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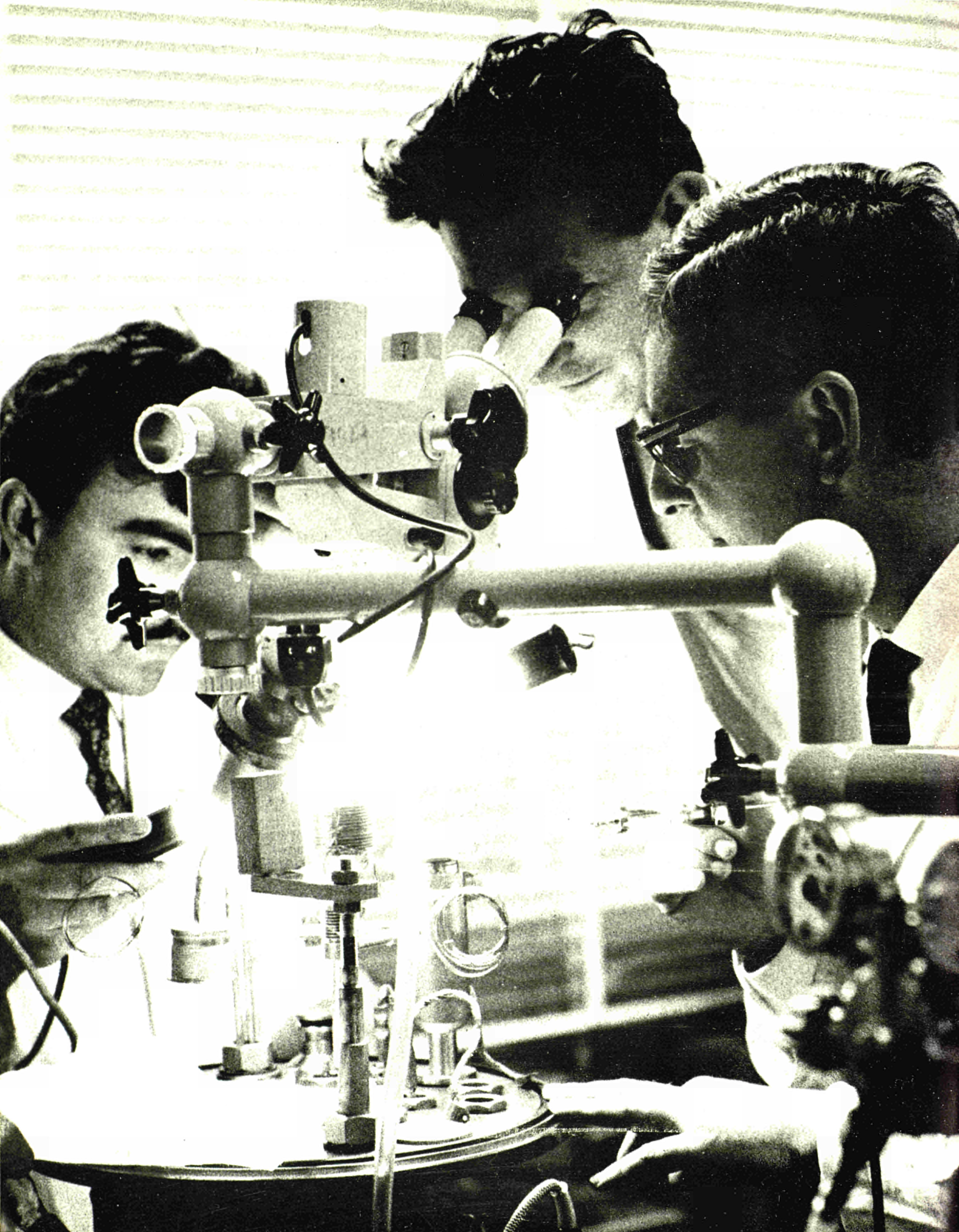

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Can nuclear techniques help the emerging countries, and, if so, how? Euratom Bulletin has been looking for replies to this question. Here, first of all, are the views of Euratom Commissioner Robert Margulies.

In 1963 the Scientific Committee of the OAMCE (Organisation africaine et malgache de coopération économique) *decided to set on foot investigations into the use of nuclear techniques in the nations of Africa and Madagascar associated with the European Community. The Committee further expressed the view that the projects in question should be of the shortterm type which could be completed within four to five years.*

The Treaty establishing the European Atomic Energy Community does not contain any article upon which activities arising out of these decisions could be based.

On the other hand, Article 20 of Regulation 7 issued by the European Economic Community Commission, which lays down the procedure governing the operation of the European Development Fund for Overseas Countries and Territories, states:

"The financing in whole or in part of scientific or technical research concerning the populations of the overseas countries and territories may be the subject of a project".

In a publication by the EEC Commission, entitled "The aims and operation of the European Development Fund", we find the following sentence: "As a general rule priority shall be given to measures calculated to have a direct and rapid effect on

the living conditions of the population".
In the meantime, the Euratom Commission had entrusted Minister Savary with the task of studying the possibility of applying nuclear know-how in the Associated African States and Madagascar. In the spring of 1965, Mr. Savary submitted a report on the subject.
On the basis of the data given in this report, Euratom embarked on preliminary work in connection with a programme the salient features of which I outlined on behalf of the Commission to the Joint Committee of the Association at its session in Berlin from 5 to 8 July 1965.
After Minister Rochereau, on behalf of the EEC Commission, had undertaken at the Berlin meeting to study the financing of such projects by the European Development Fund, four preliminary conditions were established for a programme, which for convenience I shall call the "Berlin Programme" and which consists of eight points. The prerequisites upon which agreement has been reached between Euratom and the EEC are as follows:

1. The work must have a direct bearing on the vital needs of the population of the Associated States of Africa and Madagascar;

2. The work must yield tangible results at an early date. Consequently, it cannot take the form of scientific research of indeterminate duration, but must consist in the application of already acquired scientific know-how which can be made to produce results within a period of about five years;

3. The work must have an infrastructure of plant and equipment already available in the areas concerned. Projects calling for the setting-up of new institutions would be incompatible with one of the foregoing conditions, namely that results must be achieved in about five years. Fortunately there are a number of suitable institutions already in existence to fill this need;

4. The projects must be assured of a favourable reception. Thus the activities in question must not be of the type that we in Euratom alone consider useful; we need the full backing of the governments of the Associated States and the local authorities. The governments' contribution will consist first and foremost in their submitting an application to the Development Fund. They must further be certain of having the cooperation of the local authorities, and in any event they must enact a number of additional measures designed to secure attainment of the objectives.

I should like to add some observations concerning these basic considerations:

1. The aim of the "Berlin Programme" is to find a way out of long-standing problems by new techniques.

2. These new techniques are the fruits of years of scientific research. They are not entirely new, but may be deemed proven to the extent that they have already yielded satisfactory results in other countries and have been established as being relatively harmless to man.

3. The work can only be undertaken in areas in which appropriate institutions already exist and the groundwork has already been done. The results, however, are of concern to all Associated States in Africa and Madagascar.

4. The projects are for the most part of a straightforward economic character, i.e. they produce in a foreseeable period results which can be assessed in economic terms. In this way, they open up the possibility of evolving similar projects for other African states, or other places in the same state.

5. During the implementation of the proposed project, the manpower required for other work could be trained locally.

Under the "Berlin Programme" the following eight points were to be studied:
- improvement of millet;
- extermination of the tsetse fly;
- acclimatisation of foreign breeding stock;
- conservation of fish;
- destruction of parasites in fresh meat;
- elimination of pellagra;
- combating the sandfly or onchocerciasis;
- conservation of bananas for transportation.

Since July 1965, these projects have been thoroughly examined, and investigations have shown that four of them have reached the stage at which a decision can be taken on them, while the others will require further study. These four points are:

Improvement of millet yield

In the arid zone of Africa, millet constitutes the staple diet of the population, accounting for 80% of the edible crops. In Senegal, Mali, the Ivory Coast, Upper Volta and Niger, there are altogether over 4 million hectares under millet. In 1963, the crop was estimated to have a value of 165 million dollars.
The yield, however, is unsatisfactory. In contrast with other cereals, millet is a plant which uses up its strength in producing leaves and stalks, yielding only 500 kg of seed per hectare. Efforts to secure a higher yield by traditional methods have had the opposite effect.
The work would be carried out by the Agricultural Research Institute in Bambey (Senegal) and the benefits of new techniques would be reaped in five years' time. The plan is first of all to complete the cultivation process, then carry out two successive seedings with the new seed, and finally to undertake large-scale experimental cultivation. Later on, a "seeding institute" should be set up. The overall outlay amounts to 500,000 dollars.

Extermination of the tsetse fly

In vast areas of Africa, stock-breeding is hampered by the tsetse fly and the diseases which it generates. Hence the short supply of fresh meat, which is one of the principal causes of the notorious lack of protein in the African population's diet. Action against this pest may succeed in certain regions, which are surrounded by mountains or sterile areas constituting a natural barrier to the fly.
Theoretically, there are three possible remedial measures—curing the disease, breeding species with strong powers of resistance and extermination of the tsetse fly. The only practical method is that of extermination; here too it is a matter of underpinning the work now in progress by the use of new techniques. In the early stages, chemicals will be employed, but this will have to be followed by actual biological extinction as otherwise it will not be long before new strains of tsetse fly develop which may prove able to resist the chemicals used.
The project will thus consist in breeding tsetse flies and sterilising the males by irradiation. It will also be necessary to ensure that the sterilised males preserve their biological integrity, as they are to be released in breeding grounds, where they will mate with females, without however fertilising them. In this way, the number of descendants will naturally be diminished. The project is to be assigned to the Institute for Livestock Breeding and Tropical Veterinary Medicine at Bouar (Central African Republic). The experience thus acquired could then be used immediately in the other Associated States. The work is expected to take six years, the cost being 650,000 dollars.

Conservation of fish by irradiation

The lack of protein in the African population's diet throws into relief the importance of developing fisheries and conserving their output. In tropical climates, however, fish are too perishable to be able to be transported into the interior, and cold-storage would call for a vast amount of plant and equipment, which in turn would raise prices appreciably.
By means of very low-level irradiation, however, the fish could be kept fresh for a few days (provided there is only a slight reduction of the temperature) without any adverse effect on the taste or consistency.
A factor propitious to the setting-up of a fish conservation unit is the fishing port built on the Ivory Coast with aid from the European Development Fund. Here some 15,000-20,000 tons of herring were landed in 1964; part of it was consumed in Abidjan and part in the interior as far as Bouaké. Irradiation storage would make for still wider distribution.
This part of the programme is to be carried out in three stages, i.e.:
a. Determination by the ITAL Institute at Wageningen (Netherlands) of the radiation dose required for conservation purposes;
b. Checking of the results in local conditions by means of a provisional irradiation plant;
c. Construction of an irradiation unit in the fishing port near Abidjan.
The time required for these operations is about three years, and the costs are set at approximately 700,000 dollars.

Conservation of fresh meat

A similar problem arises in connection with the preservation of fresh meat. The flesh of cattle and zebus frequently contains tapeworm larvae. Where such meat is eaten, the larvae pass into the human system, where they continue to grow. Thus the policy at the present time is to destroy the affected part of the meat. By very low-level irradiation, however, the larvae can be rendered harmless, thus making it possible to prevent a loss which at the moment amounts to 30% of the total number of animals slaughtered. Excellent conditions for a pilot plant are at present to be found in Fort Lamy (Chad). The local slaughterhouse has an annual capacity for 6000 tons and is in the immediate vicinity of the Farcha laboratory. The setting-up of an irradiation unit, in the same three stages as the fish-conservation plant, would enable the larvae to be completely exterminated, in all the animals slaughtered, within about three years at a cost of 600,000 dollars.
I should emphasise that the radiation dose employed is far below the danger-point and also that the technique is already in use in various parts of the globe. The personnel required for the work, who would have to be familiarised with the new techniques, are already present in the institutes.

These, then, are the four "Berlin Programme" projects. The quest is however being pursued for other applications of radiation biology and isotopes in the Associated States of Africa and Madagascar.

Nuclear techniques and the developing countries

FERNAND VAN HOECK, *Biology Department, Directorate-General for Research and Training, Euratom*

To some people the title of this article will probably appear rather paradoxical. If nuclear techniques conjure up a picture of highly advanced research, sophisticated and expensive equipment and highly skilled scientists, is it logical to associate all these prerequisites of the wealthy nations with countries whose major worry is how to satisfy basic needs? I believe that the paradox is in fact only an apparent one, and I should like to offer the reader some reflections which prompt this view.

There is now a world-wide consensus that the very first deficiency to be remedied in the developing countries is their inability at the present time to provide their populations with even the most elementary living conditions. The immediate barrier to development is malnutrition, and the raising of agricultural productivity is a *sine qua non* for breaking out of the vicious circle of malnutrition-low output-poverty-malnutrition. But the outlook in this respect is not encouraging, and it is certainly not improved by the so-called population explosion. The most recent annual report of the *FAO*[1] reviews the world food situation over the past ten years. The general situation depicted by the figures is that since 1958 agricultural production has barely kept pace with the rate of growth of the population; this means that the food position, which was bad in 1958, is just as bad, if not worse, in 1965.

The state of underdevelopment is worsened by the prevalence of a number of diseases, in many cases endemic, among large sections of the population. In Africa alone, bilharziasis, onchocerciasis, thyroidal goitre and a wide range of nutrition deficiencies act directly counter to the welfare, productivity and standard of living of millions, and diseases which only a short while previously had been checked, such as sleeping sickness, have in some places made a spectacular come-back during the past few years.

1. *The State of Food and Agriculture, 1965, FAO, Rome.*

Priority for education

Radical changes will of course have to be made to this state of affairs, since it is a situation harmful to rich and poor countries alike; it is the recognition of this need that underlies "technical assistance". Much has been said and written on the variety of forms assumed by such technical assistance, the eulogies and criticisms it has evoked, the causes of its successes and its failures, the blunders and wastage with which it has occasionally been associated. I would, however, like to recall the two key concepts upon which there is general agreement and which have the approval of all sorts and conditions of authorities, both individual and collective, whether givers or receivers of technical aid. I shall quote them in order of precedence, i.e.:

— it is vital for the developing countries to educate their peoples in order to make them receptive to any acquisition calculated to improve their economic situation, and particularly in the fields of public health and agriculture;

— science and technology must form an integral part of the planning and the implementation of economic and social development.

In many respects, these two concepts are complementary. Tackling local problems scientifically at source contributes to education in depth—an essential condition of any lasting and solid structure. And conversely, what is the use of introducing higher-yield crops from abroad if the native grower has no desire for them, simply because he is not accustomed to them? What purpose is served by creating a breed of good-laying hens if the eating of eggs is at variance with local conventions? Habit, custom and tradition sometimes constitute formidable obstacles, and it is only by education of the masses that diehard attitudes can be modified.

After having underlined the urgency of an agricultural revolution in the developing countries, the *FAO*'s 1965 report points out that while progress in medicine has made it possible to keep a large number of diseases in check and to reduce the death-rate by measures which do not necessarily call for active co-operation on the part of an educated population, this "agricultural revolution as such will not be consummated without education of the peasants".

We must act fast...

But it is equally true that there is a veritable gulf between productivity in the advanced countries and that in the others. The annual cost of storing US surplus production is more than 350 million dollars, but most of the inhabitants of this planet are suffering from one form or another of malnutrition. The US surpluses are already being exported in part to the needy countries, and the

Swedish economist Gunnar Myrdal has asserted that in the next decade these stocks will have to be used to the last ounce if vast regions are not to be afflicted with famine. It is axiomatic that a solution of this kind can only be partial and temporary.

... with science and technology as the means

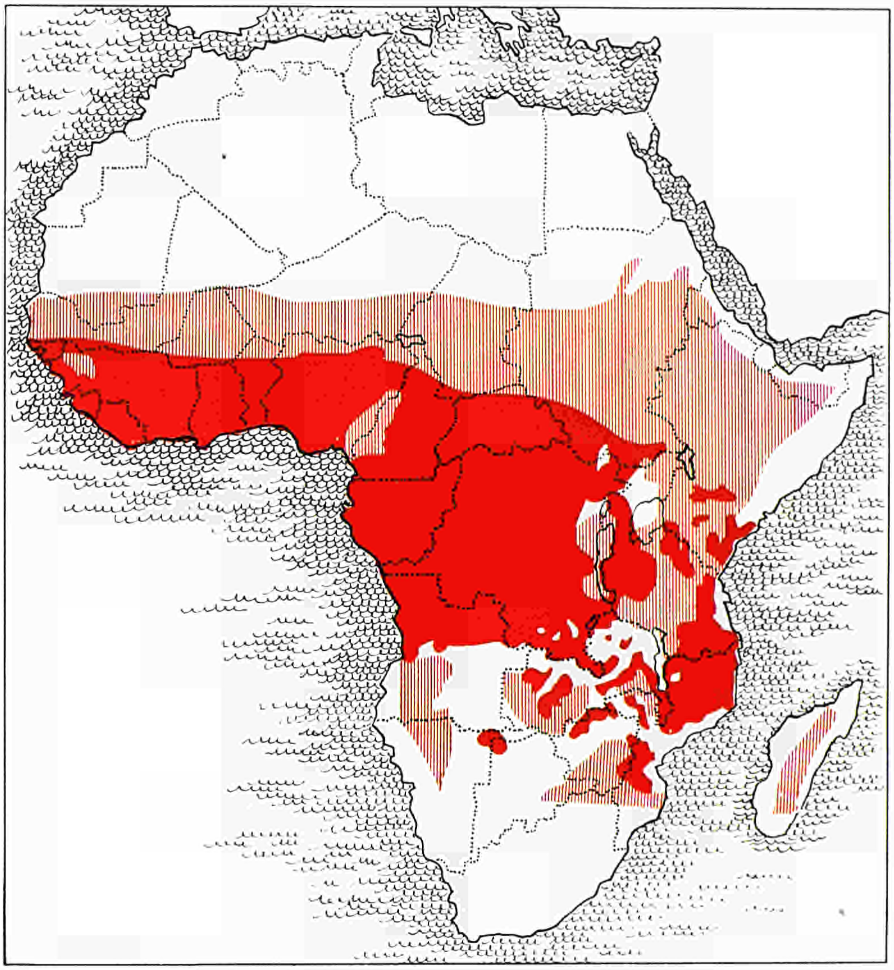
The most urgent priority is to speed up the development of the low-productivity countries to the greatest possible extent and to enable them to accomplish at an optimum rate of progress phases which in our case have occupied centuries. This is the reason underlying the opinion recently expressed by the United Nations Advisory Committee on the Application of Science and Technology to Development[2], viz: "The scientific approach offers the best hope for assisting the developing nations to speed up the process of their all-round development". And further on, the report of this Committee states that "in present circumstances, the wider and more intensive application of existing knowledge, suitably adapted to local conditions, provides the best prospect of securing rapid advancement in the developing countries".

I feel, however, that stepping-up the pace of development is not the only factor which warrants the adoption of scientific and technological methods. It seems to me that a campaign of economic and social progress can only get off the ground if it is underpinned by a build-up of home-grown capacity, failing which the tendency would be to follow the primrose path of "ready-made" solutions and unlimited external aid. And how can this instrument be fashioned if the developing countries do not pursue their own research and technology in a judicious and determined manner? I know that the weak link in the chain, the limiting factor which is liable to frustrate this purpose, is the extent of the manpower capable of fulfilling it, but is not this one more reason for going ahead and training such personnel?

Moreover, it is clear that we are far from having acquired sufficient knowledge as regards certain local or regional problems which have no counterpart in Europe or North America. If onchocerciasis is to be overcome, it will be necessary for entomologists some day to find, in the areas afflicted, answers to the innumerable questions which arise in connection with the vector insect, the sand-fly, whose life-cycle has been very little studied. If trypanosomiasis is to be eradicated in the regions in which it prevents stock-breeding, mass-extermination tests must be carried out, in local conditions, on the tsetse fly, with all the men and materials that this necessitates.

The same view is expressed by the aforementioned United Nations Committee when it says "there are a number of directions in which new basic knowledge and therefore special research efforts and pilot-scale trials could have profound effects, in a concentrated attack, on the potentialities for developing countries."

The objective will be more quickly and efficiently attained, it would appear, by the creation of a symbiotic relationship between the research bodies in the developed countries and those already operating in Africa or elsewhere, in order to afford the latter more direct assistance and a broader basis for action and to help them build up on the spot facilities essential for local research.



Main cattle production areas in Africa (hatched) and main areas of tsetse infestation (in red)— (after FAO Africa Survey—C 61/15)

2. *Advisory Committee on the Application of Science and Technology to Development, Second Report, May, 1965. Economic and Social Council, United Nations.*

No science on the cheap

If the developing countries' need of science and technology is an established and recognised fact, I think it follows logically that there must be no "science on the cheap for underdeveloped countries", and there can be no reason for not bringing the most up-to-date techniques to bear. As to the principle of their usefulness there are no two opinions, but the procedure for applying them is a matter of common sense and discernment. And why shouldn't a place be found among them for nuclear techniques, which have already supplied eloquent testimonies to their value in all branches of biology, including medicine and agronomy. In many other fields too, they render unquestionable services. The developing countries are confronted with a great many serious problems, which it is legitimate and possible to consider tackling with nuclear techniques, and all the more promptly because close links will have been forged with the appropriate bodies in the scientifically advanced countries, who are prepared to make their know-how available. The time when the craze for novelty caused nuclear techniques to be regarded as a panacea is behind us, and the superfluous and the impracticable have been jettisoned, but the efficiency of the instrument properly used has been considerably enhanced. It should be possible, by means of this symbiosis between those who have been able to move forward at a leisurely pace and those who are pursuing a race against time, to select methods in the light of the chances of success which may reasonably be expected of them.

The major problems

I revert yet again to the document published by the United Nations Advisory Committee on the Application of Science and Technology to Development. This report enumerates the various aims which it judges to be of crucial importance to the development process. They are:
— the provision of adequate food supplies;
— the improvement of health;
— a more complete understanding of population problems;
— the most effective use of the natural resources of developing countries, including solution of the problems of industrialisation;
— the invention and application of new educational techniques specially suited to the needs of developing countries.

I have already emphasised the importance of this last aim, which will decide, in the final analysis, whether science continues or ceases to be, as René Maheu, the Director-General of *UNESCO* puts it, a "product" of the advanced countries to be "imported" by the less developed countries. I should just like to illustrate by means of a few examples that nuclear techniques could even now be applied with advantage to certain aspects of the more important of the aims listed above, and further that in some cases they have already proved their worth.

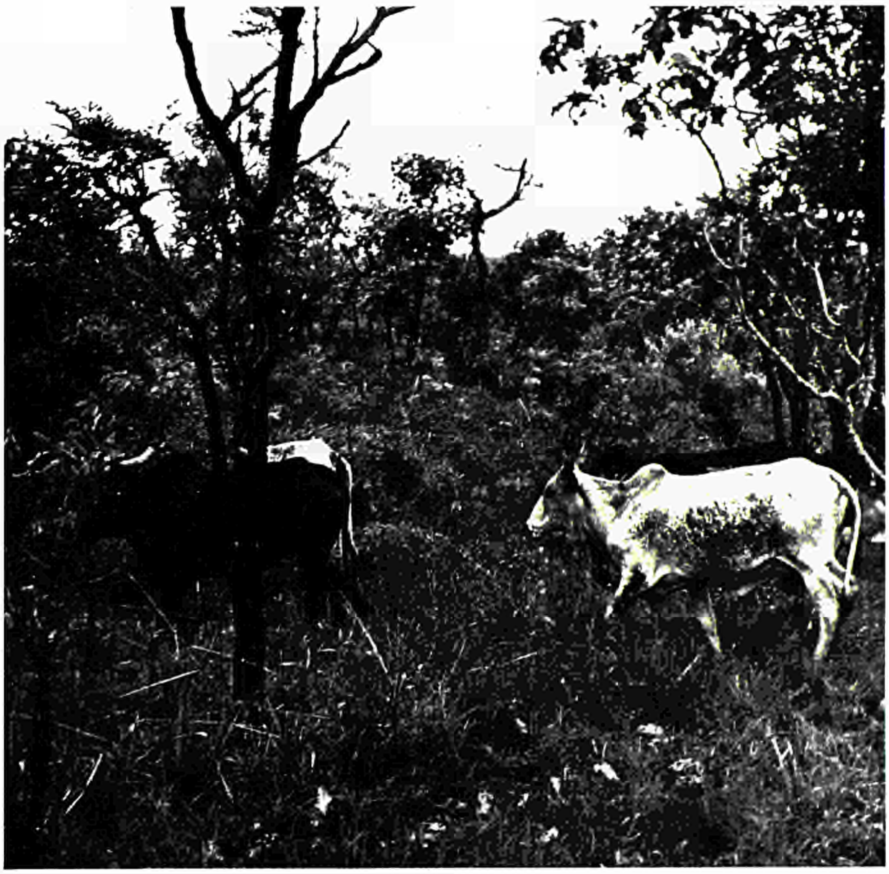
Some specific cases

First of all, a word about a highly controversial question—energy production. It is generally agreed that extreme caution must be adopted towards nuclear reactors as a source of energy for industrial use. Most of the experts recommend more thorough-going development of local resources in hydroelectric energy and mineral fuels, and are also at pains to stress the advisability of according the greatest possible attention to the non-conventional sources of energy—solar power, wind, geothermal and tidal energy. Nuclear energy has its place on the list, but in the longer term. There is, however, one exception: it could be a decisive factor in solving the problem of sea-water desalination. For there can be no doubt that desalination will become a matter of increasing urgency, partly in order to satisfy the general public's needs as regards direct consumption of fresh water, but also, and particularly, in order to provide the tremendous quantities of irrigation water which are inevitably going to be required in agriculture. In these conditions, and in very specific cases, dual-purpose reactors—production of water and energy—may become a worthwhile proposition. By way of example I shall quote the 150-megawatt reactor now being set up in the United Arab Republic, which will have an output of 5,000,000 gallons of water daily. But it is clear that, generally speaking, nuclear power as a source of energy for the developing countries constitutes a long-term prospect. It is quite a different matter as regards applications seemingly of a more modest character but bound up with aims of vital importance.

This type of bearded early millet was produced by ionising radiation. The bearding helps to protect the plant against damage by millet-eating birds.

This issue of the *Euratom Bulletin* contains an article by Dr. Dumont, Dr. Ermans and Dr. Vis on "Nuclear medicine in the service of Africa". They describe the research and preventive medicine campaign which has been conducted among the Uélé tribe and in Kivu province, where it is in progress at the present time. Here goitre is endemic and kwashiorkor has been spreading at lightning pace in recent years. These diseases are reflected in the chronic malnutrition of the peoples of these regions and there can be no questioning the fact that control of them represents a vital link in the development plan. As far as these affections are concerned, a study of the many and varied problems which are still present in the complex cause-and-effect concatenation inevitably involves the use of radioactive tracers. Without iodine-131, there is no way of measuring the rate of iodine capture by the thyroid. Without tritium, sodium-22 and potassium-40, without carbon-14- or sulphur-35-marked amino-acids, there is no way of studying the metabolism and water-salt disorders caused by nutritional deficiencies. Here the application of radioactive tracers is an indispensable technique and must be carried out on-the-spot, among the population affected.

The same point may be made about cattle-raising. Cattle trypanosomiasis is a major African problem in the Sudan and Guinea regions, where livestock-breeding is at present less developed than in the drier areas, although the grazing capacities are such that these regions would be ideal for livestock if a way could be found of protecting the animals' health. In many places it is impossible to raise more stock owing to the presence of the tsetse fly. There are three ways of combating the sickness carried by these flies—treating the infected animal, breeding stock with natural resistance to, or toleration of, trypanosomiasis, or destroying the fly. For various reasons which I shall not go into here but which are recognised by experts, the first two methods have serious disadvantages. As to the third method, the destruction of the fly can be tackled by means of conventional insecticides, but this entails a double risk, namely the ill-considered extermination of insect species that are harmless or valuable to the biological balance, and the emergence of insecticide-resistant tsetse strains. Furthermore, with chemical substances it has been found impossible in practice to reach every breeding-site and prevent rapid reinfestation except by repeated spraying in massive doses. If, on the other hand, the technique is adopted of releasing large quantities of sterile males in the area concerned, then the resultant break in the life-cycle leads to the virtual extermination of the species. Practice has shown that the attack must be carried through in two stages: an initial treatment with insecticide which makes substantial inroads on the population of the target species, followed by a release of males, which, although sterile, have lost none of their instinct to pursue the females and mate with them, but are unable to beget progeny. And the females are of course generally sought out more effectively by the insects than by insecticide particles, which merely drift and settle at random. The males can be sterilised, or chromosomal changes induced which lead to the same result, by irradiation or through the action of synthetic substances known as chemosterilisers. A serious study of the tsetse problem must consider every method of control that holds out any chance of success, for much remains to be done before the trypanosome vectors are exterminated so that areas now off limits can be opened up for cattle-raising. This will take time and money, but there is a great deal at stake.



Bonoro and Akou zebu pasturing in a wooded savannah in the Central African Republic. These cattle are liable to infection by the tsetse fly.

One way of increasing food supplies is by cutting down wastage of foodstuffs. It is a fact that in the hot regions of the globe, the climate and the frequently hazardous storage and transport facilities make it difficult to keep foodstuffs in good condition. Any improvement in this respect would be of immense economic and social benefit. It would be a mistake, however, to suppose that the process of conservation by irradiation, already practised effectively in the United States, Canada and the USSR, would be even better employed in the developing countries because losses are so high and the need to reduce them so acute. For these methods can be used only where a combination of certain conditions obtains, that is to say, local concentration of sufficient quantities of the produce to be processed, high nutritional

Breeding tsetse flies in order to study their biological cycle (IEMVT Entomology Laboratory, *Maisons-Alfort, France)*

and commercial value in low bulk, and a handling centre equipped with adequate facilities. When we come to apply these standards, there are not many situations where irradiation processing would be worthwhile at present. Two, however, do merit thorough investigation; one of these is the Abidjan (Ivory Coast) fishing area, where sufficient quantities—some tens of thousands of tons yearly—of a limited variety of fish are caught in sufficient quantity and do indeed raise genuine conservation and distributing problems. The other situation is brought about by Cysticercus, the tapeworm larva; encysted in the muscles of cattle from the slaughter-house, these larvae often render the meat unfit for consumption or cause human tapeworm infection if the meat gets through the health controls unnoticed. In the Chad and Central African Republics, considerable losses are recorded in the slaughter-houses where the animals are assembled and undergo efficient inspection. Here, too, there seems to be a useful future for the irradiation process, which has the advantage of destroying the tapeworm larvae concealed in the meat without altering its nutritional properties or taste.

I could instance many other feasible and valuable uses for radioactive tracers, in medicine, agriculture, animal husbandry, as well as in non-biological fields such as studies of the movements of ground water. Mention might also be made of the ways of improving certain features of plants by radiation-induced mutations, but I would rather keep out of the quarrel between the hybridising and the mutagenising factions! I must point out, however, that tangible results have already been achieved with millet, a cereal grown in poor, arid, tropical regions, and that there is a real prospect that further work will boost millet productivity in areas where it is badly needed.

And the wherewithal?

While the foregoing brief examples give merely a bare outline of the value of nuclear techniques to developing countries, at the same time, however, they raise the practical question of how to apply them. Are the necessary infrastructure, equipment and men available? This brings me back to the symbiotic relationship which I have already referred to several times and which, already established between certain advanced and less advanced nations, is developing and spreading. I am convinced that it is both feasible and indispensable. For in almost any research, it is the development stages which demand the greatest know-how and the most subtle techniques; and these stages can be carried out in the advanced countries. A project need not necessarily be completed in a single locality; it is far more profitable to organise its flexibly so as to make the best use of the facilities available where they may happen to be. Examples are not lacking: the initial stages of millet improvement, which call for the greatest care and atten-

tion, are dealt with at Bondy, near Paris, and then continued at Bambey in Senegal. The tsetse reproductive cycle, sterilisation methods and the fine details of mass breeding are studied at Maisons-Alfort, while the results are put to the test at Bouar and Bambari, in the Central African Republic.
The research team working on the "goitre and kwashiorkor" programme use the excellent facilities of the *IRSAC* (*Institute for Scientific Research in Central Africa*) in Kivu province, and are assisted by the *Nuclear Study Centre* at Mol for all neutron activation analyses that can be effected in Europe, while the laboratory research underlying their work in Africa is carried out in Brussels.
In the foregoing cases, this symbiosis is paying its way.

To sum up . . .

I have not been trying to show that nuclear processes must at all costs be applied to the problem of under-development, for I believe that no method or instrument is any more valuable than the results it is able to provide. I have simply tried to set out the reasons why I think it logical to include such processes in the overall plan. Hundreds of millions of people still have to emerge from the state of under-development. Their problems are known, as they are urgent and serious. There is no miracle cure, only the absolute need and the will to progress rapidly. It is the means that are wanting, and this is where the "have" countries can release a flow of experience and knowledge and share in creating, first and foremost, the conditions needed for the education of these people. At the same time, modern science and technology can help to remove the barriers to development and promote the spread of centres where such countries must build up their own experience. Provided that we do not claim for them more powers than they possess, I think that nuclear techniques have unquestionably a role to play in this work, for they are tools inseparably linked with progress.

Entomology laboratory at Bambari, Central African Republic.

The work described in this article was carried out by the nuclear medicine group of the University of Brussels, in collaboration with the internal medicine, pediatrics, clinical biology and radiology departments of the St. Pierre Hospital. Acknowledgements are due to the CEMUBAC (Scientific and Medical Centre of the Free University of Brussels in Central Africa) and the IRSAC (Institute for Scientific Research in Central Africa) as well as to the International Atomic Energy Agency. Some of the studies were conducted under a research contract concluded between Euratom and the Universities of Brussels and Pisa.

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Nuclear medicine

During the period 1960-1965 specialists in nuclear medicine from the University of Brussels carried out studies on endemic goitre, cretinism and deficiency diseases in the Congo (Leopoldville). These diseases are classified by the World Health Organisation as three of the major scourges of the emerging countries.

Endemic goitre and cretinism

Entire populations, involving all five continents, are afflicted by a disease of the thyroid, the chief symptom of which is an enlargement of this important gland. This disease, affecting 200 million sufferers throughout the world, irrespective of race or class, is endemic goitre (Fig. 2). Virtually no African country is spared (Fig. 1) and in certain regions it may encompass up to 80% of the population.
In some areas endemic goitre is so widespread and causes apparently so little immediate inconvenience that it has frequently been regarded as a minor ailment and even, in certain tribes, as an erotic attribute or at least a desirable aesthetic appendage. However, it is now known that goitre has harmful consequences for the individual affected, resulting in an overall reduction in his physical and intellectual activity owing to general metabolic disorders and local disorders which range from constriction of the trachea and possibly asphyxia to thyrotoxicosis or even cancer of the thyroid.
Once a certain percentage of the population is affected, goitre can be regarded as a major social scourge, for it has been observed that the peoples concerned were doomed, slowly but surely, to die out. Furthermore, thyroid deficiency, or hypothyroidism, which is the mark of most goitre victims, leads to a marked physical lethargy and mental apathy. It will easily be appreciated that the existence of such a deficiency in the bulk of a given population constitutes a virtually insurmountable social and economic handicap. The most dramatic feature of this disease is that it is linked with a high proportion of cases of grave mental retardation, or endemic cretinism, which can amount to as much as 5% of the population. The existence of these easily detectable serious cases would suggest that the incidence of cases of moderate mental deficiency is much higher.
It would therefore seem obvious that the eradication of endemic goitre and cretinism constitutes a pressing problem from the human as well as from the social and economic angle.

Protein-deficiency diseases

It cannot be denied that there is at present, in the emerging countries, an imbalance between population growth, which can be estimated at 2.5 or 3%, and the increase in agricultural output, which is at a somewhat lower level.
The basic problem facing these countries is that of *general* starvation, i.e., starvation due to lack of calories, or else a specific deficiency, e.g., protein deficiency (kwashiorkor). Almost half the world's population does not receive the minimum number of calories necessary (2,200 per day) and the most common infantile deficiency disease in the world is general malnutrition, sometimes accompanied by a protein deficiency. Infant malnutrition itself causes an increase in the death rate, but it also has an adverse effect on the proportion of infectious diseases which, in an industrialised country, would be regarded as benign, such as measles. On the other hand, general calorie deficiency and kwashiorkor are most frequently accompanied by various vitamin deficiency diseases, such as pellagra, avitaminosis A, etc.
According to a World Health Organisation estimate, more than 100 million children throughout the world suffer from protein deficiency either alone or in conjunction with other deficiencies. These diseases have extremely serious consequences both for the individual and from the social standpoint. It is estimated, for example, that in South America alone more than 250,000 children die each year from these diseases; furthermore, they inhibit growth and retard puberty, while there is also reason to fear that serious malnutrition during infancy affects brain development. An appreciable fall-off in physical and mental energy is observed which, in the adult, leads to a con-

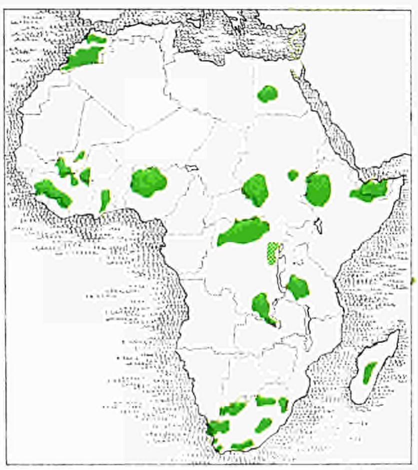

Figure 1: Map of Africa, with main endemic goitre areas in colour. The dotted area shows the field covered by the medical activities described in this article.

in the service of Africa

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siderable reduction in the productivity of the individual, and hence also of society as a whole, while during childhood schoolwork is seriously impaired. Finally, there is a high incidence of cirrhosis of the liver in adults and numerous lesions due to vitamin deficiencies are to be observed. Mention should be made in this connection of blindness caused by avitaminosis A.
Malnutrition and the associated deficiency diseases thus constitute problems of great urgency from the standpoint of world health.

Organisation of medical missions

In 1959 and 1960 two expeditions were organised to study goitre and cretinism among the Uélés (in the north-east of the former Belgian Congo). These expeditions, which were backed by the very sound medical setup of Foréami, were basically scientific in purpose.
In the same way, the studies carried out on deficiency diseases at Lwiro in Kivu province were conducted with the aid of the public health services and benefited from the magnificent research facilities made available by the *IRSAC*.
Since 1963 the teams studying endemic goitre and cretinism and deficiency diseases have focussed their activities on Kivu province. These specialised investigations are mainly carried out at the *IRSAC*. Furthermore, assisted by the *CEMUBAC* and the technical assistance corps, a health mission has assumed the medical surveillance of

Figure 2: A Uélé goitre case

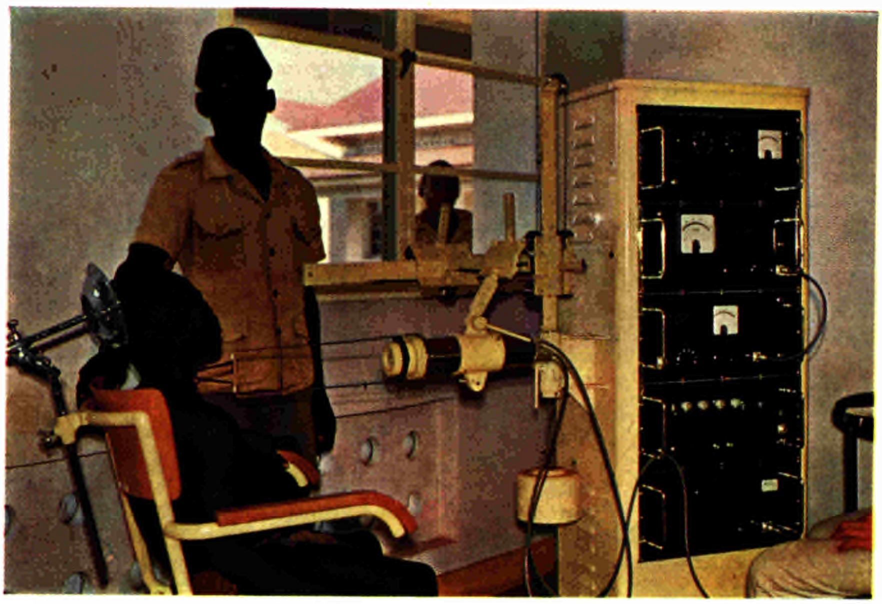
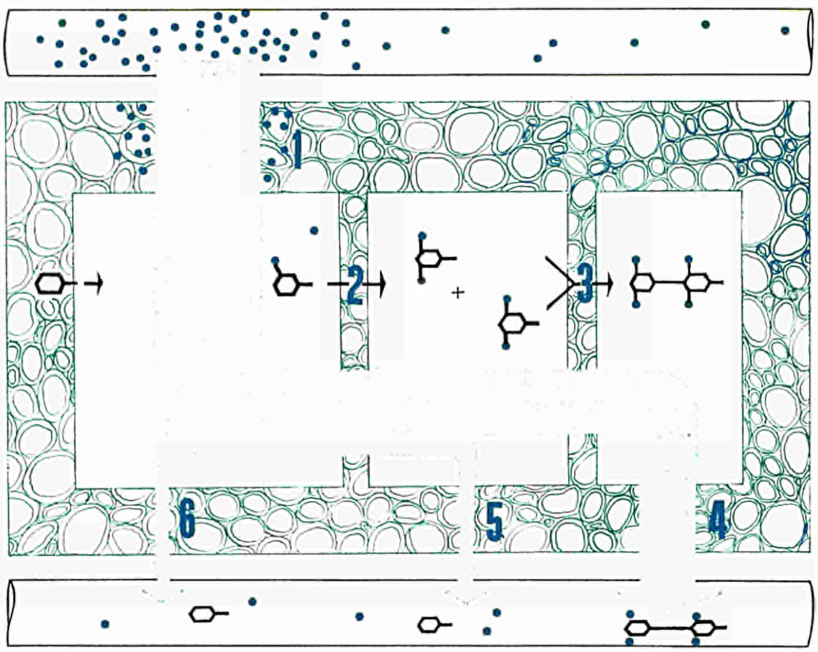


Figure 3: Measuring thyroid uptake of iodine-131 in a field laboratory

Figure 4 (p. 10): Diagram of normal thyroid function (the coloured dots represent iodine).
Cycle of synthesis of inorganic iodine into hormone (thyroxine):
1. Iodine pumped from artery into thyroid cell; formation of monoiodotyrosine (MIT);
2. Iodination of an MIT molecule, forming diiodotyrosine (DIT);
3. Pairing of two DIT molecules, to form thyroxine (T4);
4. Secretion of thyroxine in thyroid vein;
5 and 6. Direct MIT and DIT degradation and release of iodide in thyroid vein.

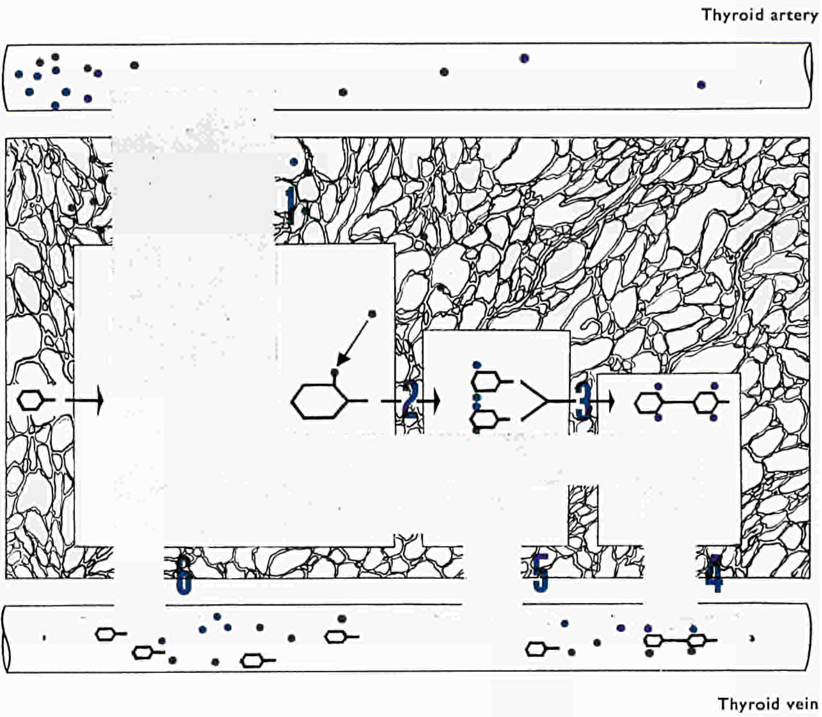
Figure 5 (p. 11): Diagram of iodine metabolism in endemic goitre. The amount of iodide in the thyroid artery is very low, but the pump's activity is increased tenfold, ultimately providing a normal iodide fixation.
Reactions (2), (3) and (4) are slowed down and the gland produces very much smaller quantities of DIT and T4.
A large amount of non-hormonal iodine passes out of the gland straight to reaction (6) without undergoing reactions (3) and (4), and causes an appreciable wastage of basic materials.



the entire population of the island of Idjwi in Kivu Lake.
Endemic goitre and protein deficiency are most frequently studied and treated in areas where conditions are still very primitive. They therefore pose complex problems from the technical and logistics angle. First of all extremely delicate electronic equipment has to be transported there (see for example Fig. 3), usually by jeep, boat or porters. Furthermore, the samples taken are subjected to very thorough analysis, which means that they must immediately be chilled to —10°C. In the Uélés tribe, a type of air-lift (Poko, Paulis, Stanleyville, Leopoldville), was used to transport the samples, the containers being reloaded with dry ice with the aid of CO_2 cylinders so that a suitable temperature could be maintained until arrival in Brussels.
In our studies now in progress in Kivu province, the two doctors in charge of the work are accompanied by an electronics expert who is responsible for all the external measurements. The samples (urine, blood, etc) are chilled in a freezer and then transported by motorboat to the *IRSAC* Institute, 25 miles from the main base on the island of Idjwi, where a series of chemical analyses are performed. For more complex analyses, such as chromatography and neutron activation determinations, the samples are sent from Bukavu to Brussels by air.
In Kivu province, the studies on goitre and malnutrition are coupled with general medical treatment, including vaccination, mass-radiography for T.B. and basic treatment for certain parasitoses. These activities are carried out by one of the two doctors making up the team, together with a nurse and two Congolese assistants, who are provided with an adequate quantity of drugs to treat all the acute cases diagnosed. Finally, there is a small hospital boat for taking emergency surgery cases to the mainland.

Studies on endemic goitre

The correlation between endemic goitre and iodine deficiency in the diet was well-known long before the element itself was actually discovered, for both the ancient Greeks and the Chinese made use of the therapeutical properties of kelp.
It was in 1952 that Stanbury and his assistants at Boston established the fundamental physiopathological features of this disease with the aid of radioiodine. They demonstrated that goitre is a syndrome reflecting the adaptation of the thyroid function to an iodine deficiency. By enlarging the gland and increasing its iodine concentration capacity, the organism manages to retain the small quantities of iodine which it absorbs. This theory has been borne out by studies conducted in the majority of endemic areas throughout the world, but it does not provide a complete explanation of the disease, in view of the fact that after a certain stage the malady becomes irreversible.
It is this aspect of the problem to which we paid particular attention during the studies carried out on endemic goitre among the Uélés, in the north-eastern Congo. Two radioisotopes of iodine were used for biochemical, kinetic and anatomical studies. With these methods it was shown that the process of adaptation to an iodine deficiency was accompanied by radical alterations in the thyroid machinery, which ultimately lead to a substantial drop in its efficiency.
The function of the thyroid gland is to



The main features of the mentally retarded subjects brought to us were their smallness and the flatness of their features (Fig. 6). All these cretins displayed symptoms of a serious and longstanding condition of hypothyroidism, such as heavy coarse features, dry cold skin, protruding abdomen frequently accompanied by umbilical hernia, and pronounced forward curvature of the spine. Although 12 to 35 years of age, none of them was capable of carrying out simple household tasks, whereas their younger brothers and sisters of 5 or 6 could manage such jobs with ease. Blood tests, bone X-rays, electrocardiograms and iodine metabolism measurements with the aid of radioiodine (Fig. 7) corroborated the hypothyroidism diagnosis.
The next question was to determine whether hypothyroidism was sufficient by itself to account for the clinical picture of cretinism.
Some of the morbid symptoms exhibited by our adult patients testified to the duration and extent of hypothyroidism during infancy. In other words, certain of their characteristics, such as size or bone age, provided a complete indication of the activity of the thyroid gland throughout the entire growth period.
If the clinical picture of cretinism were solely the result of long-term hypothyroidism, it should therefore be possible to establish a correlation between the mental development of adult cretins and their size or bone age. We were able to demonstrate the existence of such a correlation, as shown in Fig. 8, from which it can be seen that the results of the intelligence tests carried out on our patients vary according to size, the largest patients therefore also being the most intelligent.
This close link between hypothyroidism and endemic cretinism having been established, the next step was to determine the cause of this hypothyroidism. If it is taken to be, by definition, a low concentration of thyroid hormone in the blood, three hypotheses were possible:
1. The thyroid gland did not produce enough hormone
(a) because the synthesis mechanism was out of order
or (b) because it was simply too small
or
2. there was an excessive loss of the hormone produced.
The first hypothesis (1 a) could be rejected

convert free iodine into the thyroid hormone or thyroxine. This conversion takes place in five distinct stages, illustrated in Fig. 4:
1. iodide is pumped from the thyroid artery and monoiodotyrosine (MIT) formed;
2. the monoiodotyrosine is converted to diiodotyrosine (DIT) by iodination;
3. two molecules of DIT link up to form thyroxine (T4);
4. the thyroxine is secreted into the thyroid vein;
5. and 6. finally, the MIT and DIT decompose and some of their iodine is put back into circulation in the form of free iodide.
Comparison of Figs. 4 and 5 points up the mechanism for adaptation to iodine deficiency and the allied metabolic changes. These consist mainly in slowing down reactions 2 and 3 and speeding up reactions 5 and 6 considerably. In other words, the bulk of the iodide pumped in by the gland is wastefully rejected into the bloodstream without serving any purpose, as a result of which the synthesis mechanisms are slowed down appreciably. It is only the major increase in the amount of active tissue which enables secretion to be adjusted to physiological requirements.

In conclusion, goitre is admittedly a mechanism for adapting to iodine deficiency, but the main purpose of the hyperplasia of the gland is to offset the changes in the thyroid machinery caused thereby.

Study and treatment of endemic cretinism

The first problem raised by endemic cretinism was that of agreeing on a definition for this disease since although, in the Anglo-Saxon literature, a cretin is a patient whose physical and mental retardation is due to hypothyroidism during infancy, according to the continental literature a cretin is a mentally retarded person from an area characterised by a high goitre incidence, i.e. in many cases mountainous regions. The first definition is etiological, and the second geographical. The two do not necessarily apply to the same subjects and this discrepancy has given rise to a great deal of controversy.
In the goitrous region inhabited by the Uélés, we first of all sought out all cases of mental retardation, i.e. patients satisfying the continental definition of cretinism.

as the result of studies performed on iodine metabolism in cretins injected with radio-iodine, the methods used being external counting of the thyroid itself and examination of the blood plasma and urine (radio-chromatography and differential extraction). Generally speaking, the gland functioned normally.
Measurements of thyroxine metabolism (thyroid hormone) in the blood by means of tracer doses of I-131 labelled thyroxine showed a normal decomposition rate on the part of the hormone. Thus hypothesis 2 could also be abandoned.
On the other hand, various methods used to measure the stages in the iodine metabolism pointed to the overall inadequacy of this metabolism. The thyroid of the cretin picked up only a small quantity of iodine and could therefore only synthesise and secrete a small amount of hormone. The impairment in the metabolism of the gland was simply due to an insufficiency of active thyroid tissue (Fig. 9).
As a result of our work we were therefore able to pinpoint the immediate cause of endemic cretinism in the Congo, namely, an insufficiency of thyroid tissue during infancy. The therapeutical conclusion to be drawn from this is obvious. The best way to prevent the disease would lie in intensive treatment of the mother and young child with thyroid hormone. We are at present examining the possibilities for carrying out such treatment on the island of Idjwi.

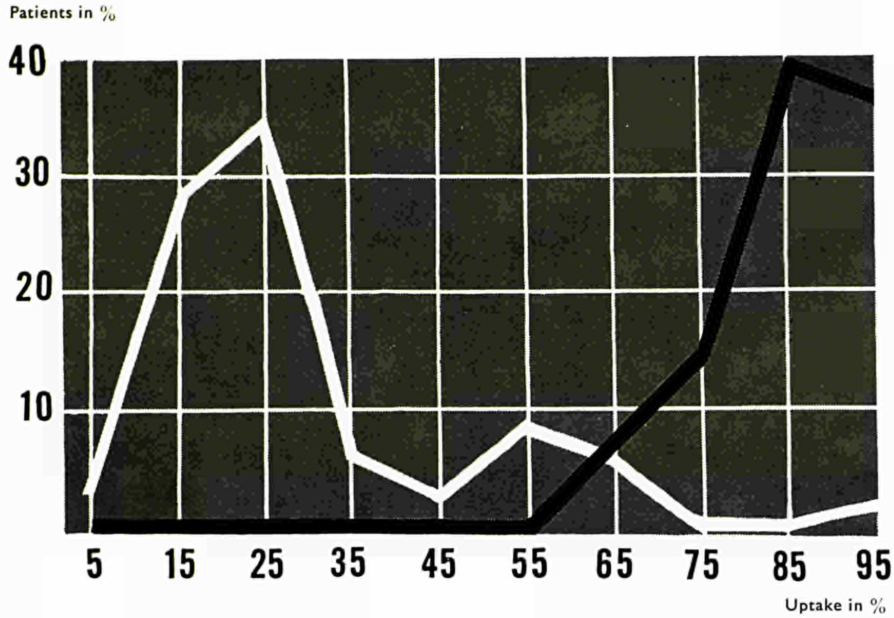


Figure 7: Distribution of iodine-131 uptake in cretins and well-developed adults in the Uélé region. The figures from which the graphs are plotted were obtained from studies of 31 cretins (white curve) and 48 normal subjects (black curve). The thyroid uptake is far lower in the cretins than in the controls; the cretin's thyroid is very small and takes up little iodine.

Study and treatment of deficiency diseases

Since 1959 we have been carrying out a detailed study of the forms of malnutrition encountered in the Bashi populations of central Kivu province. One section of this project (conducted by the nutrition and clinical studies department of the *IRSAC*) was performed by Dr. De Maeyer, who headed the department up to the end of 1963.

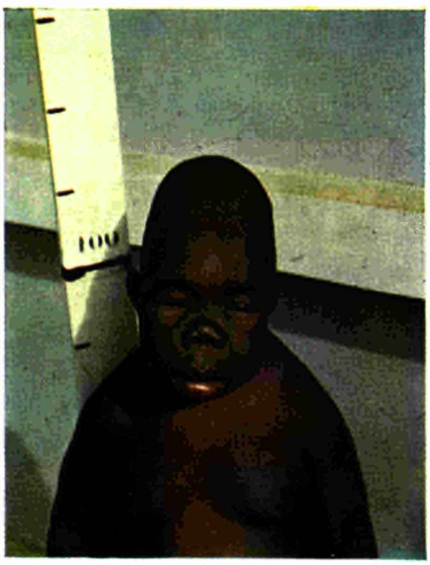


Figure 6: a 32-year-old cretin

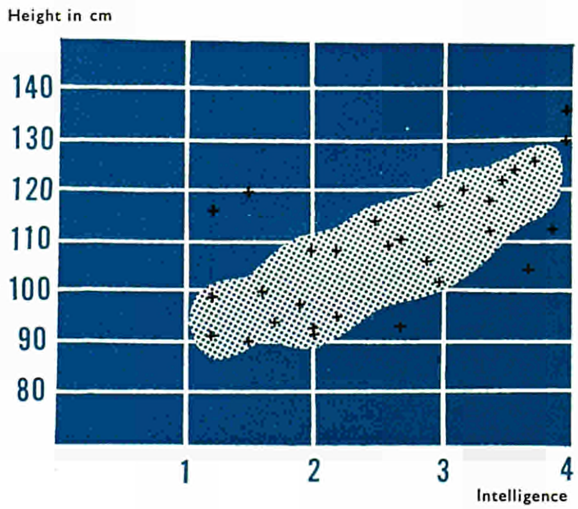


Figure 8: Relationship between size and intelligence in endemic cretins.
Intelligence was measured by simple intelligence tests suitable for Bantu children. There is a distinct correlation between size and intelligence.

Our main aim during the last few years has been to elaborate as precise a definition as possible of the clinical and biological forms of infantile protein malnutrition in central Kivu province, for owing to the variety of circumstances involved it can manifest itself in very different forms from case to case. For example, in certain areas of the world, children are to be found suffering from protein deficiency pure and simple, without calorie deficiency. This is a disease related to weaning, when the sole source of useful proteins i.e., the mother's milk, is replaced by carbohydrates. This situation arises when the production of animal proteins is inadequate to meet the requirements of the population or when local customs are opposed to feeding a weaned baby on such proteins. A diet of this nature gives the child a normal supply of calories but it is deficient in proteins. This protein deficiency pure and simple, known in the relevant literature as *kwashiorkor*, is rarely encountered, for it is usually accompanied by overall calorie deficiency and various types of vitamin deficiency.

It is not only weaned children who are afflicted by multi-deficiency diseases, for they are encountered throughout the growth period or even in adults when for one reason or another the calorie, protein and vitamin requirements rise sharply as in the case of pregnant women or nursing mothers. At present, despite the knowledge available concerning malnutrition syndromes, the average mortality rate among the acute cases receiving hospital treatment continues still to average about 30%.

It would appear that acute starvation can only be studied on the spot in its local context, for both the mechanisms of deficiency diseases and the socio-economic circumstances will be peculiar to a particular region and it would be dangerous to ascribe general validity to data which are obtained from one particular region and which at first sight might appear to be fundamental. One of the ways of predicting the type or types of malnutrition to be dealt with in a particular region is to study the normal diet of the population concerned.

The detailed study carried out on the diet in central Kivu province by De Maeyer and Roels-Broadhurst in 1957-1959 brought out a number of salient facts. The total calorie intake is just barely adequate, amounting to 93.7 to 95.4% of the minimum ration.

On the other hand, there are major seasonal fluctuations which sometimes bring this figure down to as little as 80%. Beans account for 83.7% of the total daily protein intake. While bean proteins are admittedly among the best obtainable from vegetables in general, it is nonetheless true that when they constitute virtually the sole source of nitrogen, they lead to malnutrition because they are poor in the sulphurated amino-acids which are essential to growth and

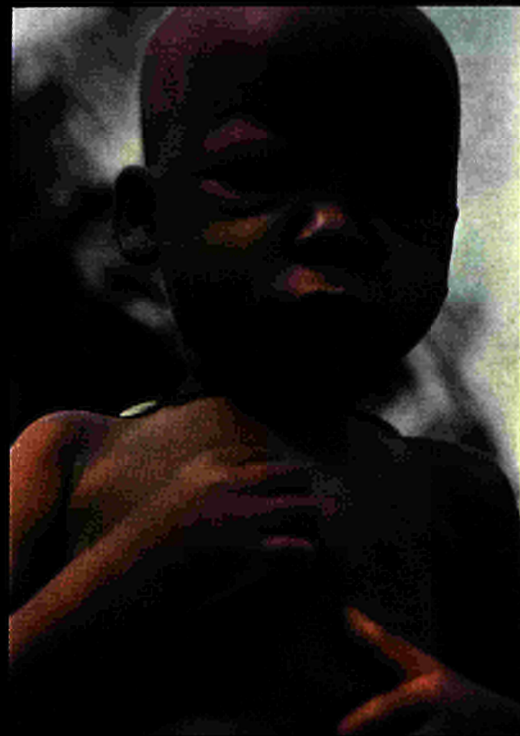


Figure 10: Typical appearance of child affected by protein deficiency (kwashiorkor).

Figure 11: Typical appearance of marasmic child (general calorie deficiency).

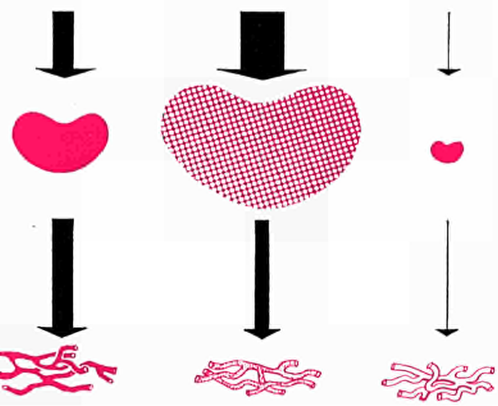


Figure 9: Diagram of iodine metabolism (left to right) in the normal person, the goitre case and the cretin.

In order to mitigate an iodine shortage in the diet, the goitrous subject's thyroid gland has become enlarged. This adaptation is accompanied, however, by profound deterioration of the thyroid machinery, resulting in diminished efficiency.

In the cretin, the thyroid takes up little iodine and therefore secretes little in hormone form; the gland is reduced to a mere vestige.

Figure 13: Comparison of average height versus age curve for protein-deficient Bashi children with height curve and extremes for normal Bashi children (in white).

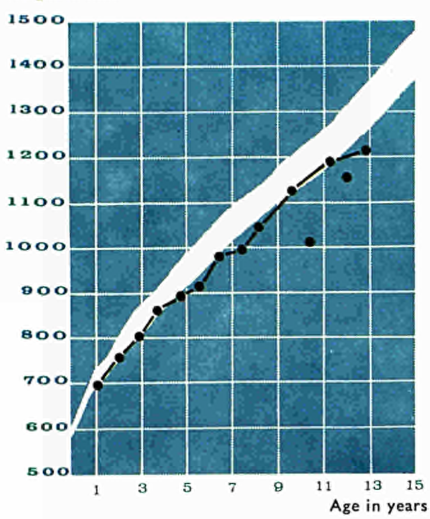
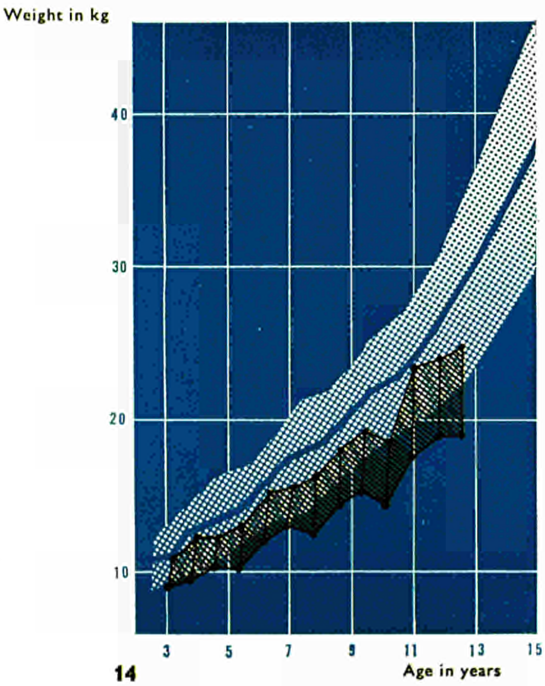


Figure 12: The graph shows the average curve and extremes of weight versus age for normal Bashi children. The hatched band shows the weight/age curve for undernourished children; the lower edge of the band indicates weight during acute starvation, the upper edge weight after two months of protein treatment; at that moment the children reach the correct weight for their height.



good health and which can be obtained in sufficient quantity only from animal protein. Alcoholic beverages yield a substantial number of calories, of the order of 242 calories per head of the population, compared with 1,822-1,875 calories obtained from food. The beverages in question are drinks with a low alcohol content made from fermented banana juice.

The low supply of fats, which make up only 8.6% of the total calorie supply, is the factor accounting for certain vitamin deficiencies such as lack of vitamin A, which is only found in certain oils.

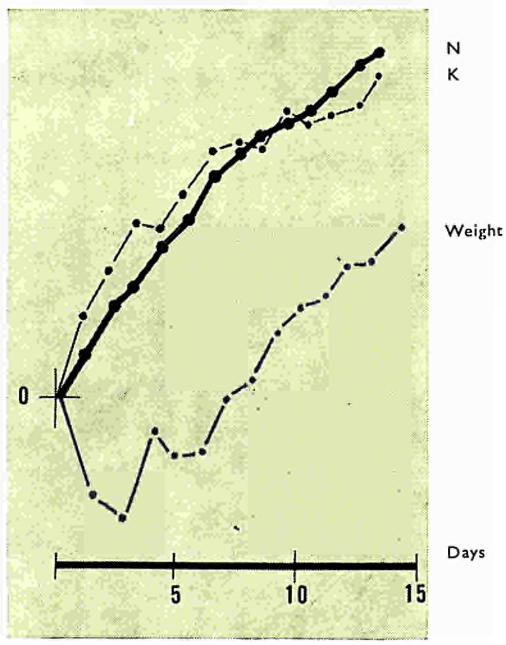
For some years now the food situation has been getting worse. Produce is more expensive and, for the sake of simplicity, beans have been replaced to a certain extent by manioc, which is easier to cultivate but contains virtually no protein at all.

On the basis of these facts one might expect to find a form of malnutrition involving both *marasmus* (calorie deficiency) and *kwashiorkor* (protein deficiency), and this was in fact confirmed by our study of the affected subjects' chemical and biological characteristics.

We attached considerable importance to the metabolism of water and salts. It had already been known for many years that protein malnutrition was accompanied not only by retarded growth (Figs. 12 and 13) and major disorders of the protein metabolism, but also by varying degrees of perturbation of water and salt metabolism. Thus during the famines that occurred in Europe during the last two wars, subjects suffering from hunger developed oedemas, the result of over-retention of water and sodium in the system. These are *famine oedemas*. These disturbances, which are secondary to the nitrogen depletion resulting from protein deficiency, can of themselves be extremely dangerous to the subject.

It has been shown that the salt metabolism disorders observed in deficiency cases actually depend on two factors. One of these is the nitrogen depletion itself. When the body is deficient in nitrogen, it loses potassium and accumulates sodium chloride and water. All this is the result of a very complex series of mechanisms. Fig. 14 shows the reverse process during treatment; when the subject retains nitrogen, he also retains potassium. Secondly, as we were able to show, the salts content of the diet is a very important factor. In the Lwiro region, beans and bananas form the

Figure 14: Progress of the weight curve for a child treated for protein deficiency. The drop in weight during the first days of treatment corresponds to the oedema reduction. The graph also shows that from the outset of treatment the subject retains potassium and proteic nitrogen.



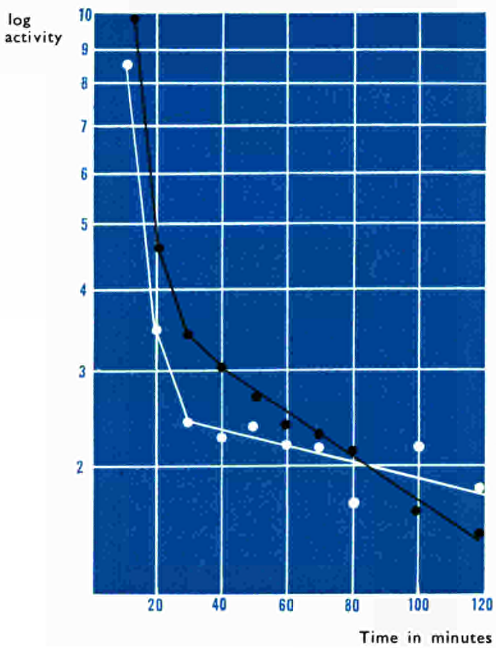


Figure 15: Measurement, by the isotope dilution method, of amino-acid turnover in a malnutrition case.
The ordinate of the graph is logarithmic and represents the activity of taurine-S^{35}, an amino-acid labelled with radioactive sulphur, injected into the subject at a given moment. The abscissa gives the passage of time in minutes. By counting the subject's blood plasma activity at regular intervals, it is thus possible to plot a curve which depicts precisely how the activity decays and therefore how the injected substance is used by the body.
The white and black curves summarise two such experiments carried out on a subject, before and after treatment. Before treatment dilution of the injected taurine-S^{35} starts off being greater by reason of the oedemata, but, at a certain point, it becomes slower than after protein treatment, which shows that the taurine has met with some obstacle preventing its assimilation by the body in the normal way.

staple diet, which is thus rich in potassium and poor in sodium chloride. Beyond all doubt, such a diet is a kind of antidote to protein deficiency and affords a measure of protection against the real dangers of serious potassium depletion and excess of sodium chloride.

It would have been impossible to carry out a thorough investigation of these complex disorders in the protein and salt metabolisms without using isotopic dilution techniques. The main isotopes employed are tritiated water, sodium-22, potassium-40, and C-14- or S-35-labelled amino-acids. For example, by injecting a sodium chloride solution whose degree of radioactivity is known exactly, it is possible by counting to determine the proportions in which the salt is diluted in the various organs, its speed of elimination, etc. Fig. 15 gives an example of the way results can be obtained by these methods.

We should add that the problem is aggravated by parasitoses and tuberculosis, which are rife among populations suffering from malnutrition. This is borne out by the figures—we found that 82.4% of the children with protein deficiency were affected with intestinal parasitosis and in 11.3% of these cases there was more than one type of parasite; in addition, 0.6% of the children had malaria and 11.4% evolutive tuberculosis.

Treatment and prevention of protein malnutrition in the central Kivu region are based on three points.

The first is to provide the inhabitants of that region with material aid, in the form of milk distribution for instance, together with a propaganda drive for more sensible crop management. The region is far from over-populated and the land, basically fertile, only needs to be properly farmed.

Next, our medical team is fighting parasitosis.

Thirdly, it treats the acute malnutrition cases, with particular attention to the characteristic and highly dangerous salt metabolism disorders. The precision of the nuclear techniques already referred to have made it possible to gauge the extent to which each subject is affected and give him individual treatment; for the subject's life often depends on the dosage of the salts administered. In this way mortality among hospitalised cases, which at the outset stood at 30%, has been brought down to less than 10%.

Modern analysis

To the expert any attempt to give a more or less comprehensive review of organic analysis methods in the space of a few pages will appear mere presumption on the part of the author. I am well aware of the impossibility of doing so. Nevertheless, I have chosen this promising title in the hope of capturing the attention of the reader who takes a general interest in technology or science. In addition, I shall confine myself to a survey of these methods as used for the analytical control of the organic reactor coolants in the *ORGEL* project.

Historical background

The development of organic chemistry was preceded by the work done in inorganic chemistry, i.e. the chemistry of minerals. Formerly, the organic chemist had at his disposal only substances of animal or vegetable origin in which he induced chemical changes and thereby created new substances. Until 1828, when Wöhler succeeded in synthesising urea—which had been postulated as an "organic" substance—from inorganic starting materials, it was believed that the compounds of organic chemistry could only be produced by the chemical synthesis machinery of the living organism. Today an enormous number of reaction routes are available to the "organic chemist" for the synthesis of new compounds, which are composed of relatively few elements: chiefly carbon, hydrogen, oxygen and nitrogen. The number of known individual compounds must by now already exceed one million; the theoretically possible number is very much greater and increases with each newly discovered reaction route in accordance with the laws of combinatorial theory. As far as the ability to produce variations is concerned, the last hundred years have shown that the organic chemist's art has left the living organism far behind. Against the background of these figures it is self-evident that convenient analytical methods of identification and classification are an absolute must for the control of matter.

In contrast to what happens in inorganic chemistry, reactions between organic compounds seldom proceed on a one-for-one basis; in other words, if a substance undergoes a chemical change or if two substances are reacted together, the number of new compounds formed is generally more than one or two. Frequently a complicated mixture is obtained wherein the "desired" or "interesting" compound, for the sake of which the reaction was carried out, is only one of the components, and often not the most abundant one.

Classical methods of analysis

Classical organic chemistry was mostly confined to the "isolation" of the "desired" compounds, and possibly also one or the other of the principal by-products, in the form of individual discrete substances. To this end, use was made of separation techniques, such as distillation, extraction or crystallisation, which need not be gone into here. After that it was a question of identifying and characterising the discrete compound obtained. "Ultimate analysis" of combustion products tells us in what relative quantities each of the constituent elements is present, but such an elementary analysis cannot, of course, give any information about the chemical architecture of the compound. For the further definition of the discrete substance the practice was, and still is, to fall back on such criteria as boiling point, colour, odour, refractive index and crystal structure.

With these methods it is seldom possible to achieve complete separation of the discrete substances from the reaction mixture.

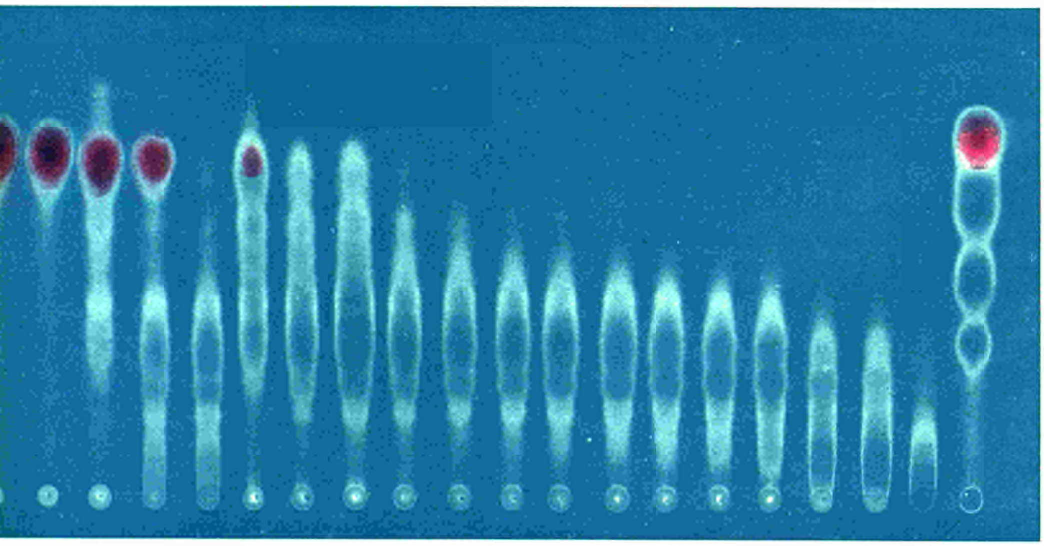


Fig 1: Thin-layer chromatogram of a polyphenyl mixture and of the various fractions distilled from it.

methods in organic chemistry

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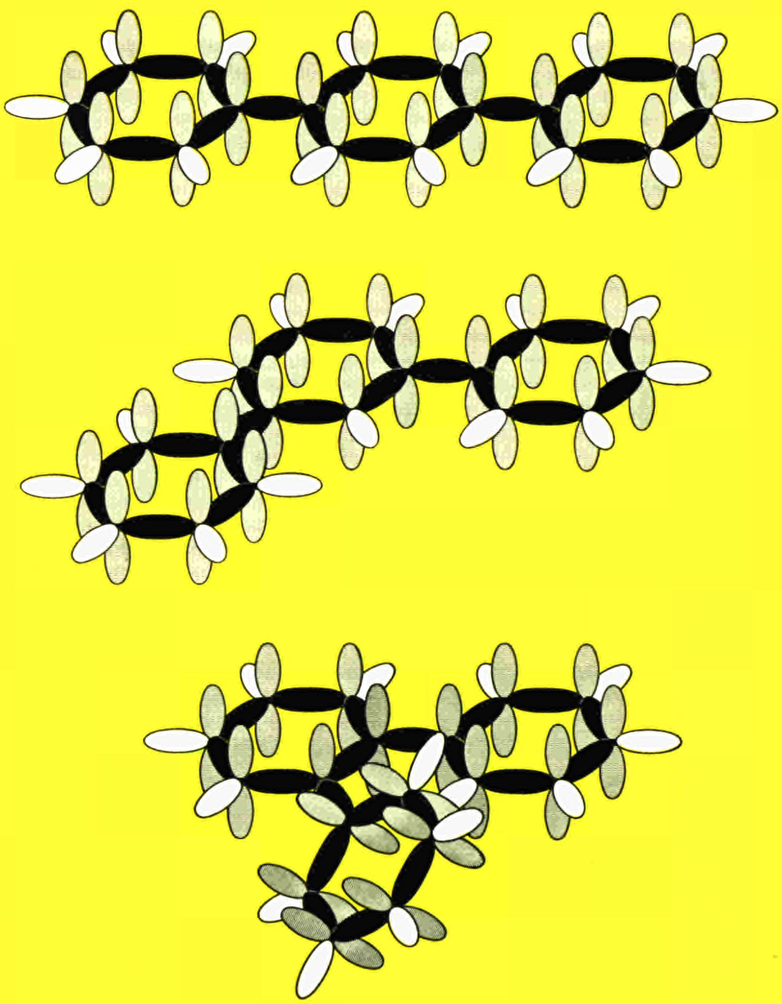


para-terphenyl

meta-terphenyl

ortho-terphenyl

Fig. 2: The three terphenyl isomers. A terphenyl molecule consists of three benzene rings, each of which is made up of six carbon and six hydrogen atoms. The three isomers correspond to the three different ways in which the rings can link up.

Remnants of these compounds are left behind in a mixture, together with, for the most part, resinous by-products. The equipment available to the organic chemist was not adequate for the analysis or impurity-free preparation of compounds which occur only in trace amounts and of these seemingly non-crystallisable resins and tars, scornfully referred to as "gums". An experiment was regarded as a failure if the reaction products were predominantly "gummy". Although they were "organic" compounds, like all the others, these unwanted by-products were for a long time neglected in organic chemistry. This was due principally to the inadequacy of the analysis methods at the organic chemist's disposal. The above-mentioned techniques are mainly suitable, as I said before, for the classification of discrete substances; they are less suitable for the identification of mixtures and quite useless for the detection of "traces".

An example: polyphenyl mixtures

The use of polyphenyls in the *ORGEL* reactor and the chemistry of these substances have already been described by Mr. van der Venne in issue No. 1/1964 of *Euratom Bulletin*.
The fresh coolants employed are "terphenyls" (see Fig. 2). There are three compounds under this designation, which have the same number of carbon and hydrogen atoms but different chemical structures. The high prevailing temperature (over 400°C) and the radiation in the reactor cause the substances to undergo a chemical change; they "decompose" and as a result hundreds of new compounds—gaseous, liquid and solid—are formed as a blackish-brown tarry mixture. This is a typical example of an organic chemical reaction. In the present state of analytical organic chemistry it is not possible to effect complete separation and identification of *all* the constituents in such a mixture; satisfactory information can, however, be obtained on those which are of practical interest.

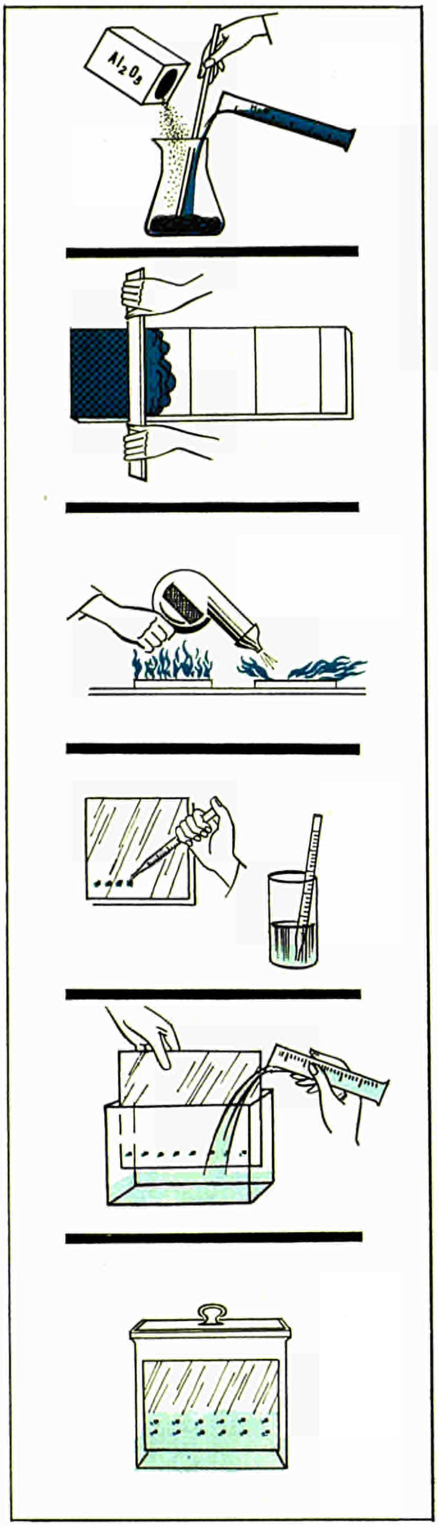


Fig. 3: Thin-layer chromatography.
From top to bottom:
preparing the paste;
coating the plates with paste;
drying the plates;
applying drops of the mixture to be analysed;
inserting the plate into the "development" vessel;
development of the plate through capillary action.

Chromatographic separation methods

I shall first describe the most recent technique in this group of related separation methods.

Thin-layer chromatography (Figures 3 and 6)

Alumina in powder form is mixed with water to form a paste. The white paste is then applied to a glass plate 20 cm square and smoothed to a uniform layer 0.1 mm thick, i.e. a "thin layer". After evaporation of the water in a drying cabinet the chromatographic plate is ready for use. One or several drops (as in Fig. 3) of a solution of, say, four dyes in chloroform are applied near the edge of the plate and allowed to evaporate. A uniform grey spot is left. If the plate is now placed with the spot downwards in a closed glass vessel filled to a height of a few centimetres with a suitable liquid (e.g. chloroform again), the capillary action of the thin layer causes the liquid to rise up the plate, forming a front as it does so. As soon as the liquid front reaches the dried spot, the four dyes present in the stain dissolve and migrate upwards with the liquid, though not at the same speed as the front itself. The reason for this is as follows: the fine pores of the alumina attempt to absorb and hold back the dyes; the liquid, on the other hand, tends to entrain the dyes in dissolved form in its upward migration. The inevitable result of this conflict is that the migration of the stain is slowed down with respect to that of the liquid front. The accompanying *separation effect* on the dyes is due to the fact that the tendency of the stationary layer to arrest their migration varies according to the molecular structure of the individual dyes, and this in turn leads to differing rates of migration. When the liquid front has reached the top edge of the plate, the plate is removed from the chamber and the chromatogram is now ready. The various stages in the "development" of such a chromatogram are shown in colour photographs in Fig. 6. On the extreme left is the dried spot in the "starting position"; in the second photograph from the left, the front has travelled a distance of 5 cm (the differing rates of progress are already noticeable). The third photograph from the left shows that, to use a sporting metaphor, the field is beginning to spread out (after 10 cm). In the fourth photograph from the left the front has reached the edge of the plate, having travelled 15 cm; a sufficient distance has now been covered for the differing rates of migration to have resulted in complete separation of all the substances.

This separation process can be conveniently explained by analogy with the power of a mountain river to transport loose soil; the fine light sand is carried down to the mouth almost without hindrance. The medium-sized pebbles are slowed down considerably by the unevenness of the river bed and are halted in mid-course. The heavy, bulky boulders remain where they have fallen at the foot of the mountain, since the current is not strong enough to move them. Similarly the green dye has not moved from the initial spot (Fig. 6, right); it is heavier than the others and its structure is such that it can easily become "caught" in the layer.

Finely ground paper can be substituted for the alumina layer and it is even possible to use paper strips without a glass backing.

Column chromatography

A forerunner of thin-layer chromatography is the method known as column chromatography (see Fig. 5). A glass tube a few centimetres in diameter is again partly filled with a fine-grained porous material and mounted vertically. A further layer of porous powder, on which the solution to be separated has previously been absorbed, is inserted at the top of the tube. A suitable liquid is then added dropwise. The liquid slowly travels down the column, wetting it completely, and finally flows out at the bottom. The components of the mixture are entrained in the liquid and are again separated owing to their differing migration speeds.

Thin-layer chromatography requires only a millionth of a gram (1 µg) of substance and is employed mainly for diagnostic purposes. Column chromatography needs quantities of several grams or more and can therefore also be used to advantage for laboratory-scale preparation of the substances concerned; its selectivity, however, is definitely lower, as can be seen from Fig. 5.

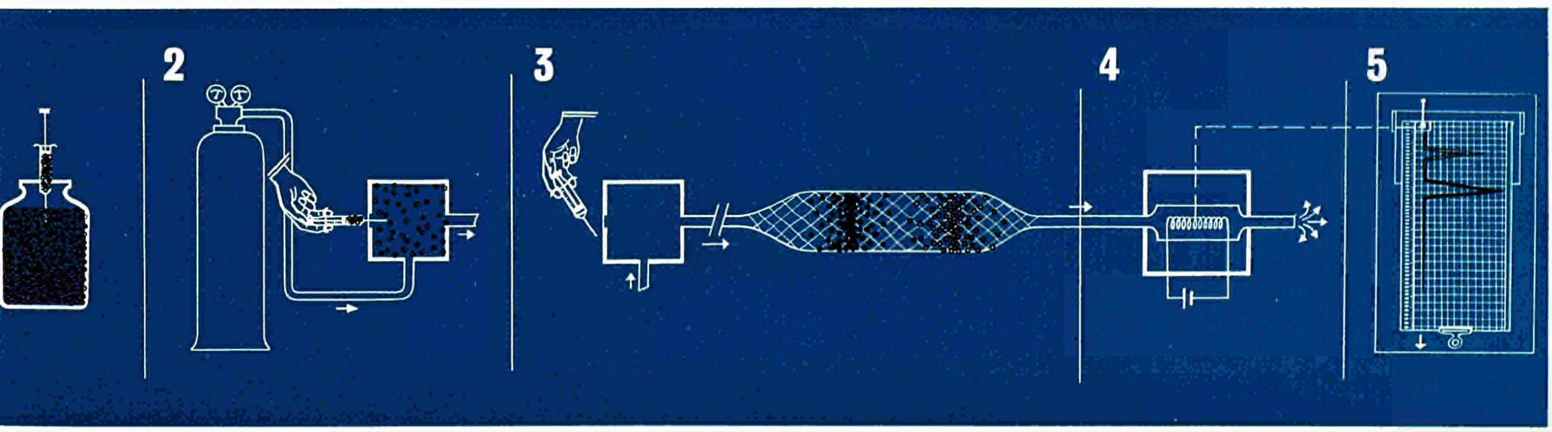
Column chromatography was discovered by the Russian botanist Tsvet as early as 1906 but then fell into oblivion for more than 20 years until, on rediscovery, it enjoyed its first triumphs in connection with the isolation and structural investigation of chlorophyll, the sex hormones and other natural substances (Willstätter, Kuhn, Lederer). Paper and thin-layer chromatography likewise went through long incubation periods. It is barely five years since the latter became known to a wide circle of chemists, but today it is already considered indispensable.

Merely because coloured substances show up on the chromatogram itself (by derivation the word chromatography means "writing in colour"), it should not be thought that chromatographic separation is confined to coloured materials. Most organic compounds are colourless but they can still be separated. Making them visible does, however, give rise to new problems: many of them fluoresce in ultra-violet light; others must first be converted into coloured compounds by chemical reactions on the plate. It is not possible within the scope of this article to go into the relevant details.

Gas chromatography (Figures 4 and 7)

Gas chromatography, since it is based on

Fig. 4: Operating principle of a gas chromatograph. A sample of the mixture to be analysed is taken in a syringe (1). The sample is injected through a rubber septum into the evaporator (2); it is vaporised and mixed with the carrier gas supplied from a cylinder of compressed helium. The mixture flows into the "separation column", packed with a porous material (3), where each component is slowed down to a different degree. A thermal conductivity detector sends a signal every time a component passes through it before being blown out (4). A scriber records the signal on a strip chart (5).



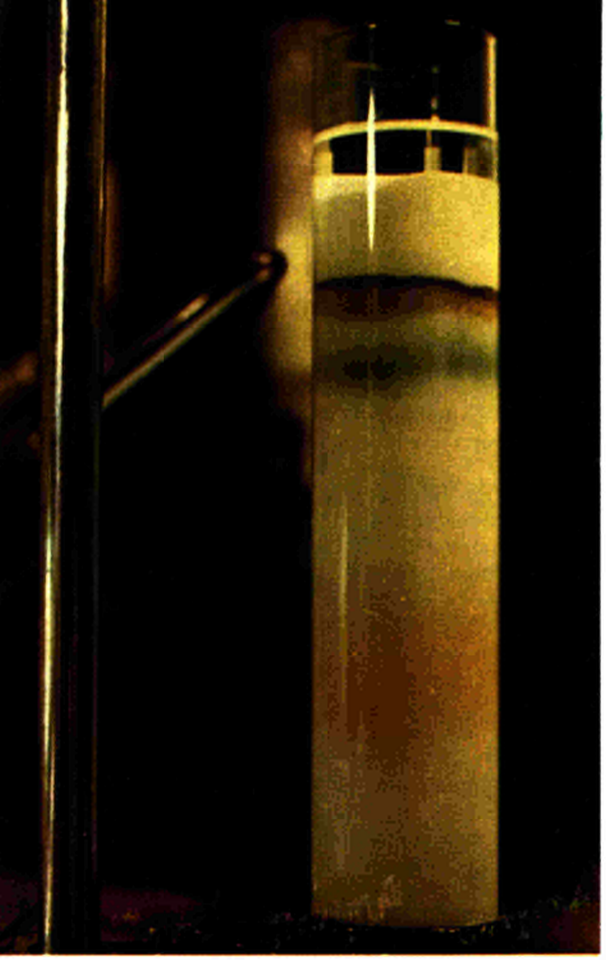


Fig. 5: Photograph of a "column chromatogram". Thin-layer chromatography is the exceptional case of an "open column".

a principle similar to that of the abovementioned techniques, is still nominally a form of chromatography despite the fact that with this method the colour, if any, of the mixture to be separated does not appear in any phase.

A metal or glass tube several metres long is again packed with a particulate adsorption medium such as alumina, but this time of coarser granularity. The resulting "separation column" is connected to the evaporation chamber, into which passes a line from a cylinder of compressed helium, which serves as the "carrier gas" and flows continuously through the column and the detector.

In addition, the evaporation chamber is equipped with a rubber septum. The test mixture can be gaseous, liquid or solid (if solid, it must be dissolved). By means of a syringe the sample is injected through the septum into the heated evaporation chamber and vaporised, whereupon the molecules—now in vapour form—mix with the carrier gas (1st and 2nd phases). As the individual components of the sample pass through the column they are once again slowed down to different degrees, so that they leave the column and enter the detector one after the other. The detector functions as follows: The well of the thermostated metal block houses an electrically heated metal filament which continuously gives off heat to the helium carrier gas flowing around it. The filament remains at a constant temperature as long as there is no change in the composition of the gas. If, however, a component of the sample that has been flushed out of the separation column enters the detector together with the helium, the thermal conductivity of the latter changes with its composition; usually it is lowered, with the result that the filament temperature increases through local heat build-up. During the brief passage of the substance—which is subsequently blown out of the detector—the filament temperature is measured by an appropriate method and logged with the aid of a strip chart recorder, as shown in the diagram. Whereas in thin-layer chromatography the rising liquid provides the (non-specific) *driving force*, in this case it is the carrier gas flow. In both processes the *separation effect* is due to the migration speed differential.

All these chromatographic separation techniques are based on physical processes and consequently the substances do not undergo any chemical change. Another important factor, especially in the case of gas chromatography, is the exceptionally sharp separation obtained with a minute quantity of substance. However, an often lamented disadvantage of gas chromatography is the difficulty in interpreting the

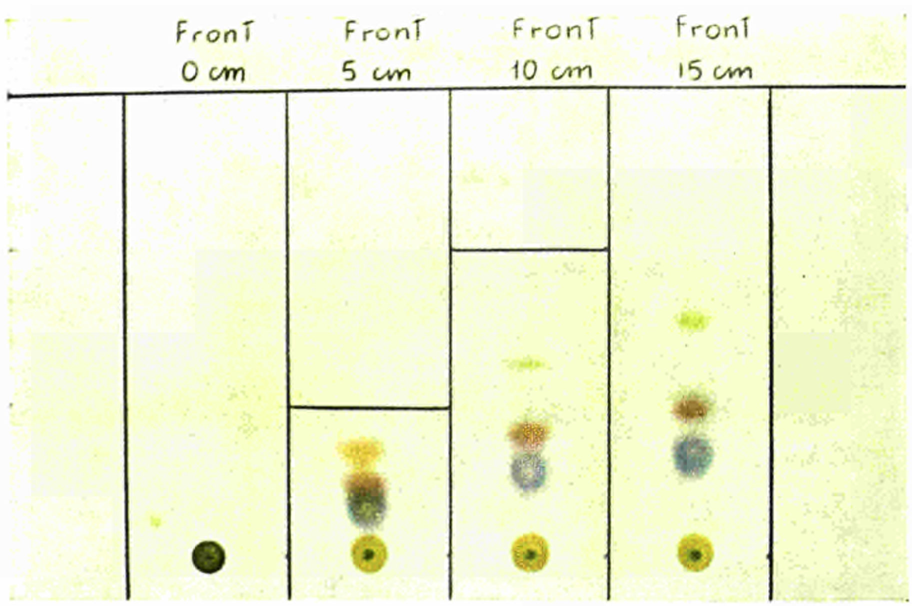


Fig. 6: A thin-layer chromatogram of a mixture of dyes.
From left to right, *initial spot left by the mixture, two intermediate phases during "development" and finally the completed chromatogram.*

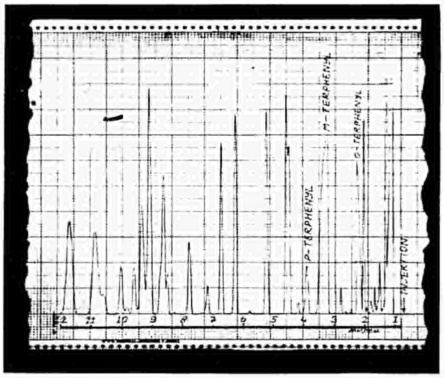


Fig. 7: Gas chromatogram of an actual polyphenyl mixture, as it comes out of a reactor. In the ideal case, there is a peak for each constituent. A mixture of this kind can be split into fractions, by distillation for instance; it is then possible to make a whole series of gas chromatograms, one for each fraction. However, thin-layer chromatography gives a better overall view, as Fig. 1 shows, because the results obtained for each fraction can be readily laid out side by side.

electrically recorded chromatogram. The shape of the band is the same for all the substances; the only difference is the time taken by each substance from the moment of injection to the moment of passing the detector. There is no possibility of identification by colour or subsequent chemical reaction.

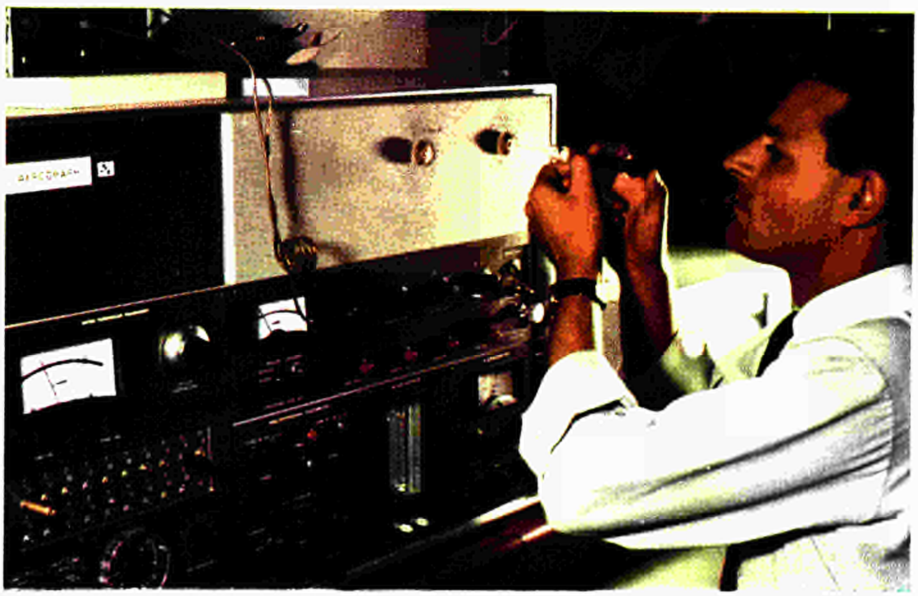
Mass spectrometry

A valuable aid to the identification of unknown substances is mass spectrometry. In Fig. 9, which shows the principle on which a mass spectrometer works, it is assumed that the evaporated sample consists of three components of different molecular weights. The sample is admitted to the evacuated spectrometer via the gas inlet. As they enter the spectrometer the molecules are bombarded with particles from a radiation source. In the resulting collisions they lose one (negative) electron and thereby take on a positive charge: they become "positive ions". They are now attracted at increasing acceleration by a circular negative electrode. They hurtle through the aperture in the electrode and are transformed into "ion beams", which then enter a magnetic field. Here, like the electron beam of a TV tube, they are deflected from their path to a greater or lesser extent according to their molecular weight, the heaviest ones being deflected least. After emerging from the magnetic field the ionised particles (in the example chosen) impinge on a photographic plate at three points, leaving dark spots or lines when the plate is developed. They could also be made visible on the fluorescent screen of a TV tube. The separation is thus based on the magnetic "sorting" of the ionised molecules in flight according to their weight, or as a physicist would say, according to their "mass".

Combined application of the analysis methods described—an example

A polyphenyl mixture can contain the compounds shown in Fig. 10, with the structural formulae and molecular weights indicated. In the gas chromatogram these are all "resolved". If the identity of the substances is not known, all that we can say with certainty is that the mixture contains at least eight components, although we may possibly make certain inferences on the basis of the specific retention times of the substances in the separation column. From the purely theoretical standpoint, there are thousands of other compounds which could occupy the same positions in the chromatogram. Gas chromatography is an extremely powerful and selective method but it is "blind"!
The thin-layer chromatogram gives greatly inferior resolution. Chemical after-treatment enables the third spot from the left to be identified as meta-terphenyl. Consequently, this method is capable of "seeing" something, but it is "lame". However, if the blind and the lame link arms they can

Fig. 8: A gas chromatograph. The working principle of a gas chromatograph is simpler than that of a household refrigerator. But, as can be inferred from the large number of controls, many measurements and checks have to be carried out on the operation of its various components.



manage to get around tolerably well. Further important clues are given by mass spectrometry, which grades the substances by weight. It recognises that substance n° I must comprise two "rings" and that II, III and IV have the same molecular weight of 230 (composed of three rings) and in all probability, therefore, are terphenyls. What it cannot decide in this way is whether one, two or all three of the terphenyls are present. However, it is able of the likewise positively charged fragments is often closely related to the skeleton of the decomposed molecule. Compound VIII, with mass 170, decomposes into the two-ring parent substance of mass 153 and OH of mass 17 (see Fig. 10, bottom). Similar fragmentation patterns were also observed in the case of the other compounds in the mixture, but it is not possible to go into the details here.
Our other two wanderers are thus joined

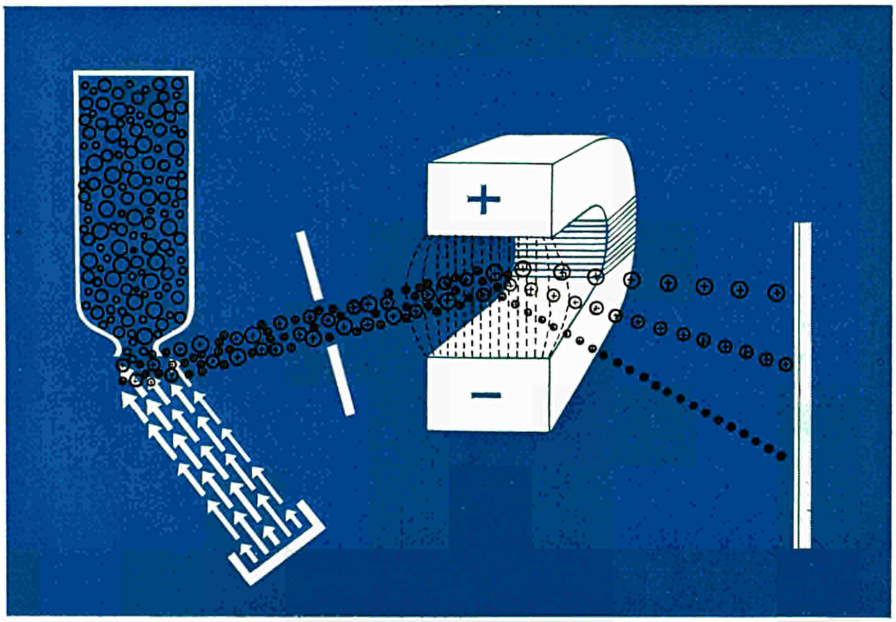
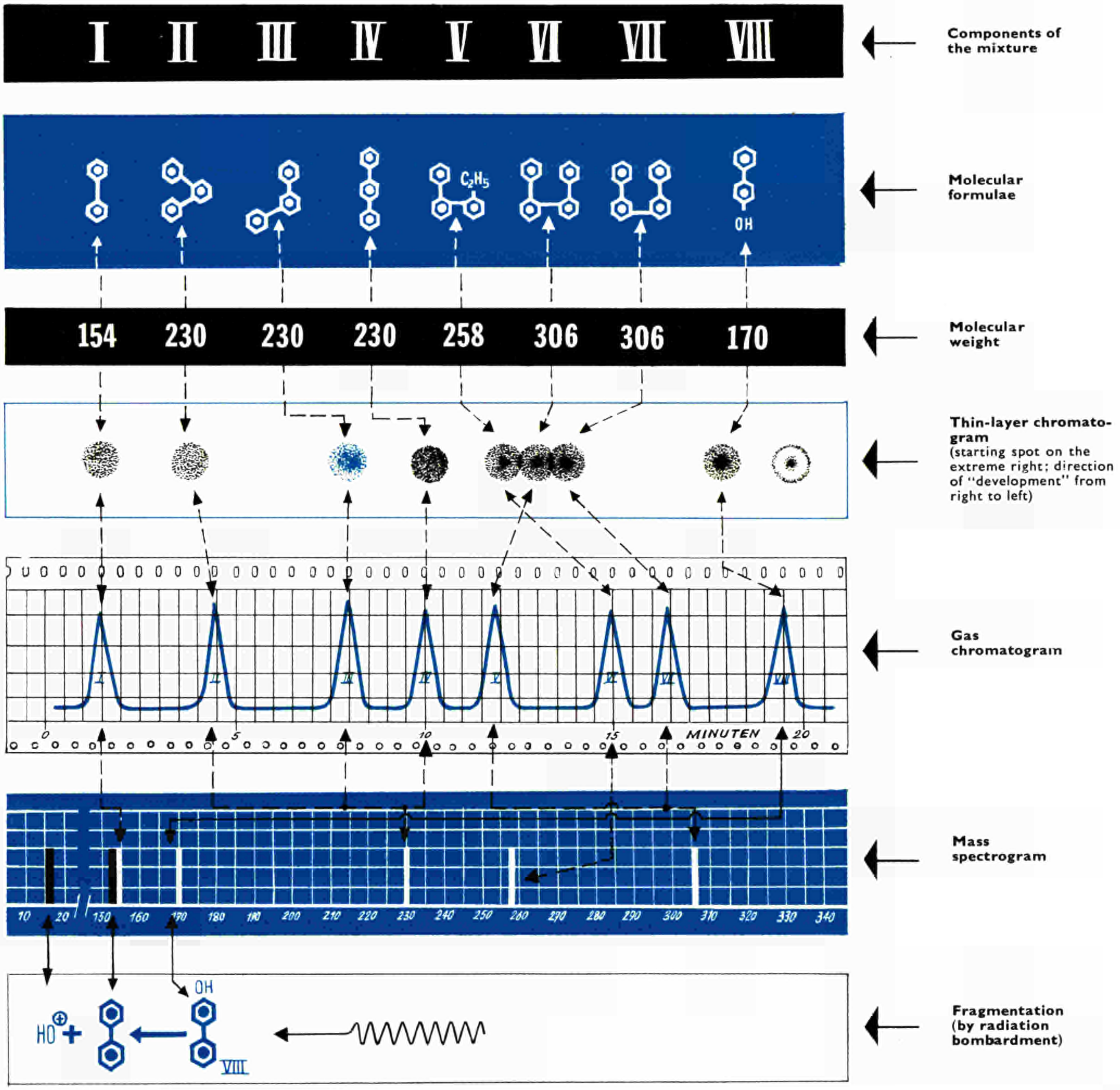
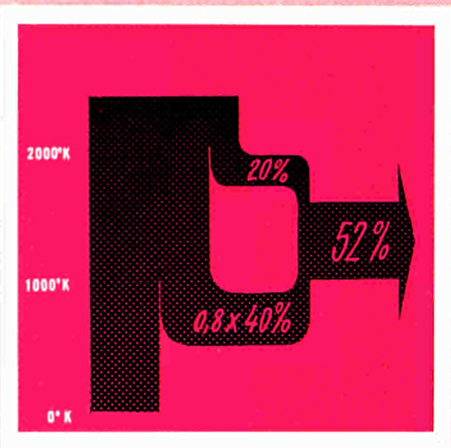


Fig. 9: Working principle of a mass spectrometer

to identify compounds V and VII as belonging to the same family, namely the tetraphenyls. Substance VIII consists of two rings to which is attached a hydroxyl group. Being particularly bulky, it migrates slowly in chromatography and could be mistaken for a substance of high molecular weight. As "seen" by mass spectrometry, it occupies a position "further forward", at mass 170.
Furthermore, mass spectrometry can help to elucidate the chemical structure of this compound: if we increase the energy of the bombarding radiation in the ionisation zone at the moment of collision, some of the molecules arriving will break up. The mass by a third, i.e. mass spectrometry, who knows the short cuts on the road and is able to avoid the wrong turnings.
After the foregoing considerations the reader may ask which of the three techniques is the most useful and which instrument he should choose if he is not able to buy them all. There is no simple answer to this question; it depends on the nature of the specific tasks to be performed and, in the end, on the financial means at hand: a thin-layer apparatus costs less than $250 and a good gas chromatograph about $2.500, whereas a mass spectrometer calls for an expenditure of over $25.000.

Fig. 10: Combined application of different analysis methods - an example





The theoretical efficiency of a system converting heat into mechanical energy depends on the top and bottom temperatures at which it works. This efficiency is given by the ratio $(t_1 - t_2)/t_1$ where t_1 is the top temperature and t_2 the bottom temperature given in degrees Kelvin (i.e. degrees above absolute zero, which is about –273°C). If we take a steam turbine, for example, in which steam is admitted at 800°K and leaves the turbine at 400°K, the theoretical efficiency is 50%. (The net efficiency will of course be smaller—about 40%—because of all irreversible losses.)

It follows that the efficiency can be increased either by reducing the bottom temperature t_2, or by raising the top temperature t_1. As the surrounding temperature sets a natural limit to efforts to reduce the bottom temperature, more interesting prospects are offered by attempts to raise the top temperature; there are no natural limits here, only practical ones, such as the problem of finding materials able to withstand the higher temperatures sought.

The practical limit in the case of steam-turbines, for instance, is today of the order of 920°K (650°C). And yet in the furnace even of a conventional steam-raising plant, the combustion of the fuel takes place at a much higher temperature; so that, although no heat energy may actually be lost, a certain degradation of this energy occurs in view of the fact that it is only used at a lower temperature.

One of the reasons why devices converting heat directly into electrical energy, such as magnetohydrodynamic generators and thermionic converters, have aroused interest in the past years is precisely that they can use heat at higher temperatures.

Admittedly another important reason which makes them immediately attractive is that they do not involve the use of fluids at high pressure or of cumbrous mechanical equipment with rotating parts, but even the low efficiency of about 20% reached with thermionic converters today must not overshadow their long-term prospects as a means of using heat "better", in the sense that they can use it at higher temperatures, functioning as so-called "topping" devices.

A numerical example will best illustrate this: if we make the assumption of a thermionic converter working between the temperature of 2000°K and 1000°K (net efficiency: 20%) as a topping device and use its heat losses to generate steam and drive a turbo-alternator (net efficiency 40%) the overall efficiency of the system becomes 20% + 0.8.40% = 52%, which constitutes a handsome improvement on present day performances.

The thermionic

By far the greatest part of today's electricity needs are produced by turbines and generators, which means that the energy stored in a fuel passes through various stages converting it into other forms of energy before final transformation into electricity.

Although for a long time now conversion processes have been known which can be used to generate electrical energy by a more direct method, none of these so-called direct converters have been capable of rivalling turbines and generators on any large industrial scale. The reason for this is easily found in the fact that the development of these converters is a very expensive business and that the branches of industry concerned considered the financial risk too high compared with the chances of success. Industrial and technological research on direct conversion did not get under way until the largely state-financed development of reactors and power sources for space research was launched, an undertaking necessitated by the fact that both nuclear energy and the requirements of space travel opened up new possibilities for the use of these converters.

The development of the thermionic converter, which was started about 8 years ago, is also to be attributed to this state of affairs. The main aim being pursued now is to develop these converters in combination with reactors or radioisotopes as energy sources for space travel. The data and know-how gained as a result of this effort will naturally also shed light on the potential terrestrial applications.

How the thermionic converter works

The main components of the thermionic

converter and its use in a reactor

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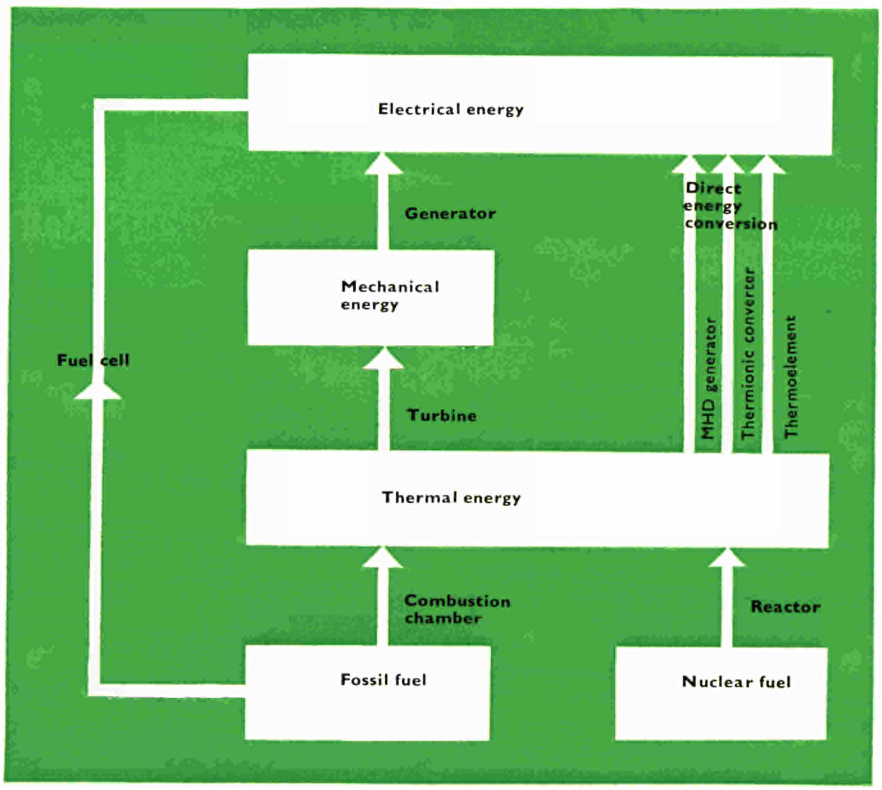
converter are two large surface area electrodes, either in flat or cylindrical array (Fig. 2).
By means of *thermionic emission*, one of the two electrodes, the emitter, emits electrons which pass across into the other electrode, the collector. Thus thermal energy is directly converted into electricity.
The explanation for the phenomenon known as thermionic emission is to be found in the electron theory of metals, according to which the electrons inside a metal move about freely. However, they are prevented from escaping from the surface of the metal by a potential barrier, called the "work function potential", but with increasing temperature there comes a point where some of the electrons have sufficient energy, i.e. are fast enough to overcome this potential barrier. In the process, these electrons are considerably slowed down, but they still possess, after escape, a fairly high potential electrical energy.
Thermionic emission, which may be likened to an evaporation process, is at the same time linked up with a cooling of the emitter. The thermal energy extracted from the emitter reappears basically as the potential electrical energy of the emitted electrons. This describes the conversion process.
What remains is to find ways of *using* the electrons' potential energy. Unfortunately, very much as it is impossible for the working fluid of a heat engine to transform all the heat supplied to it into useful work, the energy thus generated cannot be fully exploited. This is because its exploitation implies arranging for the electrons to flow, and thus constitute an electric current. This cannot be done without the presence of a collector, which receives the emitted electrons and then channels them back to the emitter via the load (an electric motor, for instance) which actually uses the electrons' energy.
But the collector, too, has, like the emitter, a potential barrier, which has to be passed by the electrons before they can be actually "collected". Obviously the system will not unction unless this potential is lower than that of the emitter. However that may be the emitted electrons will lose some o their electrical energy while passing the collector's potential barrier, this energy being converted back into heat. These losses are inherent to the process and can be compared to the compression losses of a heat engine.

Figure 1: Various energy conversion processes



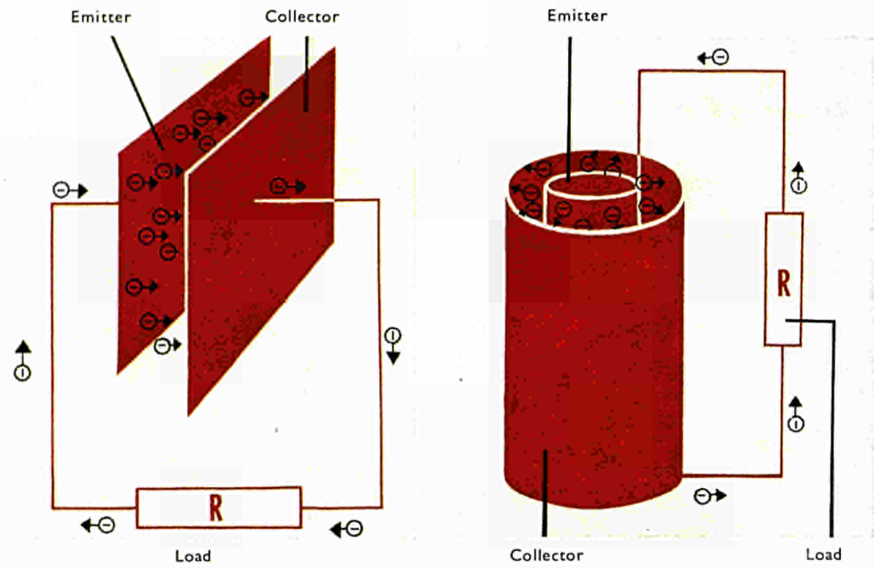


Figure 2: The arrangement of the electrodes and the path of the current in a thermionic converter

This can all be summarised with the help of a potential diagram (Fig. 3).

The theoretical efficiency of the thermionic converter

The electromotive force, or useful voltage, of the converter is derived from the difference between the work function potentials, as can be seen at a glance from the potential diagram. Since metals possess work function potentials of between 1.5 and 5 volts, the maximum electromotive force value to be expected is 3.5 volts.

It can also be seen from the potential diagram that in order to avoid excessive heat losses at the collector, the latter's work function potential must be kept at a minimum.

As for the work function potential of the emitter, it is not so easy to grasp its influence. Apart from the voltage, this potential also governs the electron current and therefore the output of the system.

But the current also depends on the emitter temperature, which on the other hand determines the amount of heat lost irreversibly by the emitter through radiation and conduction.

Figure 4 represents the calculated theoretical efficiency as a function of the emitter temperature and emitter work function potential, taking the interplay of these factors into account. For the collector work function potential, a value of 1.6 volts was adopted in the calculation (a technically feasible value). The results show that a converter does not begin to operate really effectively until working temperatures above 1200°C are reached. It will also be seen that at a given temperature, only one specific emitter work function potential will give optimum efficiency.

A further factor to be considered is the strength of the emitted electron current. Calculations demonstrate that a thermionic converter can be used for the production of electricity on a commercially interesting scale only if the current per unit surface area of the emitter is big enough. Currents of the order of 1 to 50 amperes per square centimetre are in fact needed.

A final remark under this heading of theoretical efficiency must be made. It has already been mentioned that some of the emitted electrons' electrical energy was dissipated in the collector in the form of heat. It may sometimes be desirable to operate the collector at a high temperature in order to facilitate the dissipation of this heat (in space applications, for instance, as will be seen later). In this case the maximum permissible temperature of the collector will be restricted by the re-emission of electrons. For a work function of 1.6 volts, for example, the temperature ceiling will be 800°C.

Achieving optimum efficiency

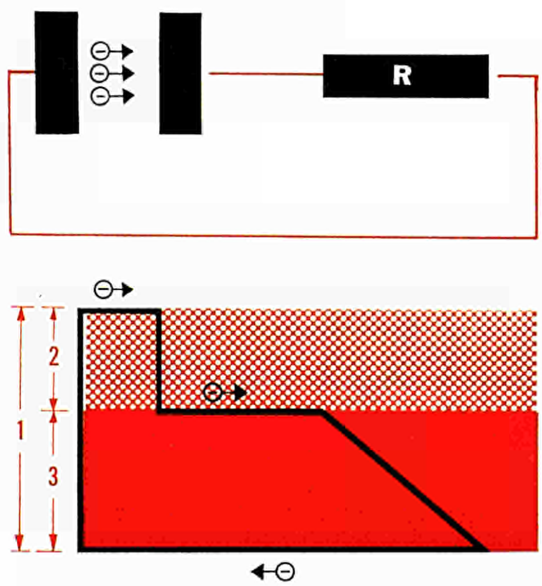
The values calculated in the last section

Figure 3: The electromotive force produced by a thermionic converter. A thermionic converter circuit has been sketched in showing, from left to right, the emitter, the collector and the load. The corresponding potential diagram has been drawn beneath it. The heat supplied to the emitter permits electrons to overcome the emitter's work function potential (say 4.5 volts) and escape to the collector. As the collector has a work function potential too (say 2 volts), the electrons will lose energy correspondingly. The actual electromotive force available is therefore reduced (in this hypothetical case to 4.5–2=2.5 volts).

1 = Emitter work function potential

2 = Collector work function potential

3 = Electromotive force



concerning work function potential, temperature and surface current density are not easily attained. There are two main stumbling-blocks.

First, all potential emitter materials evaporate readily at the temperatures required by optimum operating conditions. In the case of tungsten, for example, a temperature of more then 3000°K is required. At this temperature the evaporation rate is far too high to use this material in a converter. Reasonable working conditions can only be obtained if the work function of emitter materials is reduced by adsorption layers of suitable atoms in order to get a lower optimum temperature.

Second, the high current densities of the emitted electrons generate a space charge in the electrode gap which impedes electron transmission to the collector. The currents required can flow between the electrodes only when the space charge is compensated by positive ions.

The tests carried out in recent years show that caesium vapour is very suitable both for the compensation of the space charge and for the reduction of the emitter work function potential.

The reduction of the work function potential was measured as far back as 1924 by Langmuir, who in the case of tungsten, for example, managed to attain every work function potential value between 1.6 and 4.5 volts according to emitter temperature and caesium pressure. This possibility is of fundamental significance for the construction of long-life converters. Emitter and collector can consequently be built of the same material, so that the properties of the collector are not impaired by emitter material condensed on it. In converters of this type, both electrodes are exposed to the same caesium vapour, and the various work function potentials are set by means of the necessary temperature difference between the two electrodes. In order to prevent any change in the work function at a given emitter temperature, the caesium vapour pressure must be maintained constant at some mm Hg.

The caesium-ions necessary to neutralise the space charge can be produced by an arc discharge in caesium vapour. Under favourable conditions, an arc of this kind will burn at an operating voltage of as low as 0.4 volts. The operating power required is, however, obtained from the conversion process and therefore impairs the efficiency. Thus the optimum values indicated in Figure 4 are reduced in line with the data given in Figure 5. These values correspond roughly to measured converter efficiencies in the temperature range up to 2000°C.

Apart from the arc losses, the production of positive ions gives rise to a further problem which is of decisive importance in converter design. Arc voltages of 0.4 volts occur only at very small electrode gaps. The optimum gap, which is contingent on the vapour pressure, is only 1/10 of a millimetre at a pressure of 1 mm Hg, which means that the construction of converters with optimum electrode gaps is an extremely difficult affair.

The caesium-converter and its use in connection with a reactor

The converters developed by the various research groups are all founded on the same basic concept. The emitter, collector and a ceramic insulating the two electrodes form a vacuum-tight vessel containing caesium vapour. The caesium pressure in the cell is regulated by the temperature of a caesium-filled reservoir. The emitter and the collector, which are normally made of high-melting metals such as tungsten, niobium, tantalum, etc., are assembled with gaps of as little as a few tenths of a millimetre between them. The insulating ceramic used is almost inevitably aluminium oxide, which is welded with niobium into a vacuum-tight assembly. Fig. 6 shows a typical converter design for laboratory tests.

In such converters the emitter is electrically heated, not only in order to be able to check physical properties independently of the reactor, but also to solve all the corrosion problems bound up with the use of caesium and the high temperatures involved.

This development has already given rise to some technically useful converter designs. Cells have been constructed with a sufficiently small electrode gap and a life of up to one year. In favourable instances, the efficiency of these cells attained the values shown in Fig. 5, i.e. 20% at emitter temperatures of 2000°K. Since the small electrode gaps put a restriction on the size of the electrodes, converter output has remained confined to some hundred watts. The efficiency of a unit which must therefore consist of a large number of converters will of course be lower than that of a single element.

This level of efficiency is naturally not comparable with that obtained in an up-to-date turbine. However, converters display a number of substantial advantages for space travel, particularly when employed in con-

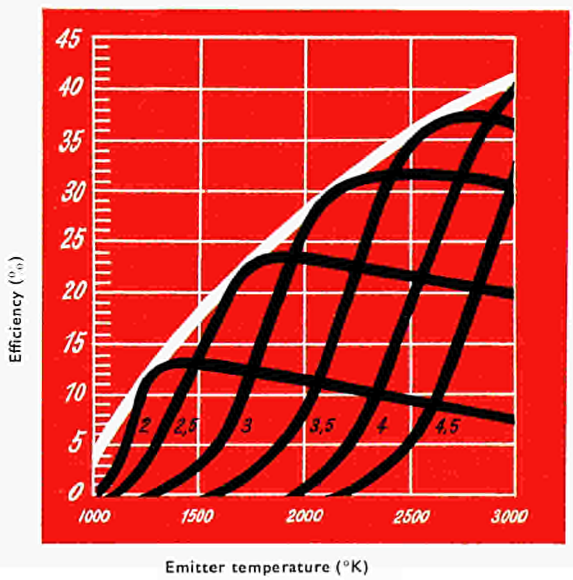


Figure 4: Calculated efficiency as a function of temperature and emitter work function potential.
Each member of the family of black curves gives the efficiency of the thermionic converter for a given emitter work-function, assuming as low a work-function for the collector as is technically feasible, namely 1.6 volts.
The white curve was formed by joining all the points of the black curves corresponding to optimum efficiency.

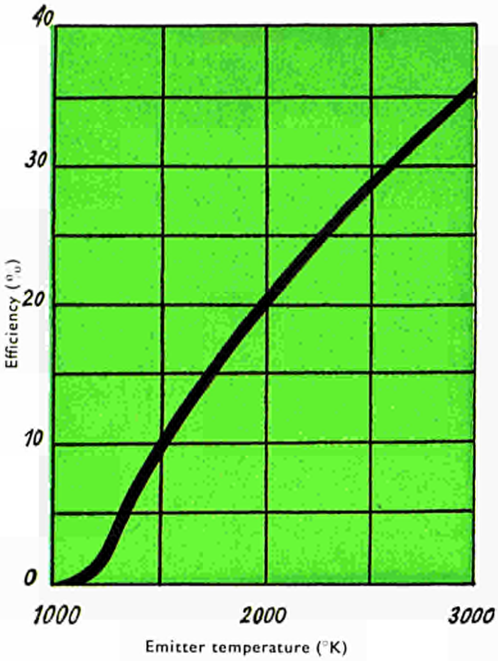


Figure 5: Efficiency of a thermionic converter, taking account of losses between electrodes

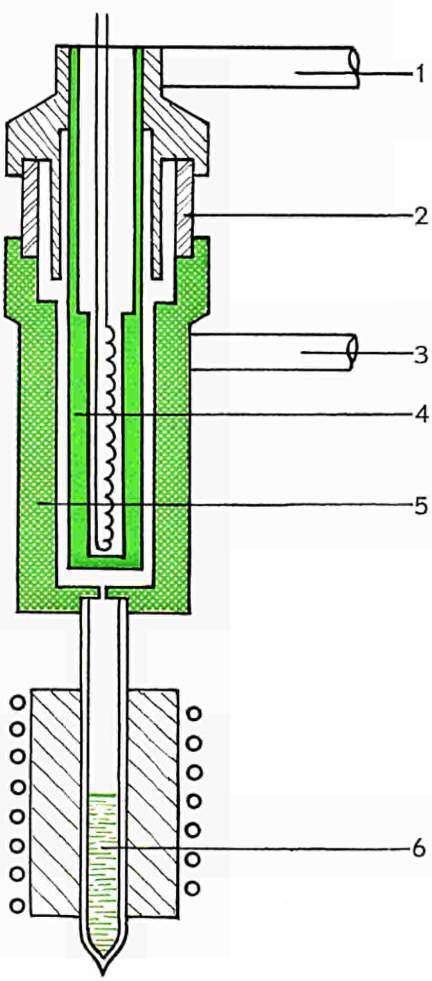
junction with reactors. They possess no rotating parts and heat losses arise at a very high temperature (the collector temperature); this latter is a very favourable factor since the energy source can be cooled in space only via heat radiation. For this purpose reflector surfaces, entitled radiators, are required, which account for a considerable proportion of the weight of the energy source. At a higher heat radiation temperature, the radiator can be built considerably smaller for the same cooling capacity, which results in a reduced total weight of the unit, and the weight of the energy source is of course of decisive importance in space travel.
The high collector temperature makes it also possible to heat up a conventional energy generator unit with the heat losses from the converter and use the converter as a "topping" device. This fact could ultimately lead to a wide industrial use of the converter, provided that it is possible to bring about substantial gains in the reliability and profitability of the system.

Nuclear-heated thermionic converters

The heating of the emitter directly with nuclear fuel is one possibility of using thermionic converters in conjunction with reactors. In this case, the converter assumes the additional function of a fuel cladding, albeit of a somewhat complicated type. In order to solve the material problems which arise, tests have been carried out at various research centres involving the in-pile operation of converters. The fuel used was enriched uranium in carbide or oxide form. As a result of the high emitter temperatures (1600°C and above) applied, these tests ran into considerable technological difficulties caused both by the production of fission gases and contact between fuel and emitter material. In order to eliminate at least the corrosion and diffusion problems stemming from the contact between emitter and fuel, in several tests carried out in the United States (Los Alamos), in Britain (Harwell) and in the Soviet Union, the fuel itself was used as emitter. In all cases the fuel used was a mixed uranium/zirconium carbide. As early as 1962, a cell of this type was operated in Los Alamos with an efficiency of 8%, although the life was only 5 days.
Since, however, in this system the electrode gap could not be kept small enough, better results were obtained with converters in which the fuel was incorporated in the emitter material. In these experiments, the combination of uranium oxide/tungsten or molybdenum, or uranium carbide/tungsten were found particularly promising. In 1963, for example, *General Electric* operated a uranium-oxide-fuelled converter at an efficiency of 9% and an emitter temperature of 1650°C with a life of 20 days. Similar experiments are reported to have been carried out successfully in the United States by *General Atomic* and the *RCA*.
Since 1964, however, the United States has maintained secrecy on these research results, so that there is no up-to-date information on the present state of the art. According to unofficial reports, successful attempts appear to have been made to develop further the clad-fuel converter type at much higher lifetimes. Compatibility studies out of pile showed a lifetime in the range of 10,000 hours for the UO_2-tungsten system.
Experiments have also been carried out in Europe with converters of this kind. There are reports from the Soviet Union

Figure 6: Thermionic caesium converter for laboratory experiments.
1. Emitter lead, 2. Al_2O_3 insulator, 3. Collector lead, 4. Emitter, 5. Collector, 6. Cs-reservoir.

Electrical heating



of tests in which both the concept and the results agree with those of the American experiments.
At Euratom's Ispra Research Establishment, in one of the experiments performed in 1964, lasting for a maximum of 3 days, a converter was operated at an efficiency of 11%. The cell tested was fitted with a molybdenum emitter heated by a uranium/zirconium mixed carbide pin.
To achieve higher cell lifetimes, the Ispra centre has likewise initiated studies on the development of fuel systems, particularly via research contracts with Community firms. The aim of these investigations is to elaborate uranium oxide cermets and spherical uranium carbide fuel particles provided with a suitable coating. Nuclear fuels of this type, it will be remembered, were first used with success in high-temperature gas-cooled reactors.

Reactor concepts

Although the efforts in this sphere are still connected with the development of a functioning converter for in-pile use and, even in the United States, the construction of a thermionic reactor will probably not be initiated in the next couple of years, it would still be useful, in the light of existing concepts, to point out the possible way ahead.
Discussion most frequently centres on a reactor project in which a number of thermionic elements are built up to form a rod-type fuel element. In the rod, the individual elements are electrically hooked up in series, the geometry being so designed that the caesium pressure in all elements can be regulated by means of one caesium reservoir. Series connection considerably raises the useful voltage, which on account of the low converter voltage is very desirable. A thin insulator is also used to seal off the converter electrically from the outer wall of the fuel element, so that the rod can be liquid-metal-cooled without shorting the converters. Fuel rods of this type, assembled in cluster array, will constitute the reactor core. In view of the considerable proportion of structural materials, the fast reactors are the best choice for this concept, in which case provision is normally made to evacuate the heat losses from the core to a radiator by means of a liquid metal coolant loop.

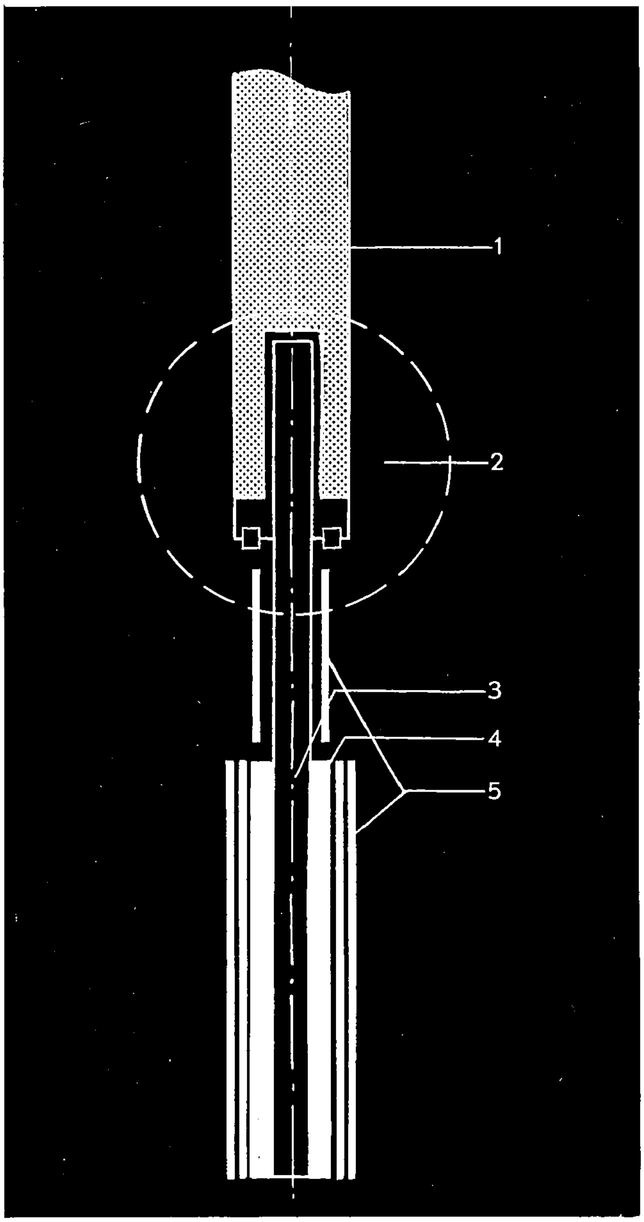


Figure 7: Heat pipe with nuclear fuel and thermionic converter. 1. Collector heat-pipe, 2. Converter, 3. Emitter heat-pipe, 4. Fuel, 5. Heat radiation shield.

In Ispra, a further concept was elaborated which might lead to a low-capacity thermal reactor (10-100 kW). This concept is based on an invention made in 1963 by G. M. Grover at Los Alamos. He succeeded in devising so-called heat pipes which functionally represent heat transfer devices of an extremely high thermal conductivity. These heat pipes are sealed tubes containing a small amount of a substance which is liquid at operating temperature. This substance is evaporated in the heating zone and condensed at the points at which the tube is cooled. Just as in an ordinary lamp wick, a capillary system on the inner wall of the tube serves to suck the condensed liquid back into the heating zone. Heat pipes of this type can be used to heat thermionic elements outside the reactor. Under this concept, the heat pipes have a direct connection at one end with the fuel and at the other with the converter (see Fig. 7).

Logically, the collector is then cooled with a second heat pipe, the surface of which operates directly as a radiator. The fuel is surrounded by a thermal radiation shield intended to prevent unnecessary heat losses. These elements are housed in a moderator matrix which in turn is cooled by heat pipes.

Fig. 8 depicts the spatial layout of this system.

Although the thermal conductivity of a heat pipe is adequate to fulfil the function for which it is designed, it cannot yet be stated with absolute certainty whether a practical use can really be found for this invention. Experiments carried out both in Ispra and at Los Alamos show that the tubes are subject to severe corrosion which leads to the destruction of the capillary system. Since, however, this development is still in its infancy, it is to be hoped that these technological problems can be overcome. Workable heat pipes might then perhaps also be used in other reactor types. The main advantages of this reactor concept as against the in-core design consist in the fact that the converters are not subjected to a neutron flux and that the need for time-consuming and expensive long-term testing of the converters in research and materials testing reactors is thereby eliminated. Long-term testing can be performed in the laboratory, with simulated electric heating, for example. Furthermore, a number of other technical problems can readily be solved at very little cost.

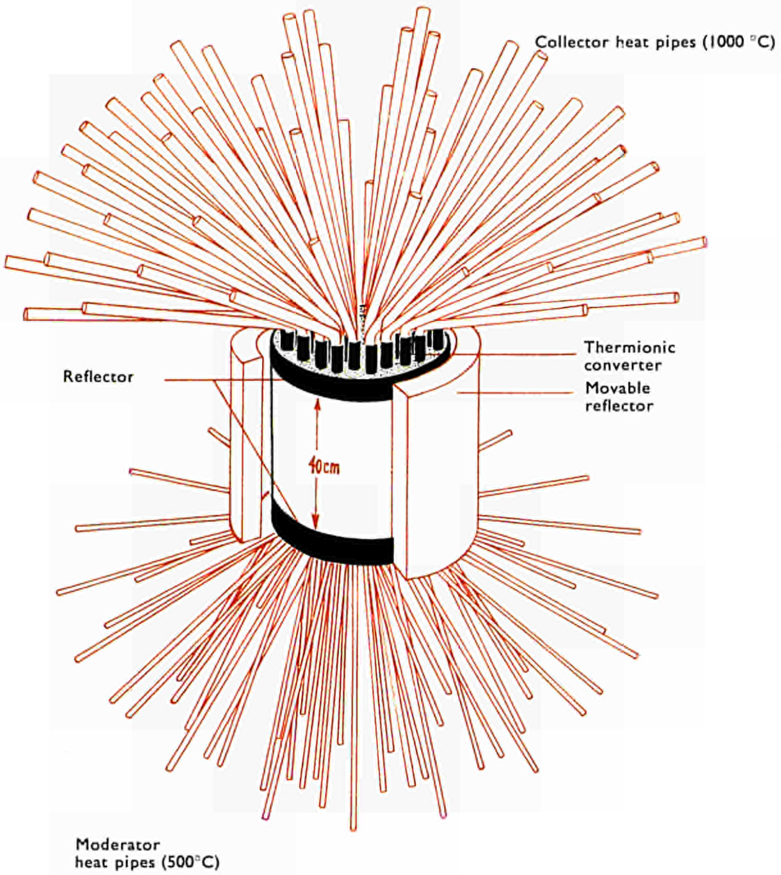


Figure 8: Reactor with thermionic converter and heat pipes (reactor concept)

Test units built at Ispra in which the nuclear fuel is replaced as a heat source by high-frequency generators have already succeeded in producing the anticipated electrical power. Preparations are being made for an operational test with a unit containing nuclear fuel in the *ISPRA I* reactor.

Importance of reactors with thermionic converters

At the present time, thermionic converters in conjunction with reactors are being developed only for space research. The research results obtained give reason to hope that it will be possible to build reactors of this type which, given the operating conditions of the converter, would have a favourable weight/capacity ratio and would become highly valuable as energy sources for satellites and space ships.

The construction of converters, moreover, makes it vital to devise new nuclear fuels and in general to forge ahead with research on in-pile high temperature technology. A fundamental point of this line of research, however, lies in the fact that it will decide the question as to whether thermionic converters will prove a reasonable commercial proposition for nuclear power generation as "topping" devices.

A new documentation centre: Eastatom

Euratom and the *Kernforschungsanlage Jülich* (Germany) announced on 28 October 1965 the creation of *Eastatom*, a centre for selection and acquisition of East European documents of nuclear interest which, according to available information, have neither been mentioned by Western sources nor translated into Western languages. Director of the centre is Dr. Günther Reichardt, well known as an expert on Eastern scientific literature.

Eastatom will supply, on request, photocopies of the original documents or translations into one of the four languages of the European Community or into English.

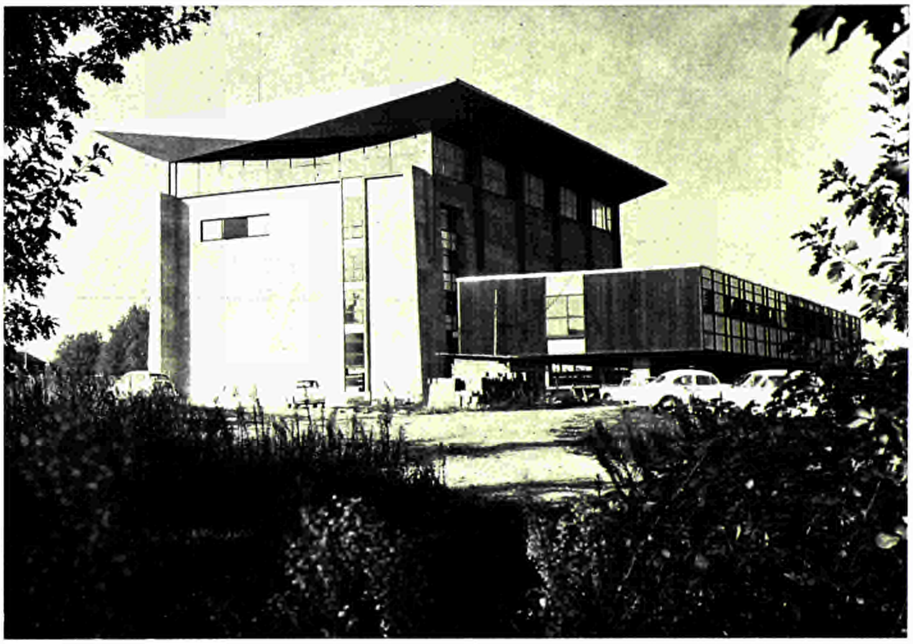
From January 1966, the monthly Euratom periodical *Transatom Bulletin* has been listing, in a supplementary Section III, a selection of titles from *Eastatom*'s collection.

ECO goes critical

The *ECO* reactor (*ORGEL* critical experiment) went critical on 11 December 1965 at Ispra. The *ECO* reactor consists basically of a heavy water vessel large enough to hold a uranium carbide and organic liquid lattice of critical size.

ECO has the special feature of possessing an automatic pitch-variation system which makes it possible to obtain a whole range of configurations and to vary the distance between the rods from 170 to 300 mm.

By means of *ECO* it will be possible to obtain extremely accurate data on the physics of *ORGEL* reactors.



ECO *reactor building at Ispra (Italy)*

Fuel elements from the Community to be irradiated in the Enrico Fermi reactor

On 13 December 1965 Euratom signed a contract with *Atomic Power Development Associates (APDA)* of Detroit, U.S.A., for the irradiation of about eighty fuel elements from the Community in the *Enrico Fermi Fast Breeder Reactor (EFFBR)*. This contract, to the value of three million dollars, was signed by the Commission on behalf of Euratom and three of its association partners in the field of fast reactor research, the *CEA* (France), the *GfK* (Federal Republic of Germany) and the *CNEN* (Italy).

The *EFFBR* is a most suitable instrument for such irradiation work since it can irradiate the longest test elements at a higher power level (due to the large neutron flux) than any other facility.

The influence of nuclear technology on conventional industry

Nuclear technology, which took its first steps in various Community countries over twenty years ago now, has exerted a major influence on conventional industry and the entire economic and social sector. The leading figures in industry, public authorities and the various organisations concerned have long been aware of the importance of this development.
The labour unions in particular made an early attempt to tackle the question of the repercussions of nuclear technology, and at a conference held by Euratom at Stresa in May 1965 with union representatives from the member countries it was agreed that the Euratom Commission should arrange for the carrying out of a study on the economic and social effects involved.
After detailed preliminary investigations, it was decided by the Euratom Commission that a survey should first be carried out on the technical repercussions of nuclear technology and on some of the economic consequences of its development, to be supplemented later by studies covering the entire social and economic sector.
A contract drawn up for this purpose with the firm of *Kienbaum-Unternehmensberatung, Gummersbach*, came into force on 1 January 1966 and is due to run for eight months.
Under this contract, the knowhow, techniques, materials and installations developed for the nuclear field are first to be listed and classified, after which they will be assessed from the standpoint of their importance and the potential uses to which they can be put in conventional industry and in certain services. In a number of particular cases, certain social effects are to be examined in addition to the industrial and economic consequences. Methods are also to be devised for future studies covering the entire economic and social sector.

Euratom concludes two further association contracts on fast reactors

The Euratom Commission announced on 4 January 1966 the signature of an association contract for research on fast breeder reactors with the Belgian Government. The Commission had already signed on 23 November 1965 a similar association contract with the Dutch *T.N.O. (Organisation for Applied Scientific Research)* and the *R.C.N. (Netherlands Reactor Centre)*, the negotiations for the two contracts having taken place in parallel.
The Euratom/Belgium Association signed on the same occasion two further contracts with *BelgoNucléaire* and the *C.E.N. (Centre d'Etude de l'Energie Nucléaire)* respectively for the execution of the research programme. Under these contracts, Euratom will be contributing \$1.1 million (35% of the total cost) for three years from 1 January 1965 for work on uranium-plutonium oxide as fuel, including reprocessing, along with fast reactor physics and technology.
Under the terms of the contract with the *T.N.O.* and the *R.C.N.*, Euratom will be contributing \$1.4 million (also 35% of the total cost) over the same period to research on problems associated with the use of sodium as coolant and the development of such reactor components as steam generators, heat exchangers and sodium pumps.
The work under the Belgian and Dutch Associations is closely linked with that under the *Euratom/GfK (Gesellschaft für Kernforschung)* Association's programme at Karlsruhe.
The conclusion of these contracts brings all fast reactor work being performed in the Community into the Euratom Programme. Altogether Euratom is allocating \$ 82½ million from the revised Second Five Year Research Programme (1963-67) to fast reactors, which is a priority field of Euratom research. With the contributions of Euratom's partners added, taking account of the fact that Euratom is contributing 35% to the cost of the work under the other three association contracts in this field (with the French *C.E.A.*, the German *GfK* and the Italian *C.N.E.N.*), the total Community effort may be estimated at around \$ 230 million over the five year period.

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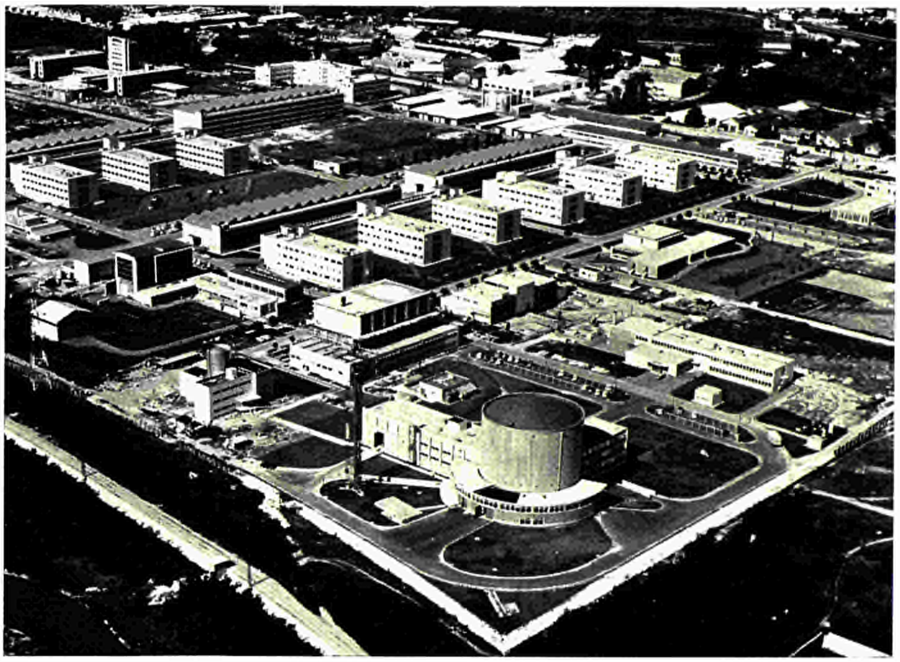
The proceedings of two international meetings held in Grenoble and sponsored jointly by Euratom and the French Commissariat à l'Energie Atomique *at the end of June 1965 have just been published.*



Grenoble nuclear research centre (France)

Plastic for accelerator targets

The first of these meetings, which was devoted to accelerator targets designed for the production of neutrons, had as its principal aim the pooling of experience on methods of improving the life of targets and the intensity of the neutron flux they produce.
This is not a purely academic aim; the long-term practical objective is to make it worth while for individual laboratories and firms to buy their own equipment for neutron activation analysis. The equipment consists basically of a low tension accelerator which aims deuterons at a tritium target. The accelerator itself is relatively inexpensive; what has acted as a deterrent up to now is rather the fact that no-one has yet been able to produce a target capable of lasting more than a few hours.
The result of this situation is that many of those wishing to reap the benefit of a refined technique such as neutron activation analysis must go to the trouble of sending samples to a nuclear centre or simply do without.
Some hopes were kindled during the meeting by a paper presented by scientists working in Liège under Euratom contract; they have obtained good results through using a rather unusual material for an accelerator target, namely plastic.

Activation analysis with charged particles

The second of the two international meetings held in Grenoble in June 1965 under the sponsorship of Euratom and the French *Commissariat à l'Energie Atomique* dealt with the practical aspects of activation analysis with *charged* particles (as opposed to neutrons).
There are very few specialists in this field in the world to-day. The meeting was made possible by the willingness of several of them to get together and allow their brains to be picked by the less expert: they were thus able to hand out the benefit of their experience with a technique which, although it offers exciting prospects, is difficult to apply.
The use of charged particles instead of neutrons for activation analysis offers startling advantages in some applications. For instance, whereas oxygen in a material will pass unnoticed after neutron activation as soon as it is present in quantities smaller than about 50 parts per million, activation with charged particles will permit the detection of as little as a few thousandths of a part per million.

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