Lacking in detail but nonetheless interesting	Sufficiently detailed
0	84	97

Table V: Replies to question No 6: "When articles in Euratom Review *cover a field with which you are not very well acquainted, do you feel they are generally: a) too difficult, or b) of a suitable level, or c) too simple?*

Too difficult	Of a suitable level	Too simple
15	150	8

answer a questionnaire about it, unless he considered the material it contained was of a suitable level. The near-unanimity of the poll is in any case only apparent. To prove this, we leave the floor to the readers who took the trouble to justify their replies:

"*Some articles are of a suitable level, but others are really too simple. My personal experience is that most of the people who read* Euratom Review *have a good scientific or technical background, which would justify less popularised articles.*"

R.L., chemical engineer, Belgium

"*The articles would gain appreciably in readability if some of the authors were to state their ideas more briefly and draw a sharper distinction between the main points and the details. In other words: it happens all too often that the obvious is stressed, although I must admit that this is done very elegantly.*"

J.v.d.H., veterinary surgeon, Wageningen, Netherlands

"*There are several theoretical principles which are fundamental to certain measurements. Hardly any attention is paid to these principles. For instance the article starting on page 66 of No 3 Vol. VI (Neutron techniques in condensed state physics—Victor Raievski) is very good but too weak on the theoretical side.*"

C.R., physicist, Boechout, Belgium

"*I find* Euratom Review *one of the best journals among those I receive and I congratulate the contributors. However, many subscribers would certainly welcome articles constructed on a somewhat more scientific basis.*"

H.D., student, Geluveld, Belgium

"*I would like to see you going more deeply into a given subject. This article could constitute the main item of a given issue of* Euratom Review."

J.A.G.W.v.M., student, Eindhoven, Netherlands

"*Besides general surveys, more concrete and directly useful information should be given.*"

W.R., Berlin, Germany

"*I find the articles of a suitable level but incomplete. For instance no mention is made in the excellent article by J. Bugl (Vol. VI, No 4, p. 98) of the energy of the neutrons or the energy spectrum on which the calculation of radiation doses is based.*"

P.R., engineer, Geneva, Switzerland

All these readers are clearly in favour of more detailed or more theoretical articles. However, another group does not quite share this view:

"*I welcome* Euratom Review *as a general review rather than for detailed technical treatment.*"

H.T., documentalist, Knutsford, Cheshire, England

"*The articles are generally well written and accessible to a wide public.*"

H.S., biologist, Snęek, Netherlands

"*I personally prefer information about general principles in general terms, that is not a surfeit of complex mathematical formulae.*"

E.A., teacher, South Shields, England

"*I do not consider this magazine as a source of detailed documentation on specific subjects. It opens up horizons for me, it indicates the possibilities offered by nuclear energy and the directions in which it is developing.*"

S.S., Faculty of Medicine, Brussels, Belgium

The following reader is quite categorical:

"*Do not make a specialised journal out of* Euratom Review . . ."

P.J.F.v.d.H., Chemist, Deurle, Belgium

A third group of readers has consciously or unconsciously tried to arbitrate between the first two. This is what they write:

"*I find the articles in* Euratom Review *very readable, clear and interesting. Some articles would be more informative if they were more technical or more theoretical. The question is: would they remain as readable as they are?*"

M.J.C., science student, Eindhoven, Netherlands

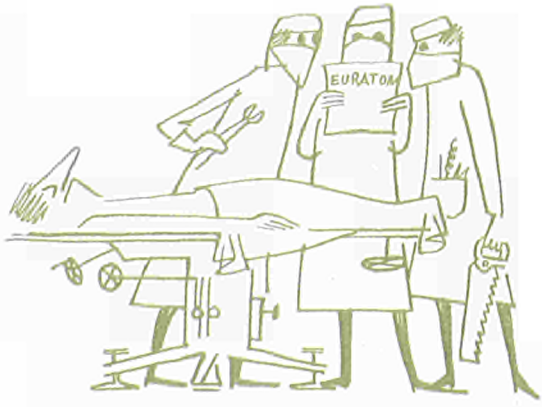
"*I have given to question 5 the answer: 'lacking in detail but nevertheless interesting'. I could not have answered 'sufficiently detailed' as I would then perhaps have had to say 'too difficult' in reply to question 6.*"

B.W.S., chemistry student, Amsterdam, Netherlands

"Euratom Review *is very suitable for giving an insight into unfamiliar subjects or topics, but in view of the superficiality or popular nature of most of the articles, little fresh information is conveyed when they happen to deal with one's own special field . . . but this is a fundamental problem relating to the character and the purpose of* Euratom Review."

Several engineers and physicists, Technische Hochschule, Aachen, Germany

It is indeed a fundamental problem and one which has always worried us, because our aim has been to give authoritative but at the same time readily "digestible" in-



formation on a wide variety of topics. There are no doubt a large number of specialists among our readers, but it is not humanly possible that they should be thoroughly conversant with all of these topics. What we have therefore tried to do is to interest them in subjects which we have reason to believe are important but in relation to which they are in most cases comparative laymen. One of our readers expresses his agreement with us on this point very explicitly:

"*Trying to comply with the wishes of all readers is, as every editor knows only too well, like trying to square the circle. Readers must be "good" and learn to accept articles which lie outside their own field.* Euratom Review *is appreciated by my customers in its present form because the articles are not too highly technical and enable them to get acquainted with interesting problems.*"

R.J., chemical engineer, 75 Paris 8, France

Having thus set ourselves up as information "salesmen", we felt that by publishing detailed and therefore lengthy articles we would merely bore most of our readers and thereby fail to reach our objective. As another reader says:

"*The relative brevity of the articles—I would gather an imposed editorial policy—helps, at least in my case, in maintaining interest in the article to its end.*"

J.G.P., Washington, D.C., U.S.A.

This apology, however, does not remove our dilemma. Should we leave *Euratom Review* at its present level, thereby leaving some readers dissatisfied, or should we try and publish more detailed, more theoretical and therefore longer articles, with the result that another group of readers might get bored and that fewer topics could be dealt with (much against the wish of at least one person, who writes: "*It seems to me that* Euratom Review *does not contain enough articles*"—L.S., programmer, Italy)?

Here again, our readers have been most helpful:

"*On the whole the articles are particularly good. In my opinion they are too sketchy from the mathematical point of view, i.e. the whole publication could become more interesting if symbols were explained separately and if the development of formulae or calculations could be dealt with more fully.*"

J.A.T., engineer, Nuland, Netherlands

"*I find* Euratom Review *very readable. I should like a little more detail in some cases and feel that this would be answered by the inclusion of a short list of references where possible.*"

J.F.H., physicist, Paisley, Scotland

"*It would be desirable if brochures could be produced giving fuller information than can be given in the review itself on the subjects which are most popular with its readers. In this way the review would not be overloaded with detail.*"

R.P., draughtsman, 94 Maisons-Alfort, France

"*It would be useful if access were given to more detailed and technical information either through a bibliography or, even better, a more detailed report of, say, 100 pages or so.*"

G.L., 38 Grenoble, France

We must confess that the production of detailed brochures is beyond the resources of the *Euratom Review* staff. However, in the case of most of the topics presented in the review, there exists an adequate specialised literature to which a bibliography could give access.

In all, some 15 readers have urged the inclusion of bibliographies and it will be noted that the suggestion has already been put into effect. This does not completely resolve our dilemma, but certainly makes it easier for us to live with it.

Another possibility, which we will consider, is to produce "two-stream" articles, in which the mathematical support for a particular statement, say, would be presented separately, alongside the main stream of the contribution. However, this system is probably worth considering only in the case of physics and certain engineering subjects.

We are unable, for lack of space, to mention all the individual wishes, suggestions, comments, etc. which we received. Let it however be made clear that this does not entail that we will ignore them. Several readers would like the "Euratom News" section, for instance, to be developed (among them A.D., 91 Gif-sur-Yvette, France, W.W., Ispra, Italy, J.G.P., Washington, D.C., U.S.A.), others would appreciate articles on the means of achieving co-ordination and co-operation between public bodies, industry and the scientific community (R.F.G., Toronto, Canada, J.H., Baudour, Belgium), etc.

We will also refrain from quoting at length the letters in which readers expressed their general satisfaction with *Euratom Review*. Needless to say, their words have gone right to our heart and encouraged us in our endeavour to improve this publication.

(EREA-A 7-12)

Using electrons to accelerate and confine ions

TERENZIO CONSOLI,
*CEA (French Atomic Energy Commission)**

BEAMS PRODUCED by conventional accelerators consist of charged particles of one and the same type, i.e., either electrons or ions. The acceleration is due to the action on the particles of an externally applied electric field. However, the beam intensity (the number of particles per second and per square cm) is still limited by space charge effects, in other words, by the mutual repulsion of particles of the same sign.

If, on the other hand, we take an electrically neutral plasma, containing an equal number of electrons and ions, it is possible to accelerate one of the two populations and thus drag with it the second, as long as it remains closely bound to the first by the space charge; one of the advantages of this solution is that there is no longer any repulsion between particles and consequently no longer any obstacle to a stepping-up of the beam intensity.

The possibilities thus inherently offered by the plasma as regards the acceleration of one or both of its constituents have not been lost on accelerator physicists, and more particularly the Soviet scientist V. L. Veksler.

It should be pointed out that where accelerator physicists are concerned, it is out of the question to increase the beam intensity (we say deliberately "intensity" and not "energy") *ad infinitum*, because it would destroy the targets. From the standpoint of controlled nuclear fusion physicists, whose aim remains the production of energy by the fusion of light nuclei (D + D or D + T), the beam, when used as a means of filling a magnetic bottle, must on the contrary have the highest possible intensity. It must have an intensity in the range of a million to a thousand million times that of accelerator beams, since the number of reactions triggered off is directly governed by this intensity.

The advantage of intense beams and the feasibility of dragging or reflecting ions by means of the electrostatic field set up by the electrons were also considered at Saclay as far back as 1958, under the plasma study programme, and have formed the starting-point for several research projects.

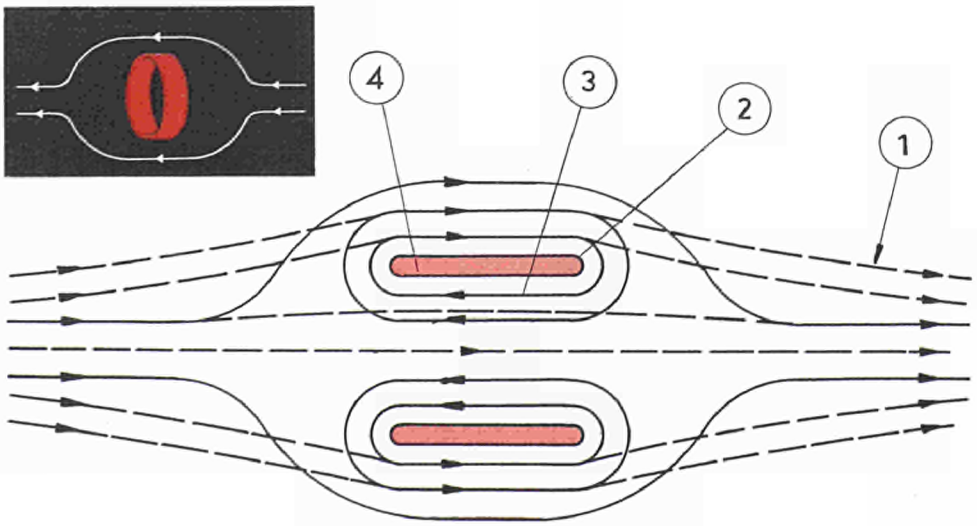
* General Ionics Division, Plasma Physics and Controlled Nuclear Fusion Department

Basic mechanism

To make it easier to understand the guiding concepts in our activities, it is necessary to recapitulate certain points concerning the basic mechanisms.

In a uniform magnetic field, an electron having a velocity v_o rotates with an angular frequency $\omega_{ce} = \frac{eB}{m}$, proportional to the magnetic field, in a circle (called a Larmor circle) with a radius $r_e = \frac{v_o}{\omega_{ce}}$, the centre of which is located on the magnetic line of force. Any electric field oscillating with an angular frequency ω_{HF} equal to ω_{ce} (cyclotron resonance phenomenon) can, if it is in phase, increase the speed of rotation of the electron up to very high energies; the electron then readily becomes

Fig. 1: Diagram showing astron *principle.*
1 Initial static magnetic field before modification by the "self field" of the relativistic ring. 2 E layer of relativistic electrons. 3 Modified static magnetic field. 4 Confined plasma volume. A layer of relativistic electrons (E layer) injected into a static magnetic field bounded by two magnetic mirrors changes, by its own field, the initial configuration by generating in the central part a closed field line confinement zone in which the hot plasma formed by interaction of the beam with the residual gas is to remain trapped.



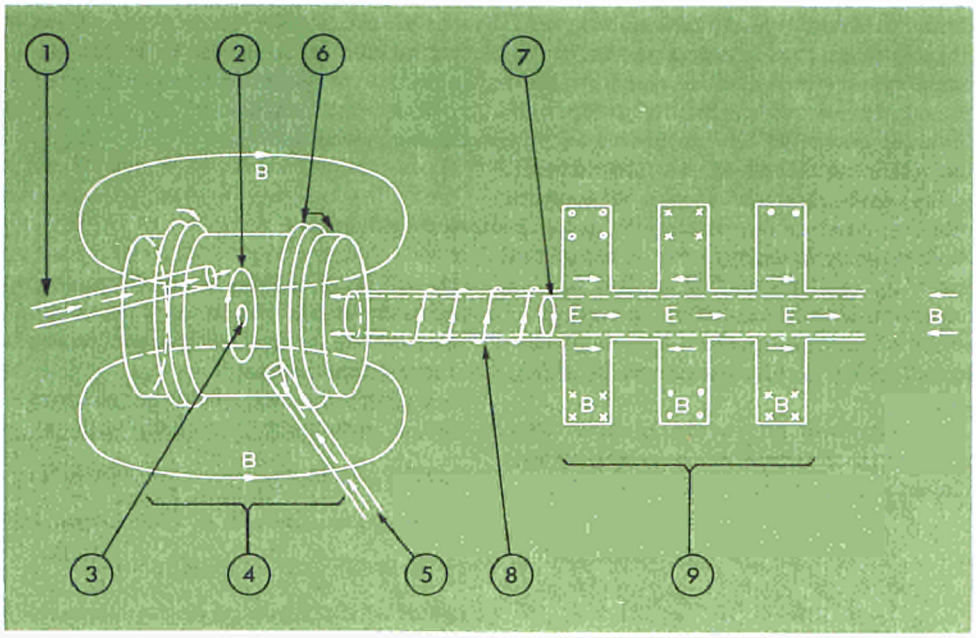


Fig. 2: Diagram showing smokatron *principle.*
1 Electron injector. 2 Ring of injected electrons – initial phase. 3 Ring of electrons after compression. 4 Compression magnetic field. 5 Hydrogen injection. 6 Compression coils. 7 Axially accelerated electron ring. 8 Solenoid for ring acceleration. 9 High-frequency ring-acceleration device ("slip cavity").
A relativistic electron beam is injected perpendicularly to the lines of force of a static magnetic field.
An electron ring forms, the energy of which is increased by magnetic compression, and sets up an electrostatic potential capable of trapping the ions.
All axial energy fed to the ring is therefore also imparted to the ions, which may thus reach extremely high energies.

quasi-relativistic, i.e. it acquires an energy which is approximately one-tenth of the energy of an electron rotating at the speed of light (511 keV). It may even become relativistic if the HF power is sufficiently high.

It is thus seen to be possible to form electron rings of high energy, and even of high intensity if they are neutralised by the presence of ions.

In a magnetic field which decreases in space, a fraction of the transverse energy ($\frac{1}{2}$ $mv_{\perp}^2$) is converted into parallel energy ($\frac{1}{2}$ $mv_{//}^2$). The trajectory of a given electron is then a spiral the axis of which is the line of force.

A group of electrons having the same characteristics create a coherent negative potential in space, which may have a dragging effect on any ions present. In that case, whatever their mass, the ions are said to acquire energy by the non-collisional space-charge field process, the spatial distribution of which determines an electrostatic potential. (Some physicists with a fondness for imagery say that in such cases the electrons are to the ions what the carrot is to the donkey.)

According to the shape of the magnetic field the electrostatic potential can be modified at will so as to be either accelerative (in a particular direction), reflective (in the opposite direction) or of the capture type, in which case there is said to be a potential well, the movement of the ion in this well being comparable to the oscillation of a marble in a bowl).

Some experimental results

The purpose of this article is to show, by outlining some representative results obtained between 1962 and 1968, the state of our research and its connections, sometimes tenuous, with devices such as the *astron* and the *smokatron*.

These machines, one of which is very recent and still at the small prototype stage (the *smokatron*), are well known. Suffice it to say that one of them, the *astron*, was initially designed for hot-plasma confinement (Fig. 1) and the other for ion acceleration (Fig. 2). In both cases, the

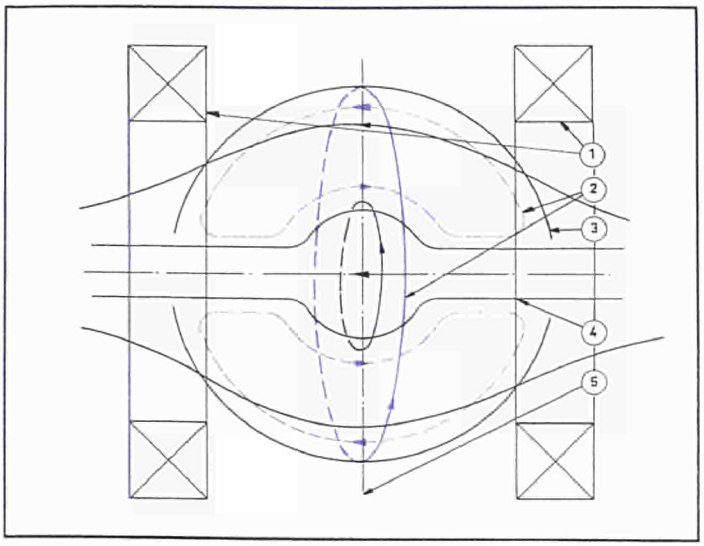


Fig. 3: Diagram showing principle of Icare I *experimental device for forming relativistic electron rings – Phase 0.*
1 Static magnetic field coils. 2 Fields (E, H) of mode TE_{101} excited in spherical cavity. 3 Spherical cavity. 4 Quartz ball with two necks. 5 Plane of symmetry of system in which resonance $\omega_{ce} = \omega_{HF}$ is set up (cyclotron angular frequencies of electrons equal to that of the high-frequency field applied) at start of phenomenon studied.

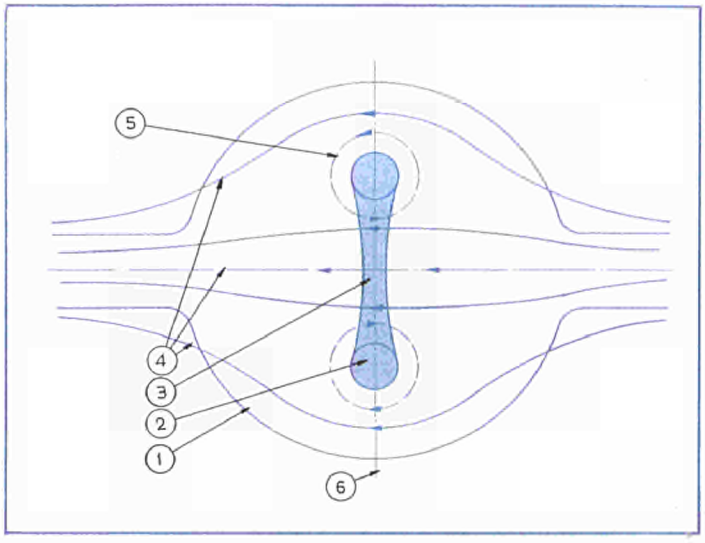


Fig. 4: Icare I – *Analysis of phase 1: Formation of relativistic electron ring.*
1 Quartz ball with two necks in which phenomenon is studied. 2 Dense plasma ring containing relativistic electrons. 3 Low-density plasma formed by secondary ionisation in electron ring plane. 4 Line of magnetic field (static field). 5 Line of inverse magnetic field set up by fast-electron current. 6 Plane of symmetry of system in which resonance $\omega_{HF} = \omega_{ce}$ initially took place.

Fig. 5: Icare I – *Analysis of phase 2: Doubling of ring or even displacement of resonance zone, as a result of relativistic and diamagnetic additive effects.*
1 Dense plasma rings. 2 Lower-density region. 3 Secondary plasma capture zone. 4 New regions in which resonance $\omega_{ce} = \omega_{HF}$ is maintained.

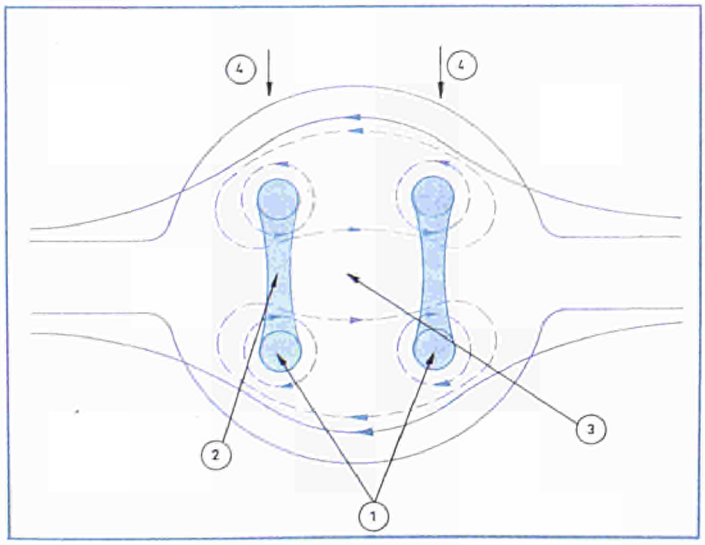
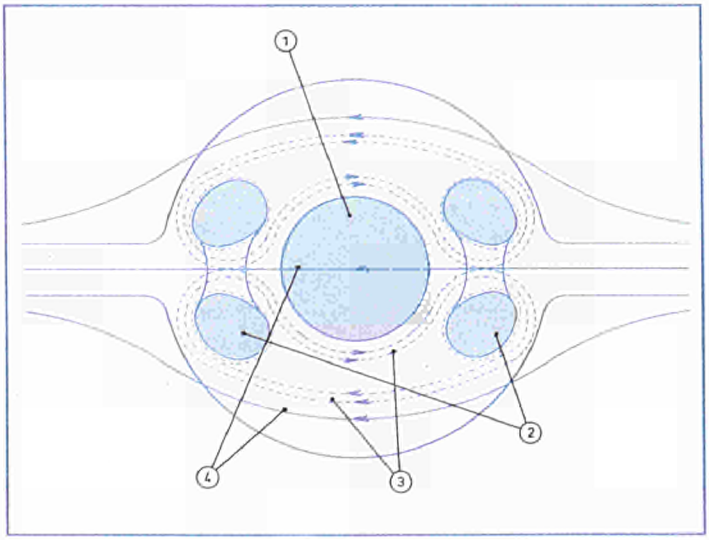


Fig. 6: Icare I – *Analysis of phases 3 and 4.*
(a) Phase 3: *Trapping of spherical secondary plasma between the rings of relativistic electrons the self-field of which, superimposed on the initial static magnetic field, forms a magnetic "mini-bottle" with a self-generated central minimum.*
1 Plasma sphere. 2 Relativistic-electron plasma rings. 3 Current-ring magnetic field. 4 Initial static magnetic field.
The magnetic "mini-bottle" with a "self-generated" three-dimensional minimum results from the superimposition of fields 3 and 4.
(b) Phase 4: *Same appearance as with phase 3. On the photograph in Fig. 7, however, a deterioration will be observed in the appearance of the spherical plasma and the rings, this being due to the disappearance of the HF field, the source for maintaining the fast electrons.*



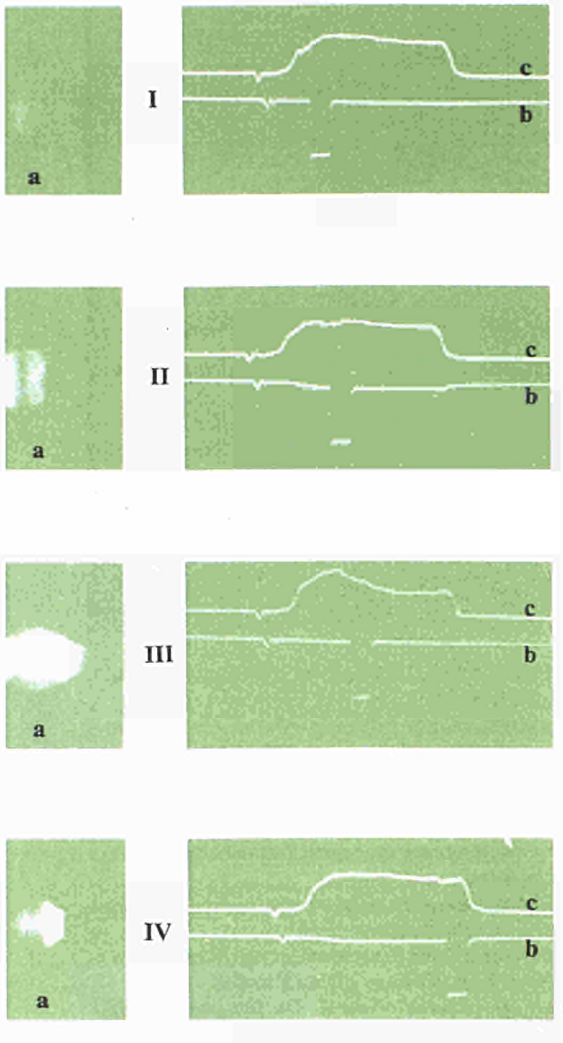


Fig. 7: Evolution of phenomenon observed in ball with ultra-high-speed electron camera.
Ia Photograph of plasma in ball at instant 1 (an electron ring).
Ib Trigger signal (opening and shutting) of ultra-high-speed electron camera.
Ic High-power HF impulse.
IIa, b, c same thing at time 2.
IIIa, b, c same thing at time 3.
IVa, b, c same thing at time 4.

aims are to be achieved by means of relativistic electrons.
At Saclay, we demonstrated with various experimental devices, such as *Icare I*, *Icare II*, *Pléiade* and *Circe*, that the mechanism for confining cold ions, and hence plasma, by high-perpendicular-energy electrons is feasible (there being an analogy here with the *astron*). We also succeeded in showing that the dragging of high-energy ions by quasi-relativistic electrons can be achieved.

Plasma confinement by relativistic electrons - Icare I

The confinement of a plasma by relativistic electrons was observed in 1962 with the aid of the experimental device *Icare I*, shown in Fig. 3.
This device consist of a spherical copper cavity 38 cm in diameter, containing a quartz ball 10 cm in diameter provided with necks, one as pumping outlet and the other as gas injection inlet or probe insertion. The whole is placed in a static magnetic field which is in the shape of a magnetic bottle and whose amplitude can be varied in such a way as to obtain, in the absence of any ionisation (in the plan of symmetry of the system), the resonance $\omega_{ce} = \omega_{HF}$ between the cyclotron angular frequencies of the electrons and that of the electromagnetic mode TE_{101}. This mode is excited in the cavity at 1,250 MHz by a 500 kW travelling-wave tube (50 pulses of 10 μsec). The mode electric field E and magnetic field H are those shown in Fig. 3, in the case of no ionisation (phase 0). As a result of the cyclotron resonance $\omega_{ce} = \omega_{HF}$, the gas ionises; the plasma electrons are raised to energies in the 100-500 keV range, depending on the pressure in the ball (10^{-4}—10^{-5} torr) and the HF power applied. At the start of the impulse (phase 1, Fig. 4) a ring of quasi-relativistic electrons is formed, the magnetic self-field of which causes a displacement of the resonance to the stronger magnetic-field regions (zones lateral to the plane of symmetry of the system), since the diamagnetic and relativistic effects combine and decrease the resultant magnetic field in the centre of symmetry of the system. Thus a minimum induction region, or even a three-dimensional magnetic well, is created. As a consequence, the resonance regions split in two (phase 2, Fig. 5).
The secondary plasma, formed by ionisation of the residual gas, remains trapped, assuming a spherical shape, in the magnetic "mini-bottle" generated by the quasi-relativistic electron rings (phase 3, Fig. 6).
The phenomenon lasts (phase 4) as long as the HF field impulse.
Fig. 7 shows the phenomenon illustrated in the preceding sketches as seen by an ultra-high-speed electron camera viewing the ball in the direction represented in Fig. 8.
It will be observed that the appearance of the phenomenon in times 1, 2, 3 and 4 of the HF impulse (Fig. 7) is in good agreement with the theorical explanation. In this figure, one of the tracks is the HF impulse (7b) and the other (7c) is the exposure time (opening and shutting of the electron camera).
Fig. 9 is a photograph of what is seen by an ordinary polaroid camera during an exposure time of one second, that is to say when fifty consecutive impulses take place. The phenomenon observed is therefore the result of the superposition of rings and spherical plasma which form and then disappear in succession. The impression of the average luminosity, i.e. that of the rings and the plasma sphere, nevertheless remains on the film; the diffused light seen on the photograph corresponds to the recombination of the plasma in the intervals between impulses.
This experiment would appear to offer factual evidence that ions can be confined by the initial static magnetic field transformed into a magnetic well by that of the fast electron rings.
Logical continuity leads to ion accelerators using the space charge formed by fast electrons having a high transverse velocity and a low axial velocity.

Plasma acceleration

Whereas the foregoing has been concerned with the obtaining of a magnetic well, making the ions captive, the present section concerns the opening of a breach, as it were, in the wall of the well in order to enable the ions to be expelled. For this purpose it is sufficient to eliminate one of

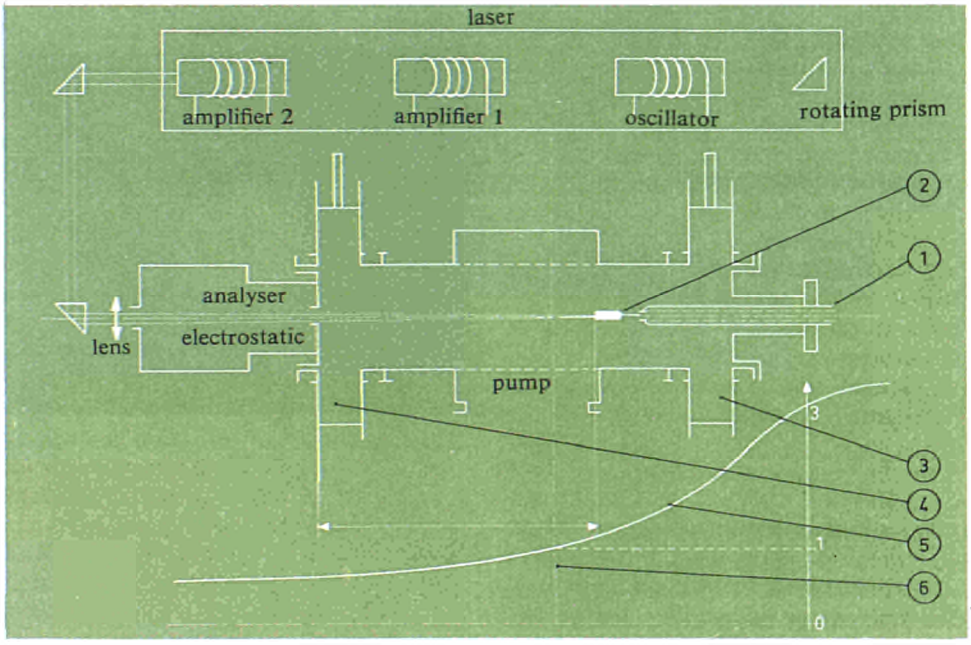
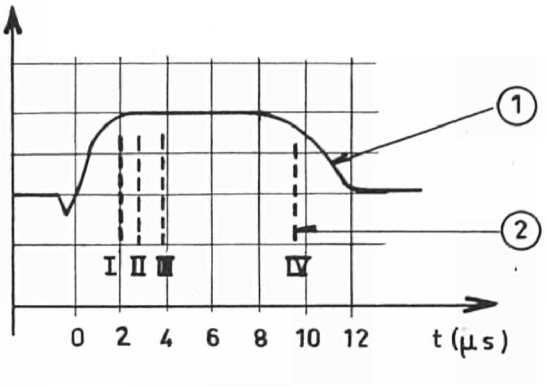


Fig. 10: Icare II *experimental device (1 MW at 1,250 MHz for 100 μsec.)*
1 Cryostat (outside diameter = 20 mm) for producing deuterium icicle (length = 2 mm, diameter = 0.5 mm).
2 Solidified deuterium target.
3 HF pick-up for attacking cylindrical cavity by means of guide coupled to broad-band klystron (1,250 MHz) for exciting standing TE_{111} or travelling TE_{11} mode.
4 Second HF pick-up for symmetrical excitation or for measurement of HF power transmitted.
5 Profile of static magnetic field B_z decreasing with z.
6 Resonance zone $\omega_{ce} = \omega_{HF}$.



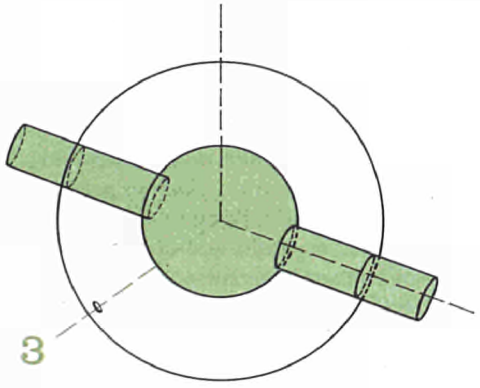


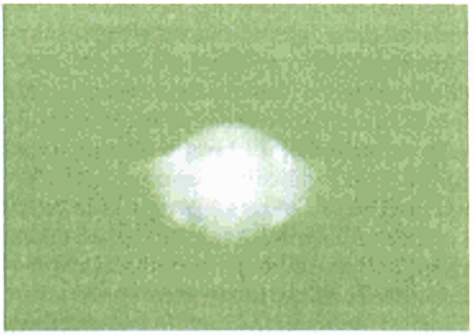
Fig. 8: Observation of phenomenon with ultra-high-speed electron camera.
1 High-power HF impulse (P_{HF} 500kW).
2 I, II, III, IV (ultra-high-speed electron camera exposure times—image converter). Camera exposure time for each image is 1 μsec.
3 Direction of shooting.

the two magnetic mirrors and thus obtain a decreasing-field configuration.
Two cases have to be considered.

Case one.—The accelerative structures contain neutral gas ($p \simeq 10^{-4}$—10^{-5} torr). It ionises in the crossed HF and static magnetic fields as a result of the resonance. The ionised gas interacts with the HF field in the resonance zone; the HF field energy is transferred to the electrons in the form of perpendicular energy which is gradually converted into parallel energy as a result of the static magnetic and HF gradients. When certain conditions depending on the initial values (velocity, density) are fulfilled, the space charge existing between the electrons and the ions ensures that they are dragged with exactly the same axial velocities, i.e. with parallel energies in the mass ratio.
The accelerated plasma behaves like a fluid the transverse mass of which is that of the electrons (it may be relativistic) and the axial mass is that of the ions.
In the case described, the HF field fulfils two functions: it ionises the neutral gas and it accelerates the plasma formed. This type of operation does not lend itself readily to verifications of theoretical estimates, the physical parameters being interdependent.

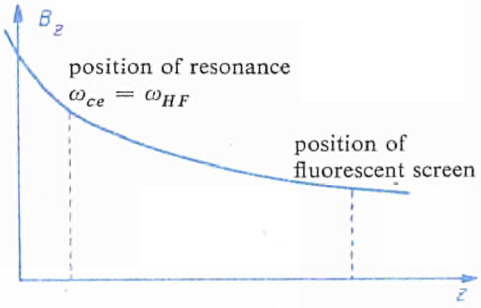
Case two.—The ionisation and acceleration processes are kept apart, e.g. by building up the plasma with a *Circe*-type accelerator, which acts as an injector for a second device. *Pléiade* (two accelerators

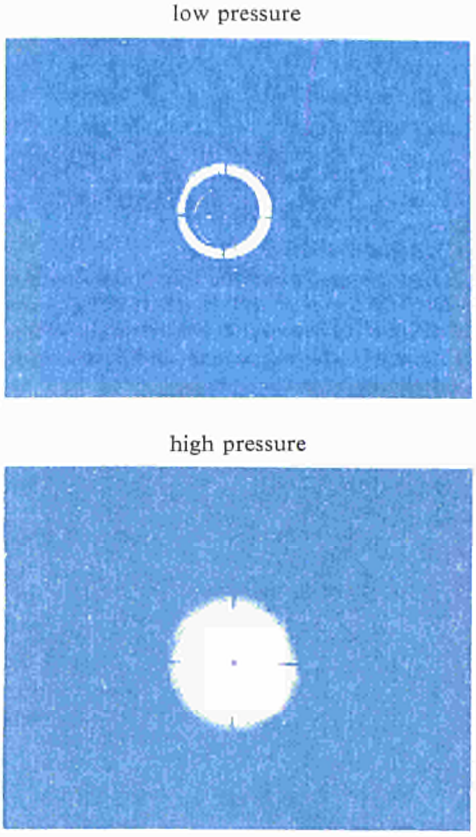
Fig. 9: Observation of phenomenon with low-speed camera.



in series). In this case, the structures are separated by a non-ionised atom extraction chamber in order to prevent any subsequent parasitic ionisation.
The plasma can also be built up "in situ" in the cavity (this being the case with the *Icare II* device) by laser-beam ionisation of a supported target (Fig. 10).
This method of preionisation or injection offers the advantage of working with a very weak residual neutral gas background and consequently limiting the loss of accelerated ions through charge exchange. It is more readily adaptable to high-power pulsed accelerators.
In *Icare II*, the cylindrical cavity (16 cm in diameter and 70 cm long) can operate in standing or travelling-wave conditions at 1,250 MHz. It is coupled to a broad-band klystron which can deliver a power (P_{HF} = 2 MW) for 100 μsec.
By means of a cryostat, a deuterium icicle can be formed at the end of a needle placed in the axis of symmetry of the system. Preionisation is effected by means of a pulsed laser focussed on the solid deuterium target. The plasma thus built up has an initial average energy of not more than 100 eV (for one joule in the laser beam).
When the HF field is applied, the same mechanism as that described previously accelerates the ions by means of the electrons. Fluxes of 10^{17} deuterons/cm². sec of more than 20 keV have been obtained.
In order to visualise the accelerating layer and to show both the importance of the initial conditions as regards ion drag and the existence of a cylindrical layer of high-perpendicular-energy electrons, a qualitative demonstration experiment has been set up. Pulsed injection of laser-formed plasma has been replaced by continuous injection of neutral gas. At low pressure, a luminous ring is then observed on a fluorescent screen set in the path of the accelerated jet, in the same region as the electrostatic analyser (Fig. 11). The initial density then being insufficient, the electrons are decoupled from the ions. A cylindrical layer of electrons with a perpendicular energy of approximately 50 keV is formed, the impact of which, following a genuinely annular pattern, corresponds to the beam cross-section through the fluorescent screen.
At higher pressure, the ion drag is effective and the impact of the accelerated beam (Fig. 11) is a luminous spot without a central shadow. An electrostatic analyser, set on the axis of the system, detects the ions around it.
The results obtained with *Icare II* (high-pulsed power) which, moreover, are in agreement with those obtained at lower continuous HF power, confirm the theoretical predictions.

Fig. 11: Visual display of acceleration phenomenon at high and low pressure. Note the track of the beam impact on a fluorescent screen.





Conclusion

All the experiments described from a qualitative standpoint in this article show clearly that ion confinement or drag by the space charge of rings or of electron sheaths having a high perpendicular energy is a phenomenon the physical reality of which has been thouroughly established. The *astron* and the *smokatron* are in our view "relativistic extensions" of the structures studied at Saclay. (EREA-A 7-13)

Technological co-operation—note from Commission to Council

Technological co-operation is a major focus of interest in the present European context. Everybody wants it, but some difficult problems are involved.

It was for this reason that on 15 May 1968 the Commission of the European Communities submitted to the Council of Ministers, at the latter's request, a note designed to assist discussion of the problems in question.

In this note, the Commission recalls that "on 31 October 1967 the Council was unanimous in considering that Europe's leeway in the technological field constitutes a serious danger to its medium- and long-term economic and social development and in expressing the intention to take vigorous measures to remedy the situation and to promote activity in this field".

At the same time, the Commission is compelled to record that "six months have elapsed since the adoption of the Luxembourg resolution, and that the work prescribed in this resolution has been interrupted, whereas impending options of importance to Europe's technological future necessitate a common approach and closer methods of co-operation".

The Commission's note accordingly endeavours to set out, on the one hand, "the state of the activities undertaken by the Community and the main options to be selected in the months ahead" and, on the other hand, "the basic conditions to be fulfilled in order to ensure the efficiency of the methods of co-operation to be pursued or initiated".

Present Community research activities

The note starts with a round-up of current Community activities, relating to coal and steel, the nuclear field, agricultural research and the subjects referred to in the Luxembourg resolution of 31 October 1967 (see *Euratom Review*, Vol. VII (1968) No. 1, p.30).

We are not concerned here to give the details of this survey, but rather to record its main conclusions. The experience acquired by the *ESCS*, the *EEC* and above all by Euratom "yields information which is also valuable as regards the setting-up of collaboration in other scientific and technical fields, in particular the organisation of research centres, the implementation of research and development programmes by means of contracts, the dissemination of information and co-operation with non-Community countries".

The resolution of 31 October 1967 embraced several operations, perhaps the most important of which is examination of the possibilities for co-operation in seven fields (automatic information processing, telecommunications, transport, oceanography, metallurgy, nuisances and meteorology).

Work has started on the study of these seven fields, but has been suspended on account of certain differences of viewpoint between the Member States. However, on the basis of the results already achieved, "and without there being any question of anticipating whatever conclusions may be reached by the working group responsible for analysing them, it appears to the Commission that it would be desirable to accord priority to the detailed technical and economic studies on the advantages to be derived from co-operation in certain fields to which especial importance attaches. These fields are automatic information processing, telecommunications and meteorology".

Decisions to be taken in 1968

The Commission's note goes on to enumerate the decisions to be taken under various heads in 1968. The most important of them concern the European space programme, the nuclear programme, the European airbus and data processing and telecommunications.

The decisions on the *European space programme* have in the meantime been reached, during a conference held in July, and are marked by a tendency towards Europe's withdrawal from this leading sector.

The possible courses of action in the *nuclear field* had already been outlined in a report submitted by the Commission to the Council in March 1968 on Euratom's future activities (see *Euratom Review*, Vol. VII (1968) No. 2, p.62). In this connection, the Commission draws attention to the fact that Euratom is at present having to manage on an interim programme and that the absence of any decision on a new pluri-annual programme threatens to deprive the Community of the benefits of the co-operation set up over the past ten years.

With regard to the *European airbus*, the Commission is of the opinion that the major question to be settled, of far more importance than the technical production problems involved, is the amount of potential orders; the governments of the six Community countries will have to examine whether they can undertake to purchase a sufficient number of machines to be able to give the go-ahead for the construction of prototypes.

Action in the field of *automatic data processing and telecommunications* is, according to the Commission, becoming increasingly urgent.

"While in the case of the foregoing subjects reports resulting from several months of study are available, matters are not yet so far advanced in the sphere of automatic data processing. As regards the fundamental questions, must we venture at the outset into the realm of the most powerful computers, which may still be very much in a state of flux? If so, how is the construction of such computers to be organised?. . ."

Apart from these four major fields requiring large-scale financing from public funds, there are a number of other subjects on which decisions are required. The Commission makes particular reference to the

construction of the *CERN* 300 GeV accelerator, the organisation of dissemination of information on an international basis, the *EMBO* molecular biology laboratory and oceanography.

Conditions for efficient technological co-operation

Here, in conclusion, are some extracts from the passage, a highly important one, devoted by the Commission to the conditions required for efficient technological co-operation:

"The efforts of the six Community countries in the field of research and technology have been stepped up considerably in recent years; in particular, *co-operation projects*, whether in a bilateral, a multilateral or a Community framework, have increased in number. In most cases, however, there has been disappointingly little to show for them at the industrial level; the manpower and the money diverted to this purpose have been far from yielding the expected results. The main drawbacks to efficiency have been excessive dispersion of efforts, the precarious nature of the commitments involved, the inadequacy of outlets and the insufficient participation of industry in the various projects.

Dispersion of efforts is the most virulent of these factors. Overlappings of Member State programmes have persisted unchecked and very frequently the Community's international programme has been regarded not as supplementary to but competitive with some of the national programmes. Furthermore, co-operation programmes have been organised within an assortment of groupings, the number of participants varying according to the fields concerned. As a natural consequence, the participants have endeavoured to obtain, within the framework of each project, as strict a balance as possible between what they have contributed to the project, particularly in cash, and the benefits they hope to derive from it. In some cases, the accent has been laid not on the long-term aim of the operation but on the straight return, in the form of research and development contracts, of the bulk of their financial contribution. Euratom itself has not been immune from this tendency. Thus it has too often happened that the allocation of research and development tasks has not conformed with rational scientific and economic criteria.

The seriousness of the second factor at work, namely the *precarious nature of the commitments* undertaken, scarcely needs emphasising. Every isolated project is dependent from year to year on the "political will" and the available financial resources of each of the participants. If either the will or the money is wanting, this is sufficient to jeopardise the entire project. At best the scheduled programmes undergo modifications or delays which prejudice, in many cases irremediably, their ultimate success.

If the co-operation projects which have been conducted for several years do not seem satisfactory to-day, this is also because they are in many cases *confined to actual research* and have not covered a follow-through up to the industrial stage. Too many discoveries and inventions arrived at under a co-operation programme have remained unutilised, while governments and industries gave their preference to processes developed outside the Community.

Again, we have all too frequently seen that *industrial enterprises have only been partially associated* in the implementation of major projects. Having had no say from the outset in the overall planning and seeing no outlets in prospect, they have not felt interested in the successful execution of the project as a whole.

The scant results from scientific and technological operations associating several countries must not, of course, blind us to the existence of a number of positive results. But vigorous action to redress the situation is called for, especially as such international technical co-operation remains absolutely essential. It is essential because in some cases the creation of teams or the provision of the necessary facilities for such teams requires an effort which is difficult or impossible for a single country to undertake. It is perhaps still more essential to the extent that production cannot be made profitable without sufficient outlets, which it is frequently beyond the capacity of a single domestic market to furnish.

The twofold necessity of international technological co-operation and a considerable strengthening of its effectiveness makes it imperative and urgent to *revolutionise the methods employed hitherto*. On this point some fundamental guidelines may be set out.

It is clear at the outset that absolute priority must be given to *co-ordination of efforts*. But it is equally certain that it would not be rational to pursue this aim by the creation of a new organisation such as a European technological community, since such a measure would set up a most regrettable barrier between research and technological activities on the one hand and the market on the other, whereas the existence of the economic community is the best asset as regards increasing the efficiency of international co-operation, through the fact that it enables a comprehensive solution to be found for the problems involved in tariff policy, industrial policy and general economic policy.

Completion of economic rationalisation is clearly a fundamental first step, particularly as regards the creation of a large-scale market and an adequate legal framework.

But in the case of the products of advanced technology, orders from the public sector frequently account for a considerable proportion of the available outlets, especially during the first few years of production. *Co-ordination of official orders* placed by various States participating in projects carried out on a joint or co-operative basis is therefore a factor of capital importance in bringing such operations to industrial maturity. Needless to

say, a proper balance must be maintained between the principle of Community preference and that of international specialisation.
As regards the *legal framework*, the Luxembourg resolution called in particular for active pursuit of work on the 'European company' and the 'European patent'. As it is, absolutely no progress has been made over the past six months. This is all the more regrettable as the time required to implement the decision, when it comes, will be considerable.
A confrontation of the national programmes and an examination, within a comprehensive framework, of the various co-operation projects will enable an *order of priorities* to be drawn up which will accord with the long-term aims for the development of the European economy.
In order to set up *joint financing machinery* of a stable character, i.e. not exposed to the vicissitudes of annual budgetary decisions, it is necessary at the very least to draw up a *pluri-annual programme*, covering all technological research and development activities forming the subject of co-operation between the countries concerned. The requisite resources should be made available within a pluri-annual budget. Such a procedure must not, of course, rule out the possibility of making programmes flexible wherever this may seem necessary, but any decision along these lines should be taken as a result of a periodical examination of all the programmes. Under the overall pluri-annual budget, it would be far easier to strike an appropriate balance between the contributions and returns for each participant and at the same time secure a rational distribution of the activities involved.

Finally, *systematic and organised association of enterprises* in the projects decided upon by governments, at all stages in the operation, is another fundamental condition of efficiency, as without such a measure research results will certainly not be exploited promptly in the form of industrial production".

Dodewaard reactor goes critical

The Dodewaard (Netherlands) nuclear plant operated by the *Gemeenschappelijke Kernenergiecentrale Nederland (GKN)* went critical for the first time on 24 June 1968.
This 50 MWe plant, which is included in Euratom's participation programme, is equipped with a boiling-water reactor. It is also the first nuclear power station to be built in the Netherlands.

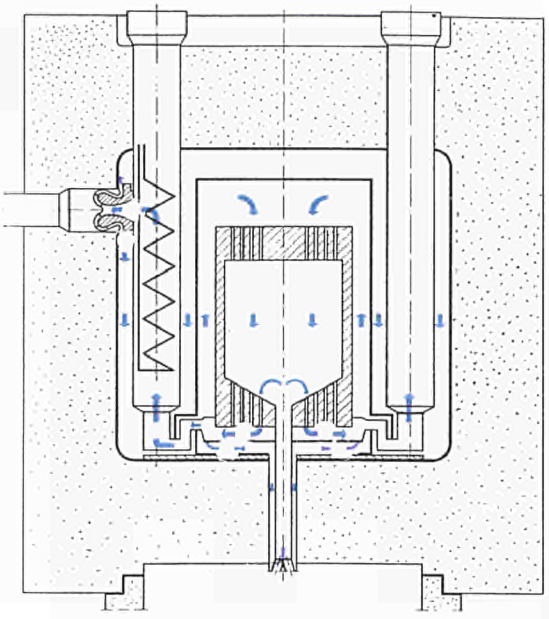
Rapsodie proving satisfactory

The fast neutron reactor *Rapsodie* came to the end of a fourth fuel irradiation campaign in the course of July 1968. The burn-up at the centre of the reactor reached about 32,500 MWd/ton.
It is worth recalling that *Rapsodie*, which was built at Cadarache (France) under the *CEA*/Euratom Association, went critical on 28 January 1967 and began its first power run-up on 17 March of the same year. This was followed on 30 August 1967 by the commencement of the first fuel irradiation cycle.

The reactor's fuel utilisation was excellent. By way of an example, it was 97% during the first cycle. The reactor's normal power was fixed at 24 MWth, after a satisfactory test at 25 MW, whereas the rated power is 20 MW.

It has been shown that interventions on sodium-cooled reactors are easier than was imagined and the few minor incidents which were encountered during normal operation of the reactor only disturbed its operation for a very short time.
In addition, work is being carried out on simplification of handling; in particular, a simplified loading/unloading device has been commissioned. To sum up, the operation of *Rapsodie* represents a success for the fast-neutron reactor type.

NEWS FROM THE EUROPEAN COMMUNITIES



Vertical cross-section of the 300 MWe prototype pebble-bed reactor, showing in particular the path taken by the cooling gas and one of the six blowers. (It will be observed that the gas flows through the core from top to bottom).

The THTR Association reports

On 3 and 4 July 1968, at Jülich, Germany, the *THTR (Thorium-Hochtemperatur-Reaktor) Association* (see *Euratom Bulletin*, Vol. IV (1965) N° 2, pp. 44-48), which comprises Euratom, *Brown Boveri/Krupp (BBK)* and *Kernforschungsanlage Jülich GmbH*, gave an account of its work to date before an audience of nearly 400.

The principal results of the *THTR* project were summarised by Prof. Schulten as follows:

– the successful commissioning of the *AVR* reactor (see *Euratom Review*, Vol. VII (1968) N° 1, p. 32) has proved the feasibility of the high-temperature pebble-bed reactor concept;

– the spherical fuel element has been fully developed and tested and can now be put into large-scale production;

– plans have been completed for the construction of a 300 MWe prototype power plant;

– realistic economic evaluations concerning various types of power plant indicate that high-temperature reactors will account for a large share of the German market during the next thirty years.

As regards the 300 MWe prototype, it is considered that, on the assumption that a favourable decision on its construction will be taken towards the end of 1968, work could already be started in the spring of 1969; in that case full-power operation could commence at the end of 1974.

In this connection, mention must be made of the setting up of a new company, *Hochtemperatur-Kernkraftwerk GmbH (HKG)*, in which a number of German electricity producers are associated and which is a potential customer for the 300 MWe reactor.

Fourth ECSC congress in Luxembourg

Steel in the chemical industries and in particular the behaviour of steel under extreme chemical and physical conditions —these were the themes of the fourth ECSC congress which was held in Luxembourg from 9 to 11 July 1968 under the sponsorship of the Commission of the European Communities and brought together 400 participants from some 20 countries.

Like its predecessors, which were devoted to steel in the building industry (1964), steel processing (1965), steel in agriculture (1966), this fourth congress brought together steel producers, users and research workers for an exchange of information and views.

The congress did not aim at the promotion of steel, being concerned more specifically with scientific and technical aspects.

This being so, the subjects submitted to the participants for examination were not chosen with a view to restating already well-publicised facts, but rather with a desire to review the most recent results achieved in metallurgical research and also the major unsolved problems affecting the expansion possibilities open to steel products in a highly competitive market.

The congress proceedings were grouped under four main heads:

– effects of high multiaxial stresses;
– effects of high and low temperatures;
– effects of chemical attack—theoretical studies;
– effects of chemical attack—practical studies.

Formation of Inter Nuclear S.A.

The *Inter Nuclear S.A.* Company was officially formed in Brussels on 1 August 1968. Its shareholders are *BelgoNucléaire* (Belgium), *Gutehoffnungshütte* (Germany), *SNAM Progetti* (Italy) and *The Nuclear Power Group* (United Kingdom).

Its chief object is the construction and marketing of high-temperature gas reactors (see also *Euratom Review*, Vol. VII (1968) No. 2, p. 43).

First-ever curium 242 isotope battery in Europe

On 5 July 1968, an isotope battery, the energy for which is derived from the radioactive α-decay of the isotope curium 242 (specific activity 3,320 Ci/g), went into operation at the European Transuranium Institute.

This isotope battery is the first of its kind in Europe. In the United States, two curium batteries have so far been commissioned as part of the space programme. Their salient feature is a favourable power-weight ratio.

The isotope battery does not owe its origin to any special and costly research programme; it came into being because a series of experiments under the Institute's transplutonium programme had to be broken off. In March 1967 the Institute had started on the irradiation of 13 g of americium in the *BR 2* reactor at Mol, Belgium, with the aim of producing about 100 mg of curium 244 and traces of californium. Curium 244 is a relatively stable isotope (half-life 18 years) and therefore suitable for various types of scientific research. Through causes which have not yet been clarified, however, the can of one of the capsules inserted in the reactor for irradiation developed a leak, and irradiation had to be suspended, this at a time when the curium 242 concentration was relatively high but the curium 244 concentration still very low.

In early 1968, the irradiated capsules were returned to the Institute, for examination of the can damage. For various reasons, however, the obvious course—separation and transfer of the curium which had been generated to another capsule, and resumption of the irradiation process—could not be adopted.

The enforced interruption of irradiation operations offered a good opportunity to conduct a searching enquiry into all problems arising in connection with the handling of fairly large quantities of highly α-active and neutron-emitting material and to gain valuable know-how. Such experience is valuable not only from the standpoint of producing transuranic elements with higher atomic numbers but also from that of research into the physical and chemical properties of many of these elements, i.e. work occupying a leading place in the Institute's programme.

As in the present case there could be no question of re-irradiation, the obvious course was to conduct the operations involved in recovering the curium 242 and fitting it into a capsule in such a way that the end-product would be a small heat source which, together with a suitable thermocouple rig, would form an isotope battery. The additional expenditure entailed was comparatively small, especially as *AEG* undertook to construct the centre section of the battery with the thermocouples.

The most important result of the work, the acquisition of know-how, was thus enhanced by the construction of an isotope battery.

All operations such as purification of the irradiated material, design, construction and filling of the heating capsule, design and construction of the other battery parts, and all preliminary experiments and preparations were completed inside six months, one of the reasons being the urgency due to the short half-life of curium 242.

Under these conditions it was not possible to optimise various parameters, such as efficiency and weight. However, it can be stated that the facilities available at the Institute make it possible to handle curium 242 in quantities of the order of several grammes and that the technology of isotope battery construction is being mastered.

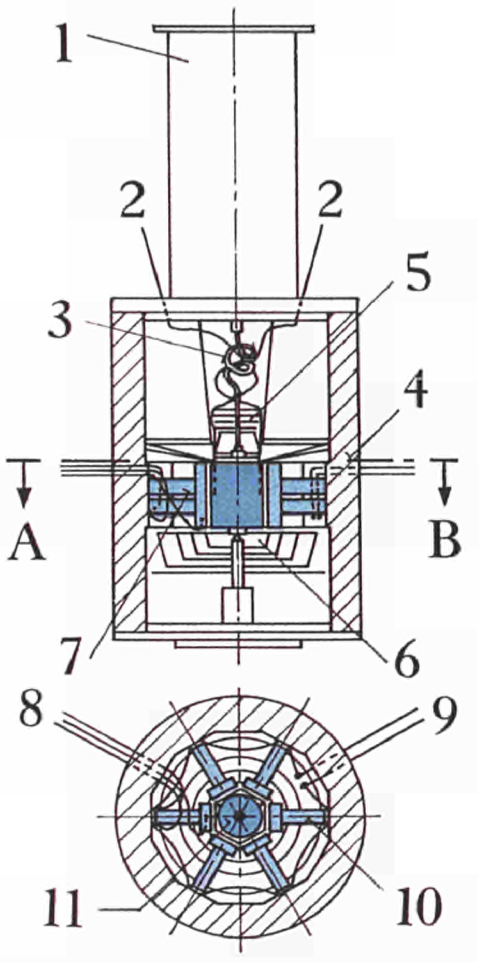


Diagram of curium 242 isotope battery. The curium is enclosed in oxide form in a small double-walled platinum capsule, which is heated by the decay heat. The capsule is under vacuum in a copper housing. This is equipped not only with shielding and thermal insulation material, but also with six silicon-germanium thermocouples, one leg of which is heated by the hot capsule and the other connected up to the housing and cooled. In this way, the heat generated by the α-decay is partially converted into useful electric current. The thermoelectric section of the isotope battery was supplied by AEG.

1 Gas compensation tank.
2 Measuring thermocouples.
3 Capillary tube for drawing off helium (α-decay generates helium atoms).
4 Housing.
5 and 6 Radiation shielding.
7 Mid-section packed with glass wadding.
8 Measuring thermocouples.
9 Current discharge.
10 Power thermocouples.
11 Curium container.