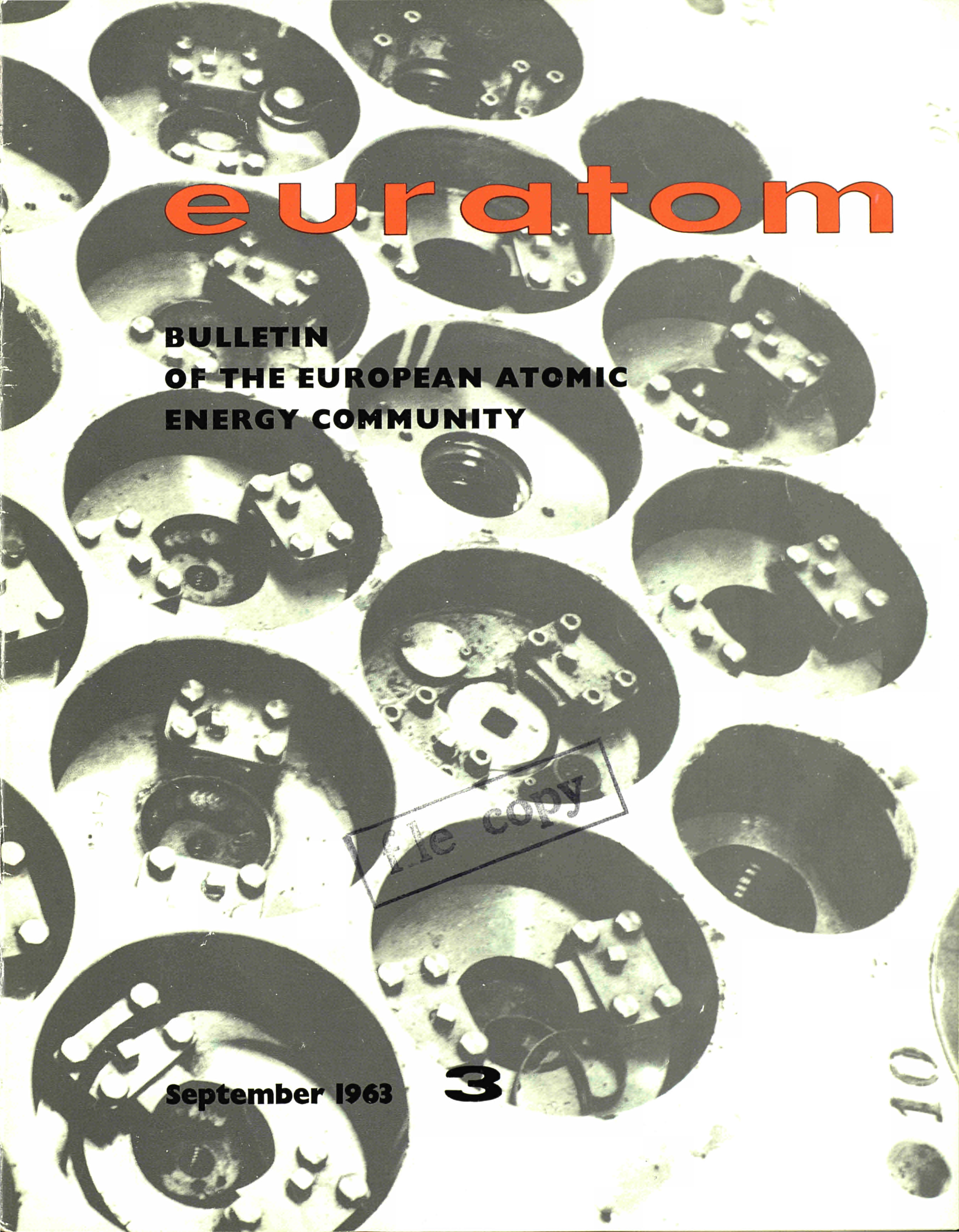
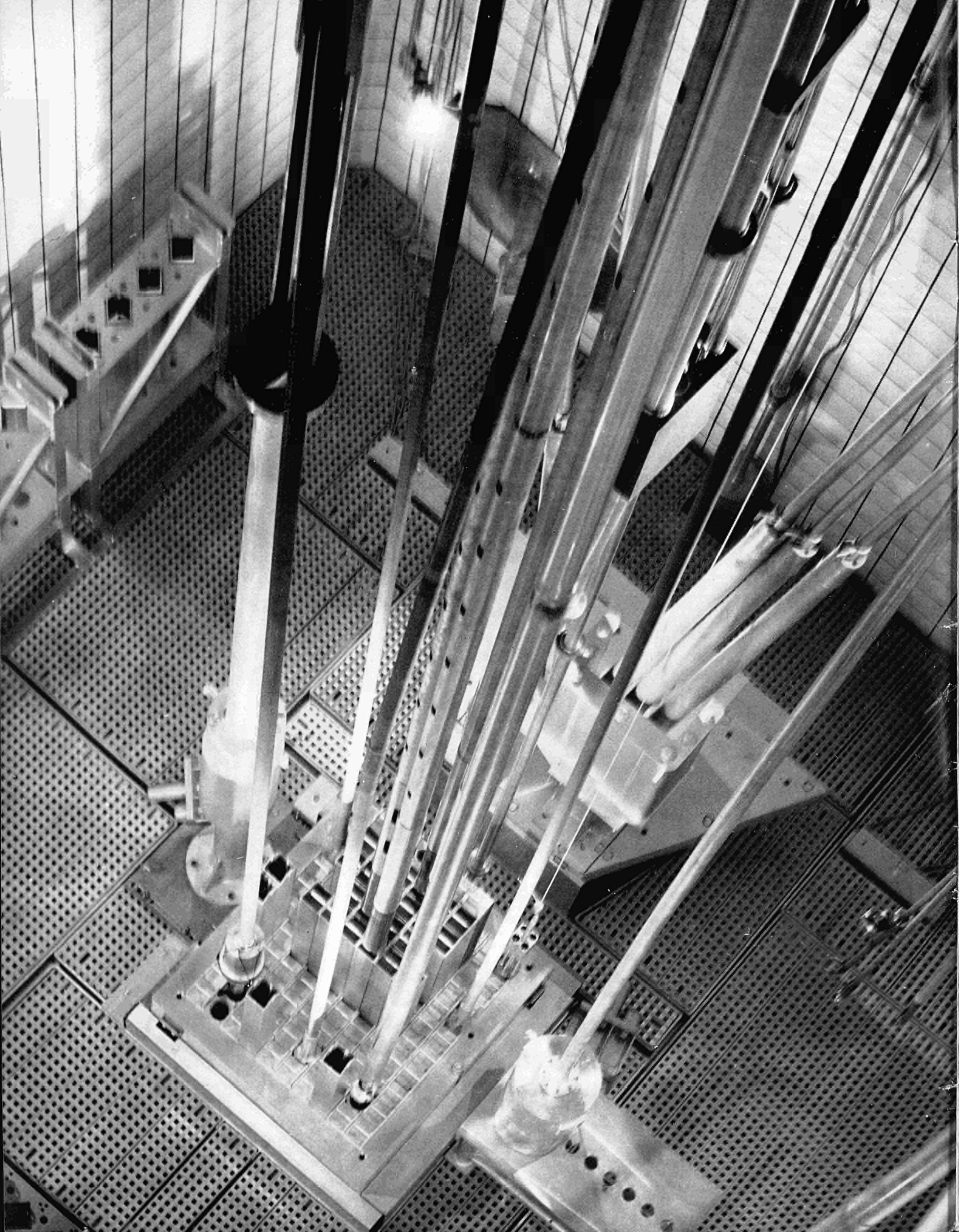


euratom

BULLETIN
OF THE EUROPEAN ATOMIC ENERGY COMMUNITY

September 1963 3



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

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◄ *The research reactor SILOE at the Nuclear Study Centre, Grenoble (France), in which an organic loop belonging to Euratom will soon be installed.*
Cover: *Fuel element container in the reactor hall Ispra I*

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

1963 - 3

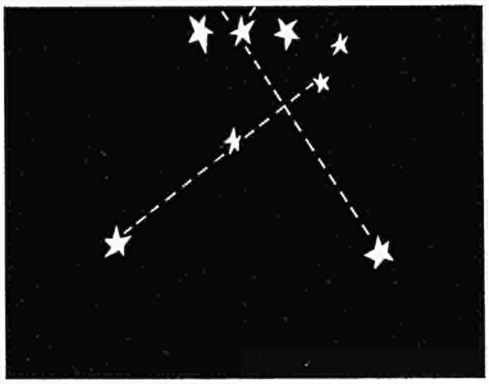
The Community's mission is to create the conditions necessary for the speedy establishment and growth of nuclear industries in the member States and thereby contribute to the raising of living standards and the development of exchanges with other countries (Article 1 of the Treaty instituting the European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

adioisotopes radioisotopi radioisotopen ship propulsion schiffsantrieb propulsion navale propulsione navale scheepsvoortstuwing biology biologie biologie biologia biologie medicine medizin médecine medicina geneeskunde health protection gesundheitsschutz protection sanitaire protezione sanitaria bescherming van de gezondheid automatic data processing automatische information information automatique informazione automatica automatische verwerking van gegevens insurance versicherungswesen assurances assicurazione verzekeringen economics wirtschaft économie economia economie education and training ausbildung enseignement insegnamento onderwijs en opleiding power reactors leistungsreaktoren réacteurs de puissance reattori di potenza energie reactoren nuclear fusion kernverschmelzung fusion nucléaire fusione nucleare kernversmelting radioisotopes radioisotope radioisotopes radioisotopi radioisotopen ship propulsion schiffsantrieb propulsion navale propulsione navale scheepsvoortstuwing biology biologie biologie biologia biologie medicine medizin médecine medicina geneeskunde health protection gesundheitsschutz protection sanitaire protezione sanitaria bescherming van de gezondheid automatic data processing automatische information information automatique informazione automatica automatische verwerking van gegevens insurance versicherungswesen assurances assicurazioni verzekeringen economics wirtschaft économie economia economie education and training ausbildung enseignement insegnamento onderwijs en opleiding power reactors leistungsreaktoren réacteurs de puissance reattori di potenza energie reactoren nuclear fusion kernverschmelzung fusion nucléaire fusione nucleare kernversmelting radioisotopes radioisotope radioisotopes radioisotopi radioisotopen ship propulsion schiffsantrieb propulsion navale

There is much talk nowadays of the "breakthrough" of nuclear energy as a competitive source of electricity. Facts and figures support the view that it will occur in 1970 or thereabouts and that nuclear energy will then be swept forward into a career of intensified development under the impetus of economic forces. The mere passage of time is not, of course, what will bring this prediction into fulfilment. The success of nuclear energy depends on a major research effort; it depends on careful sifting of the data provided by operating experience on existing power plants; it depends on "optimisation".

There is nothing essentially novel about optimisation. A manufacturer who tries, for instance, without adversely affecting the quality of his product, to improve its design in order to reduce its price is "optimising". Many of the products on the market to-day have emerged ultimately out of long processes of development stretching far back into time. The designers of nuclear power plants, faced with the task of trying to compress the processes of development into as short a time-span as possible and finding that the method of trial and error and piecemeal improvements is incompatible with this purpose, have perhaps become primarily responsible for making optimisation into a fine art. It is an art which, as Mr. Lafontaine shows in the following pages, has to make use to the full of the opportunities for speed and accuracy offered by modern electronic computers. Nuclear energy will therefore owe much to optimisation for the speed with which it passes its first hurdle.

ORgel optimisatION



FRANÇOIS LAFONTAINE,

"Orgel" Project, Directorate-General for Research and Training, Euratom.

At the beginning of the atomic age, the construction of a nuclear reactor was not governed by economic considerations. The chief aim was to construct an apparatus with the sole merit of being workable. It was the same when the steam-engine was invented. The concepts of output and cost were born when people began to compare the various modes of producing energy with one another.

The heroic epoch of nuclear energy is now over and nuclear power stations must conform with the present economic exigencies. Unfortunately nuclear technology cannot be based on long and multiple experiments which swallow up a great deal of time and money. To make a judicious choice between the various relevant experiments and between the various designs for a proposed power station it is necessary to undertake lengthy theoretical work and to "optimise".

Optimisation

"Optimisation" is no novelty. Every human being has to face a number of choices every day; since his resources are limited, he organises his expenditure in such a way as to derive the maximum benefit from it. In technology too, every industrialist optimises his activities in order to obtain maximum profits. For example, most motor car manufacturers strain every nerve to reduce the price of their vehicles, to make them more comfortable, to make them more economical from the point of view of petrol consumption, etc. The sort of problem which arises can be seen at once: to what extent should light alloys be used, thereby making the vehicle dearer but promising lower fuel consumption to the user? To put the question in a more general form: if one embodies this or that improvement, is one not liable to create drawbacks which will cancel out the gains one is seeking?

However, optimisation presents special difficulties when applied to nuclear power reactors. With conventional machines it is admittedly necessary to make judicious compromises, but each new design can be based on experience gained from many older installations, whereas in nuclear energy this experience is more often than not lacking.

The reason why the compromises to be effected when a nuclear power station is designed are so complicated is, of course, that the requirements of the specialised sciences concerned are often contradictory —thermics, neutronics and thermodynamics, to name only three. For example, a high outlet temperature for the fluid which extracts the heat from the reactor core offers unquestionable a priori advantages, as it enables the power plant to give a better thermal yield; but on the other hand it entails high temperatures and pressures in the reactor core, thus raising problems in various fields, and in particular those of metallurgy, technology, chemistry and neutronics. Although the price per kWh of the power supplied by the station tends to fall in direct ratio to the rise in the outlet temperature of the heat-transfer fluid, a limit is finally reached beyond which the influence of other factors will produce the inverse phenomenon. Hence it is necessary to arrive at exact compromises between the requirements of the different specialised sciences.

Optimisation of an ORGEL power plant

This necessity became apparent, for example, in the ORGEL (ORGanique Eau Lourde) programme under which power stations are to be constructed with reactors cooled by an organic liquid, moderated by heavy water, and fuelled with natural uranium[1]. The calculations could, of course, be done "by hand", but this solution would involve

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[1] The ORGEL project has an important place in the Euratom research programme, being the main focus of activity at the Joint Research Centre, Ispra. In addition, various institutions and industries of the European Community are studying ORGEL problems under contract to Euratom. A "critical ORGEL experiment" (ECO) will soon be ready at Ispra and the preparation of the site for a test reactor (ESSOR) is under way, also at Ispra.

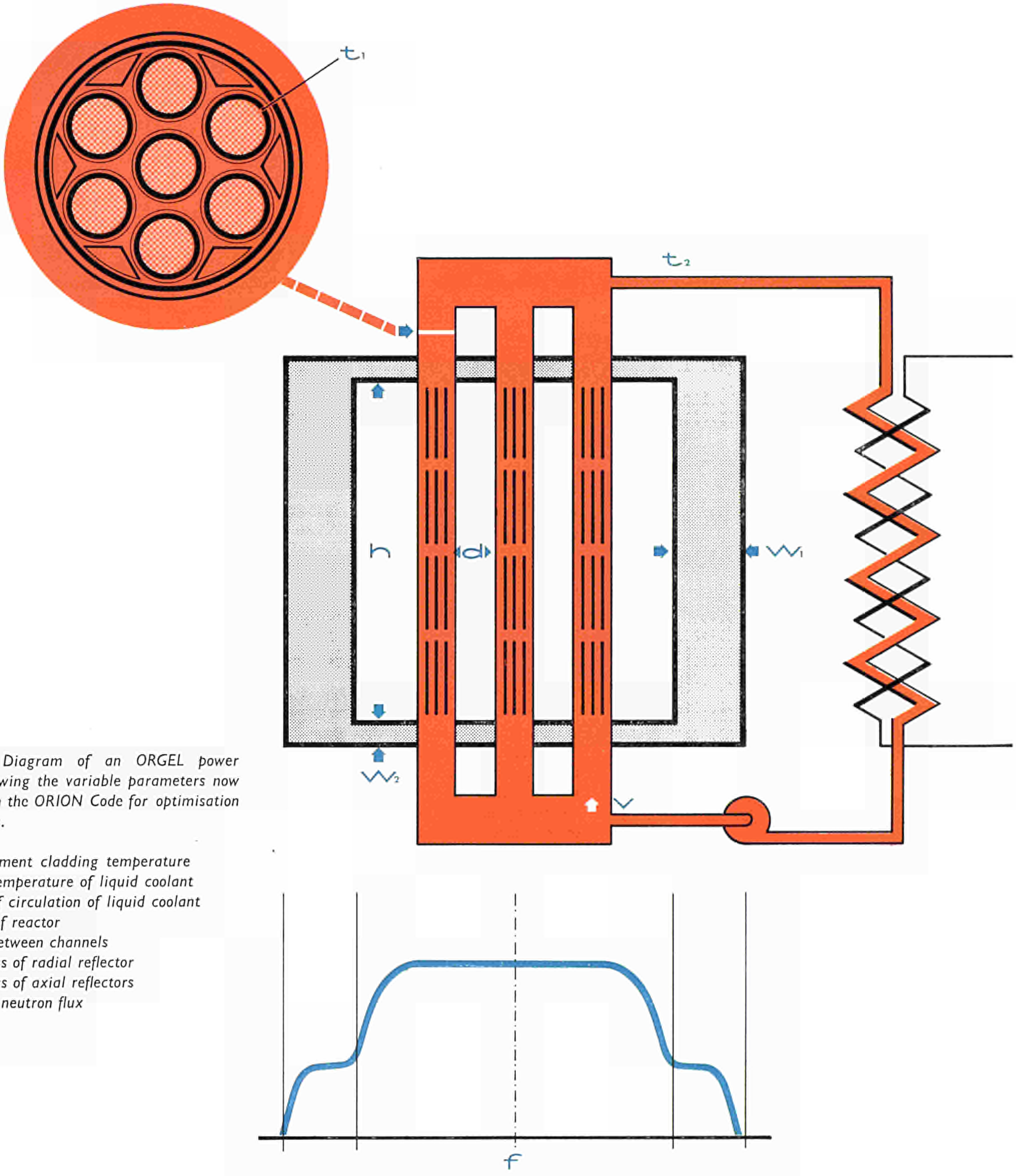


Figure 1. Diagram of an ORGEL power reactor showing the variable parameters now employed in the ORION Code for optimisation calculations.

t_1	*fuel element cladding temperature*
t_2	*outlet temperature of liquid coolant*
v	*speed of circulation of liquid coolant*
h	*height of reactor*
d	*space between channels*
w_1	*thickness of radial reflector*
w_2	*thickness of axial reflectors*
f	*form of neutron flux*

such protracted and laborious work that it has been decided to do them by computer. A mathematical model of the power plant has therefore been constructed, reproducing as faithfully as possible the inter-relations of the various component parts of the station and making it possible, given certain basic data, to calculate the cost of the energy produced and to elicit automatically the "optimal" compromise between the divergent requirements of the specialised sciences in question.

This mathematical model, which was programmed on an IBM 7090 under the name of "Code ORION" (ORgel optimisat ION), makes it possible to determine the characteristics of an Orgel power station, with a certain output, capable of supplying electrical power at the lowest possible price. The method has another advantage besides rapidity: account can be taken of the results of the various calculations so as to redirect research along the most promising lines from the economic point of view.

The following brief description of the ORGEL power plant will make it easier to illustrate the usefulness of the Code:

This plant, whose power is at present fixed at 250 MW, consists mainly of (see Fig. 1):

1. A reactor in which nuclear energy is transformed into heat energy and transmitted to an organic heat-transfer liquid;
2. A group of heat-exchangers in which the heat energy of the organic liquid is transmitted to the water/steam system;
3. A turbo-alternator group in which heat energy is transformed into electrical energy.

The nuclear reactor is worth describing in greater detail; it is composed of a cylindrical tank filled with heavy water and crossed from side to side by about 400 "calandria" tubes. Inside the latter are placed "pressure-tubes", so called because the cooling fluid—in ORGEL an organic liquid—circulates in them under slight pressure. The pressure-tubes also contain the fuel elements; in order to facilitate heat extraction, the latter are more or less finely divided, assuming the form of either an assembly of concentric tubes or clusters consisting of a number of rodlets.

In order to limit the heat losses between the heat-transfer-liquid, fuel-element and pressure-tube assembly, called "the channel", and the heavy water, an insulator is placed between the pressure-tube and the calandria tube; this insulator may be inert gas, organic liquid, or a porous solid.

Design choices and dimensional choices

It is easy to see that such an installation derives from a large number of choices, which may be classified in two main categories—*design* choices and *dimensional* choices.

The following may be quoted as examples of *design* choices: the kind of fuel (metallic uranium, uranium oxide, or uranium carbide); the geometric form of the fuel element (cluster or assembly of concentric tubes); the method of insulating the channels; the method of loading the fuel; the steam cycle. As *dimensional* choices may be instanced the numerical value of certain parameters such as the distance between the rodlets of a fuel cluster, the inlet and outlet temperature of the organic liquid, the height and radius of the reactor, the distance between the channels.

Design choices are few in number; the same is not true of dimensional choices, whose number is practically limitless. It is therefore impossible to classify dimensional choices in order of importance without recourse to modern electronic computers. The amount of calculation depends on the number of parameters under consideration; in fact, the higher the number of parameters the greater the quantity of possible choices. For example, the number of possible solutions to a problem with four parameters, each of which can have ten numerical values, is 10 10 10 10, i.e. ten thousand, whereas if the number of parameters is ten the number of solutions is ten thousand million.

As the number of the principal parameters to be considered in designing the ORGEL power plant is fifteen, it can be seen at once that the optimal design for the plant can only be obtained with the aid of a computer.

The ORION Code

The first version of the ORION Code made it possible to calculate the characteristics of an optimal ORGEL plant with respect to four parameters: the present version makes possible the same calculation with respect to eight parameters, which is a decided improvement.

The ORION Code comprises three main parts, corresponding to three clearly marked stages in the calculating operations—the dimensioning of the reactor, the calculation of the cost of the energy produced by a reactor with these dimensions, and finally the search for the numerical values for the eight parameters which will reduce the cost of the power to a minimum.

The Code has, of course, what may be called a skeleton, and it is around this that the values of the eight parameters can be made to vary. This skeleton consists of a collection of data corresponding to "design" choices, in the sense already defined. For example, the organic liquid which is to be used as a coolant is the result of a design choice and therefore its physical characteristics do not need to be introduced as variable parameters; on the contrary, once they have been determined as accurately as possible, the relevant data are introduced into the skeleton of the Code. The same is true of the neutron characteristics of the lattice, since they depend upon the fuel and the moderator, both of which have been fixed by a design choice. As for the conventional part of the power plant, it is hardly appropriate to speak of choice, since this cannot, to all intents and purposes, be anything but a water/steam cycle; however, it was necessary to calculate the outputs corresponding to various outlet temperatures of the organic coolant liquid, using as a basis the wealth of experience available in this field.

All these data were obtained with the help of either experiments or theoretical studies, some of which were carried out at the Ispra establishment of the Euratom Joint Research Centre and others in the numerous laboratories and computer centres in the Community.

Dimensioning of the reactor

On the basis of these data, the first stage of calculation may be embarked upon, i.e. the dimensioning of the reactor. The eight parameters mentioned above are introduced, namely the outlet temperature of the organic liquid, the temperature of the fuel-element cladding, the organic liquid circulation speed, the height of the reactor, the distance between the channels, the thickness of the radial reflector, the thickness of the axial reflectors and the form of the neutron flux (see Fig. 1). This first

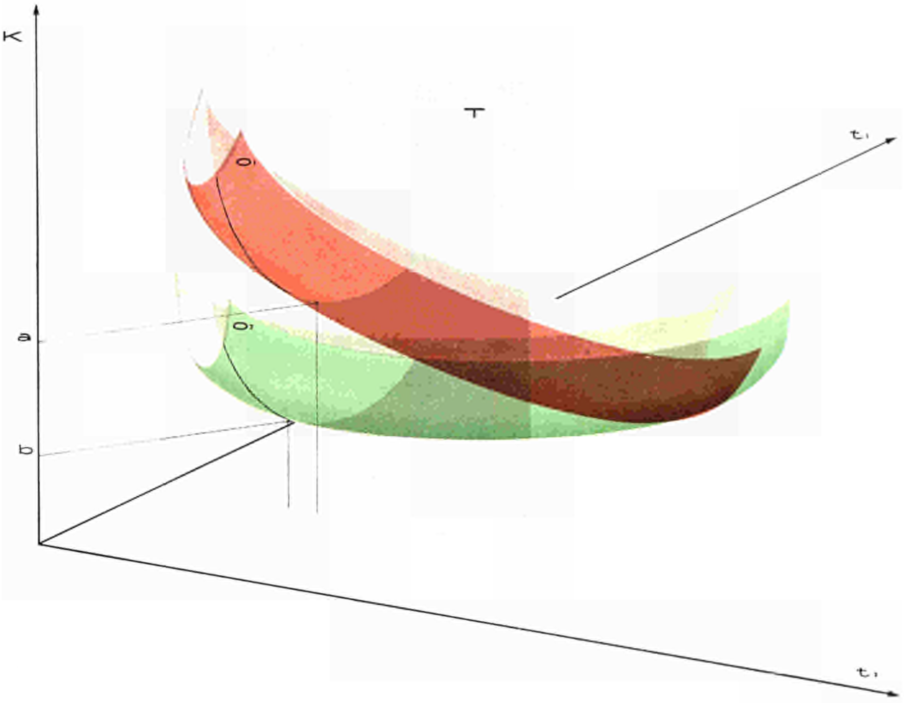


Fig. 2: Three-dimensional graph ("banana skins")

K = cost of the electricity produced by the plant
t_1 = fuel element cladding temperature
t_2 = coolant outlet temperature

The "banana skin" drawings represent the price of electricity as a function of two parameters t_1 and t_2 (the other parameters being fixed). The figure 0_1 is representative of present conditions, while 0_2 represents advanced conditions in which the heat-resistance of the organic liquid coolant would be appreciably improved. This improvement is inversely proportional to the temperature of the coolant, a relationship which is expressed by the different slant of the two banana skins. Plane T represents the restriction on the fuel element cladding temperature, and since technical reasons make it impossible for this temperature to be increased, the only possible region is to the left of this plane.

Banana Skin 0_1: Graphic representation of present conditions

The minimum power cost is situated at point "a". How can the cost of energy be reduced, i.e., how can a permissible point lower than "a" be obtained?

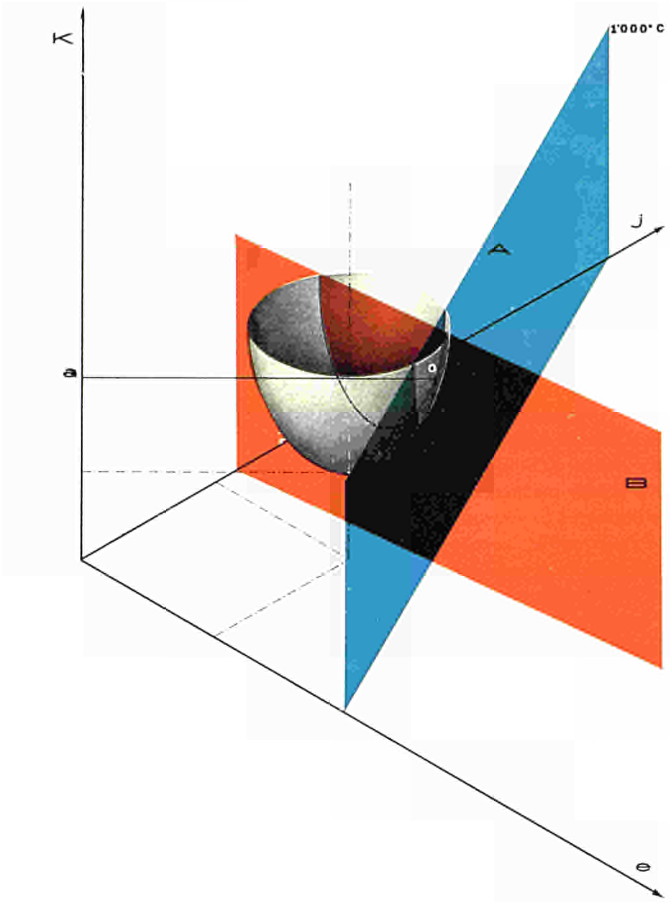
1.—By conducting research aimed at improving the mechanical strength of the cladding, thus enabling plane T to be shifted to the right.

2.—By conducting research aimed at improving the heat-resistance of the organic liquid.

Banana skin 0_2: Graphic representation of advanced conditions derived from the research outlined above

The research undertaken in an attempt to improve the mechanical characteristics of the cladding proved a failure, but the heat-resistance of the organic coolant was increased, the improvement being appreciable at low and medium temperatures and only slight at high temperatures. This situation is represented by the combination of 0_2 and T. The minimum energy cost is situated at point "b", which is considerably lower than "a".

It is obvious that there would be no point in launching a new programme of research aimed at improving the mechanical characteristics of the cladding. The only way of lowering the energy cost even further is to press ahead with research into the heat-resistance of the organic coolant.



calculation stage consists in assigning numerical values to these eight parameters and then determining the dimensions of the reactor, the burn-up of its fuel elements, and the general characteristics of the heat-exchangers and the conventional part of the installation. The numerical values assigned to the parameters are not, of course, selected arbitrarily; they are a first approximation which should give a reactor fairly near the optimum design.

Calculation of power cost

Starting from the dimensions and general characteristics of the power station as they emerge from this first stage, the Code then calculates the direct and indirect investment costs and the fixed charges resulting from them. It also works out the fuel and organic liquid consumption costs.

The important data in this part of the Code are the price data. It is no longer a question of rigorous scientific values but of estimates. However, there have been numerous consultations with the Community industries, and the estimates are thus as representative as possible.

Finding the optimal power plant

In its third stage, the Code determines the mathematical characteristics of the function relating power cost to the eight parameters already mentioned. These parameters are then "set free" in the sense that at this stage they are considered as variables. Taking into account various technological restrictions such as the maximum speed of the coolant fluid, the maximum permissible temperature of the fuel-element cladding and of the fuel itself, the Code then seeks the eight numerical values of these parameters which will afford the lowest-cost electrical power.

In this way, the general characteristics of the optimal power station are obtained.

It should be emphasised that the present-day form of the ORION Code is not fixed and final. Indeed, if the ORGEL project is thought of as a living thing which develops by deriving the maximum benefit from current research, then the ORION Code, being a sort of mathematical image of it, must adapt itself to its evolution. The "skeleton" of the Code must therefore not be considered as immutable: it is conceivable that the present data which it contains, e.g. on the irradiation behaviour of the organic liquid, may have to be modified as a result of information furnished by current experiments.

From similar considerations (see Figs. 2 and 3), one of the main advantages of the Code may be emphasised, namely that it can reveal the importance of the various technological restrictions which prevent this or that improvement. Thus it makes it possible to assess the reduction in electrical power cost which can be obtained by improving the mechanical properties of the various structural materials, the irradiation behaviour of the organic liquid, etc. In certain complicated cases it can also decide between several "candidates" for improvement. For example, it is scarcely possible at the moment to envisage an outlet temperature for the organic liquid of more than 400°C; output suffers from this, because it is not possible to make use of a modern water/steam cycle with a high temperature and consequently a high output. This limitation is itself conditioned by several factors, such as the maximum permissible temperature of the cladding, or the chemical decomposition of the organic liquid above a certain temperature. Thanks to the Code, it is possible to plot curves showing which factor constitutes the most serious obstacle to a rise in temperature (see Fig. 2). Another example, dealing with the design of the fuel-element, is shown in Fig. 3.

It can thus be seen that such a tool is indispensable to the guidance of every reactor project. Not only does it enable the maximum advantage to be derived from present technical knowledge, but also, by indicating clearly the interest of the various possible improvements, it allows research to be directed along the most promising lines with the minimum risk.

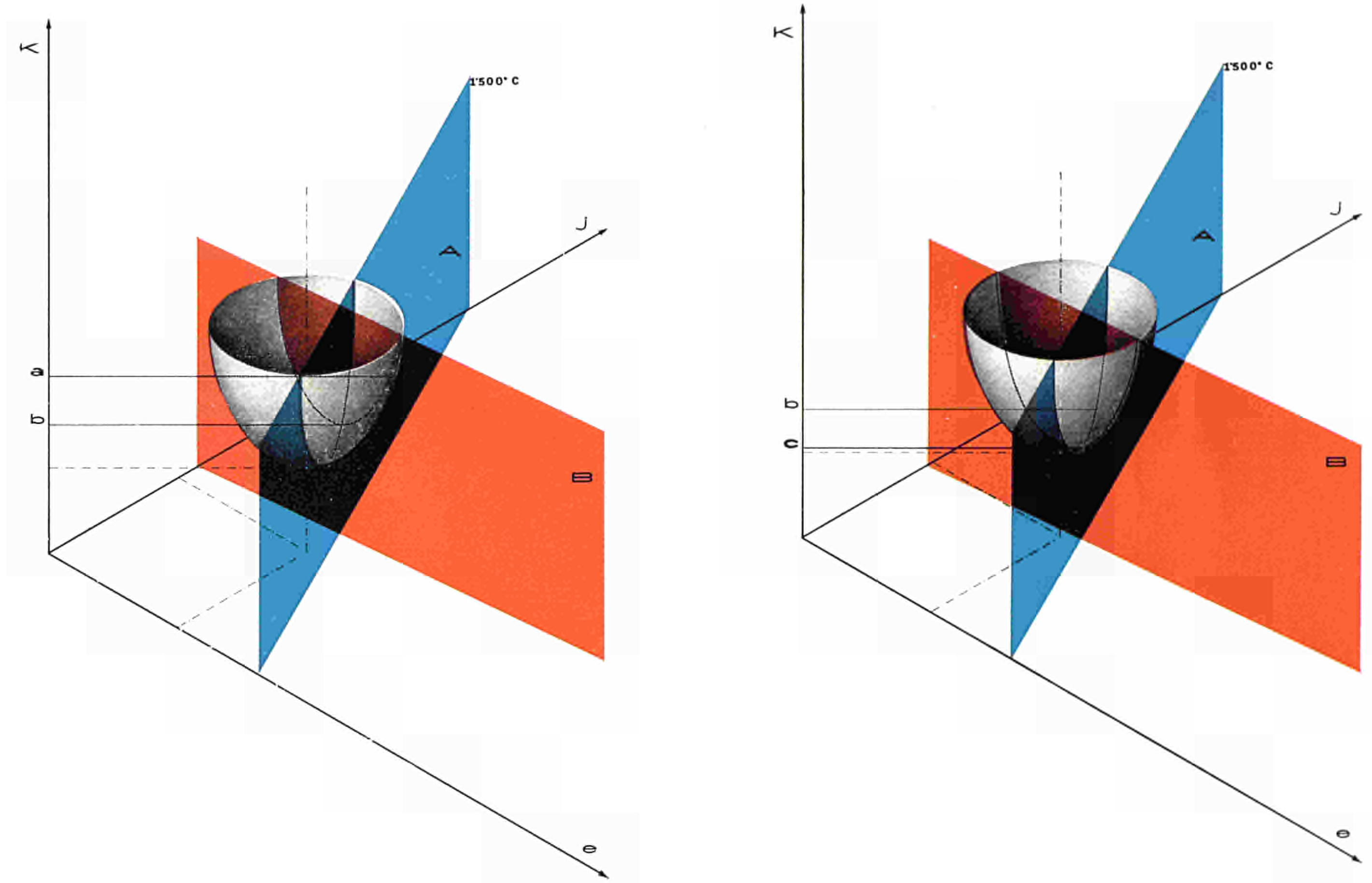


Fig. 3: Three-dimensional graph ("egg-shell")

K = *cost of electricity produced by the plant*
j = *distance between the fuel rodlets*
e = *height of the fins*

The different figures represent the electricity cost as a function of the two parameters j and e. Planes A and B represent restrictions due to the temperature at the centre of the fuel and to production tolerances respectively. The permitted area is situated beyond B and to the right of A.

Fig. 3 a: Initial situation
The optimum point is represented by "a". In order to cut the power cost, at least one of the two planes A and B must be moved, i.e., either the restriction on the temperature at the centre of the fuel must be reduced or manufacturing techniques improved.

Fig. 3 b: Intermediate situation
The restriction on the temperature at the centre of the fuel was reduced (the permissible temperature was stepped up from 1000 to 1500°C). The optimum point shifted from "a" to "b". If plane B remains unchanged, the optimum point remains in "b" even when plane A continues its shift to the left. It is therefore futile to hope to reduce the energy cost by continuing to reduce the restriction on the temperature at the centre of the fuel, which should rather be done by improving manufacturing methods.

Fig. 3 c: Final situation
Manufacturing methods have been improved. The optimum point has moved from "b" to "c". It is impossible to reduce the cost of electrical energy either by reducing the restriction on temperature at the centre of the fuel or by improving production methods. The optimum point remains at "c" even if planes A and B continue their shift.

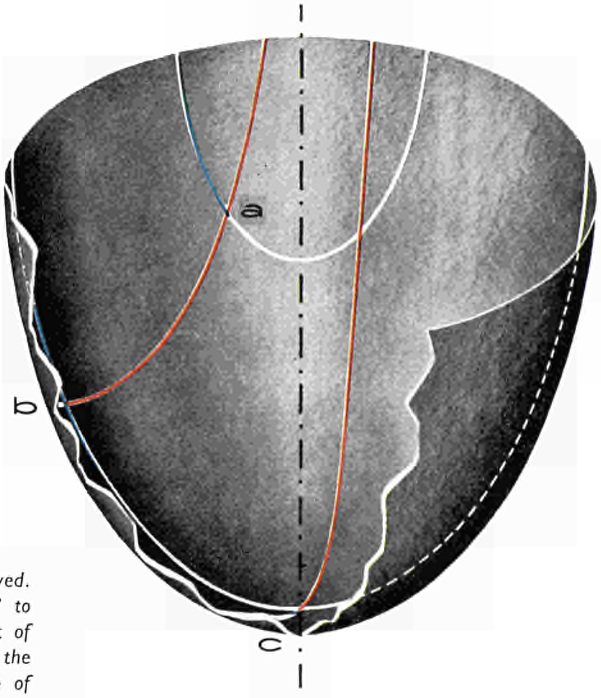


Fig. 3 d: Summary of the three phases represented by Figs. 3 a—3 c
(the egg-shell has been turned through 120°)

Biology

in Euratom's second five-year research programme

◀ *Fission product absorption: tests in progress at Ispra on rice in controlled medium.*

Ispra Biology Group. Test animals.

In compliance with the broad lines laid down in the Treaty of Rome, Euratom's biological research programme concerns itself with three main fields:
- the study of the harmful effects of radiation on living organisms;
- the application of nuclear techniques to agricultural problems;
- the application of nuclear techniques to medical research.

The harmful effects of radiation on living organisms

The most important of these fields is the study of the harmful effects of radiation on living organisms, a study which has been planned with the exclusive aim of improving the protection of workers and the general public against the hazards involved in the utilisation of nuclear energy. These harmful effects may reveal themselves either in the progeny of irradiated persons *(genetic effects)*, or in the irradiated persons themselves *(somatic effects)*. In both cases it is important to know how frequently they accompany exposure to radiation, how serious they are, how they can be watched, what is the entire range of effects produced, how they are related to the nature and distribution of the radiation in time and in space. Direct observation in man is usually not sufficient to enable us to reply to these questions, and an indirect approach is thus necessary for the main lines of research, e.g. experiments on animals.

One of the serious genetic risks is an increase in the frequency of congenital malformations, diseases such as mongolism, neonatal mortality and alterations in certain quantitative characteristics such as intelligence or length of life.

The most important somatic effects are on the one hand the *delayed* effects, and on the other the *premature* effects. The chief delayed effects are (a) the development of malignant tumours and (b) a shortening of the life span which cannot readily be either defined or explained. They constitute the most serious risks for the general public and are an essential factor in determining maximum permissible doses. Delayed effects lend themselves more to statistical study. Premature somatic effects, on the other hand, are easier to study in individuals. Special attention will be paid to effects such as those relating to the hematopoietic system, with a view to improving the *diagnosis and treatment* of radiogenic lesions.

Research into the mechanism of the action of radiations and into questions such as the deliberate chemical modification of this mechanism have a common application in several of the fields just mentioned. They accordingly form the subject of a special chapter.

All the effects of radiation depend to a considerable degree upon the dose received and its distribution in time and space, factors which in cases of practical importance are often functions of the absorption, retention, distribution and elimination of radioisotopes. It is therefore necessary to study *the movement of isotopes in the medium* (soil, water, plants) and in *animals and man*. It is also important to *improve practical instruments for measuring doses, and methods of protection*. Progress in these matters is contingent upon theoretical and experimental research into the measurement of radiation doses.

The application of nuclear research to agricultural problems

A firm foundation for action in the field of application of nuclear techniques to agriculture was already laid during the first five-year programme of research as a result of the contract of association signed with the Dutch institution ITAL ("Stichting Instituut voor Toepassing van Atoomenergie in de Landbouw"). The main spheres are those of conventional experimentation in the use of radiation or other nuclear techniques for crop improvement, food preservation, and the development of methods of analysis. A plant mutagenesis programme is also to be embarked upon.

The application of nuclear techniques to medical research

Nuclear processes ranging from neutron irradiation of tumours and experimental surgery with the aid of beams of high-energy particles to the use of tracers in the study of the renal and hepatic function are being employed ever more widely in numerous *medical techniques*. Euratom restricts its activity in this field to the development of new techniques of a specifically nuclear character and to a drive for co-ordination.

Training of radiobiologists in a second speciality

As the scale of activity of the European Community (Euratom and Member States) and its influence in the field of radiobiology develops, the lack of qualified research-workers will act as a bottleneck. It is of primary importance to give young research workers who so desire a theoretical and practical training in a second speciality—e.g. a branch of biology for physicists and chemists, or a branch of physics or chemistry for biologists—so as to prepare them for a career in nuclear biology. Hence the reason for *the training of young research workers* as a supporting activity of a general but necessary character which Euratom is pursuing under its biological research programme.

It is a well-known fact that the utilization of nuclear energy involves certain potential risks to the health and safety of the population. Although these risks have often been exaggerated, this is no excuse for minimizing them. This is why considerable efforts are being made in many countries to assess as exactly as possible their nature as well as their extent. The study of radioactive contamination in the food chain is a good example of the kind of work which has to be done.

Radioactive contamination in the food chain

J. P. G. M. SMEETS / *Directorate for Health and Safety, Euratom*

Various factors have brought it about that the Earth is relatively free from cosmic radiation. The dense atmosphere which surrounds our planet shields us so well against the full force of radiation from space, that only about a quarter of natural radiation at the earth's surface comes from this source, the balance being provided from radioactive isotopes in the ground or in the atmosphere. Not so long ago, the study of ionizing radiation and the effect it could have on life was, to the extent that it existed at all as a subject, considered to be of minor importance. However, since man has learned to produce radioactivity artificially, it has received careful attention. The effect of fall-out after the explosion of a bomb probably looms largest in people's minds; at the same time we are faced with the prospect of a proliferation of installations making a peaceful use of atomic energy (nuclear reactors, scientific laboratories, hospitals, industries, agricultural research institutes etc.) and, although the stringency of public health regulations have brought down the risks of radioactive contamination from this source to a minimum, it is only common sense to try and acquire as much knowledge as possible about the consequences, for instance, of accidental contamination.

Although the actual study of the interaction of ionizing radiation with living matter is of interest in this connection, a number of other problems have to be tackled. For instance, as radioisotopes in the environment are responsible for radiation inside the human body it is important to have clear ideas on the ways in which they are transported and distributed and therefore on the extent to which they can actually be in a position to cause harm. Since the inhalation of contaminated air and the ingestion of contaminated drinking water expose the internal organs of the human body to radiation, it is important to know the mechanism of the transport of radioisotopes in the atmosphere and in the waters of the earth. Similarly—and this will be the subject of this article—the manner in which they can find their way into our food and the extent to which this can happen obviously deserves careful study. However, the mechanism of radioactive contamination of the animal and vegetable products which constitute our food bristles with its own peculiar problems. This is due, among other things, to the great diversity of biological, physical and chemical processes that take place while food is being produced in the so-called "food chain", with all their consequences on the radionuclides that have to pass through the various production stages.

The effect of the different processes on the concentration of any radionuclides present varies considerably, but it is fortunately the case that the qualitative and quantitative selection to which they are subjected leads to a considerable decrease in their original concentration. Many radionuclides will in fact not succeed in passing through the food chain at all.

Figure 1 shows how radioactive materials can be absorbed by man and particularly the many ways in which food can become contaminated. We speak of *direct* contamination when radioactive materials find their way into food without the intervention of any biological process. This applies, for instance, when radionuclides are deposited on leaves of such vegetables as cabbage or lettuce which are directly used for human consumption.

This is to be distinguished from the *indirect* contamination of food, in which one or more biological processes intervene. This occurs when radionuclides are absorbed by the plant from the soil, when contaminated fodder and drinking water are ingested by livestock and when fish are contaminated via the atmosphere, water or plankton.

Figure 1. The paths of radioactive contamination

Top left: Direct contamination through ingestion of water

Top right: Direct contamination through ingestion of air

Below: Contamination in the food chain

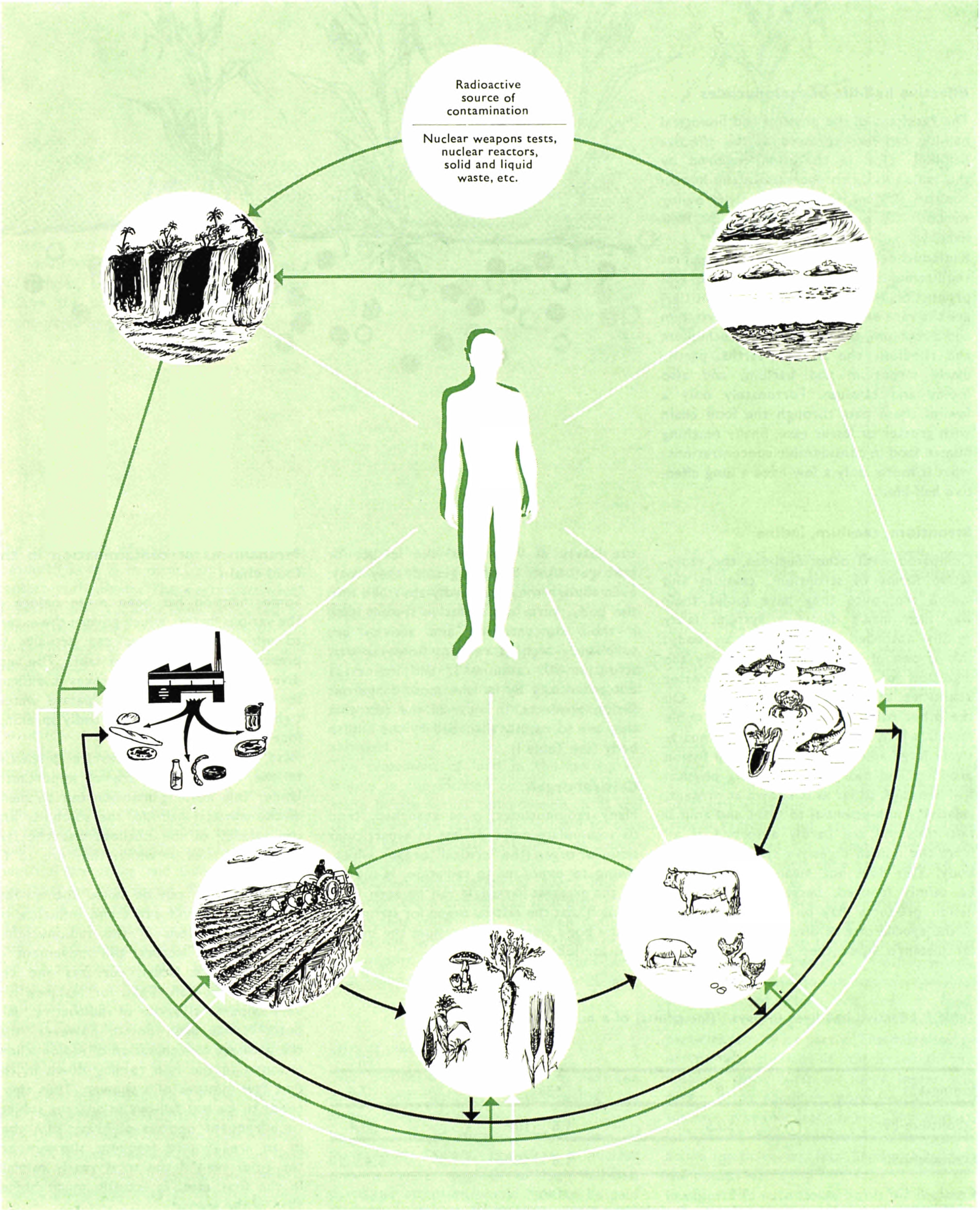
(Some of the less obvious processes which can lead to the contamination of food are also shown on the diagram, e.g. the use of fish-meal as fodder for animals and the deposition of faeces on the soil or the use of manure).

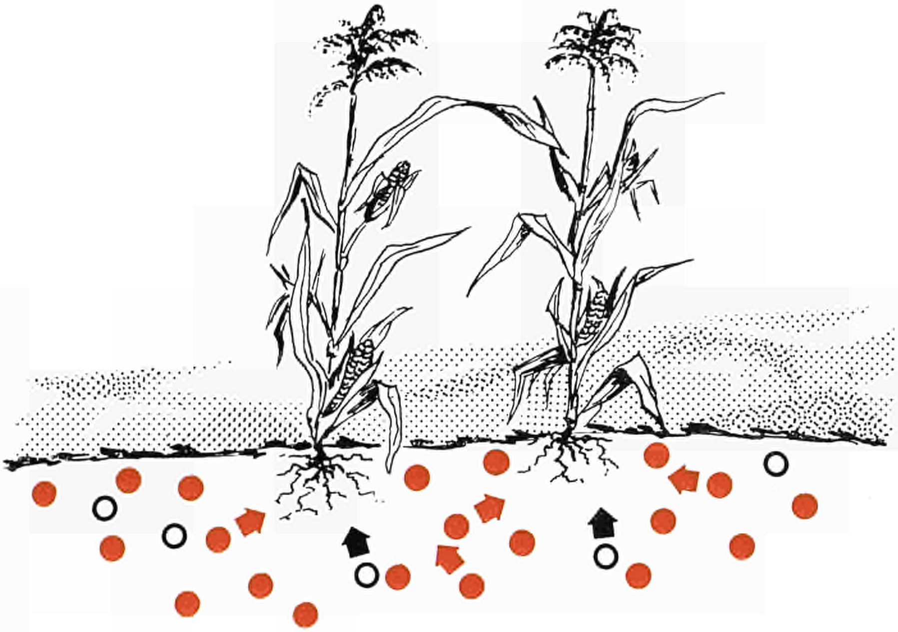
The fission process

Artificial radioactivity presents a somewhat complex picture: some 170 different radionuclides, derived from 35 elements, can be formed in the fission process which is used in nuclear reactors and in nuclear weapons.

In addition to these fission products there is a number of important radionuclides formed as a result of collisions between the neutrons emitted during the fission reaction and stable nuclei (induced radioactivity). Among them are carbon-14, to which increasing attention is being paid because of its possible harmful genetic effects, and also sodium-24, phosphorus-32, sulphur-35, potassium-42, calcium-45, iron-55 and -59, cobalt-60, zinc-65, etc.

However, agricultural and public health authorities tend to draw up a short-list of these radionuclides, as only a few among the 170 are worth worrying about in the great majority of cases. They are in the first place the radionuclides which do not decay rapidly i.e. which have a relatively long *physical* half-life[1] and are formed in relatively large amounts during fission. If, in addition, such nuclides have a comparatively long *biological* half-life[2] and are readily absorbed into the human body in the metabolic process, particular attention is needed.


Radioactive source of contamination
Nuclear weapons tests, nuclear reactors, solid and liquid waste, etc.



Effective half-life of radionuclides

The resultant of the physical and biological half-life can be expressed as the *effective* half-life[3]. This is the time required by the radionuclide to decrease in the human body to 50% of its original activity owing to both its physical and biological half-lives.

Radionuclides which comply with the first requirements (long physical half-life and production in relatively large quantities) are the rare earths, such as cerium, yttrium and zirconium, the noble metals ruthenium and rhodium, the alkaline earths, particularly strontium and barium, and also iodine and caesium. Fortunately only a few of these pass through the food chain with greater or lesser ease, finally reaching human food in considerable concentrations; what is more, only a few have a long effective half-life.

Strontium, caesium, iodine

Compared with other nuclides, the radioactive forms of strontium, caesium and iodine are, once they have found their way into man's digestive system, fairly readily absorbed into the human body; this is one of the main reasons why the ingestion of these isotopes in greater quantities can be highly dangerous. On the other hand the rare earths and noble metals, which are also produced in comparatively large amounts in the form of fission products and nearly all have long physical half-lives are, so far as is known at present, relatively non-essential to plant and animal nutrition and are hardly absorbed at all from the human digestive system into the body. This does not mean that they can be calmly ignored, because, in fact, *any* fission products may be ingested by man in the special case of direct contamination, for instance when they are deposited on the leaves of vegetables like lettuce or cabbage; after being ingested they may, even though they are hardly absorbed into the body, harm the digestive system itself if their concentration and activity are sufficiently high. It remains however that strontium-90, caesium-137 and iodine-131 are potentially by far the most dangerous fission products, in view of the fact that they are so readily absorbed by the human body (see Table I).

Critical organ

Many radionuclides, once absorbed, tend to accumulate more or less in a particular tissue or organ (the "critical" organ), which, owing to exposure to radiation, is subject to the greatest hazard. It can be seen from Table II that the critical organ for strontium is the bone system, for caesium the muscle and for iodine the thyroid.

Table I: Effective half-lives in days [4] (for adults) of a number of nuclides

	Tph	*Tb*	*Teff*
Iodine-131	8	138	7.6
Strontium-89	50.5	1.8×10^4	50.4
Strontium-90	10^4	1.8×10^4	6.4×10
Caesium-137	1.1×10^4	140	138

Mechanisms of contamination in the food chain

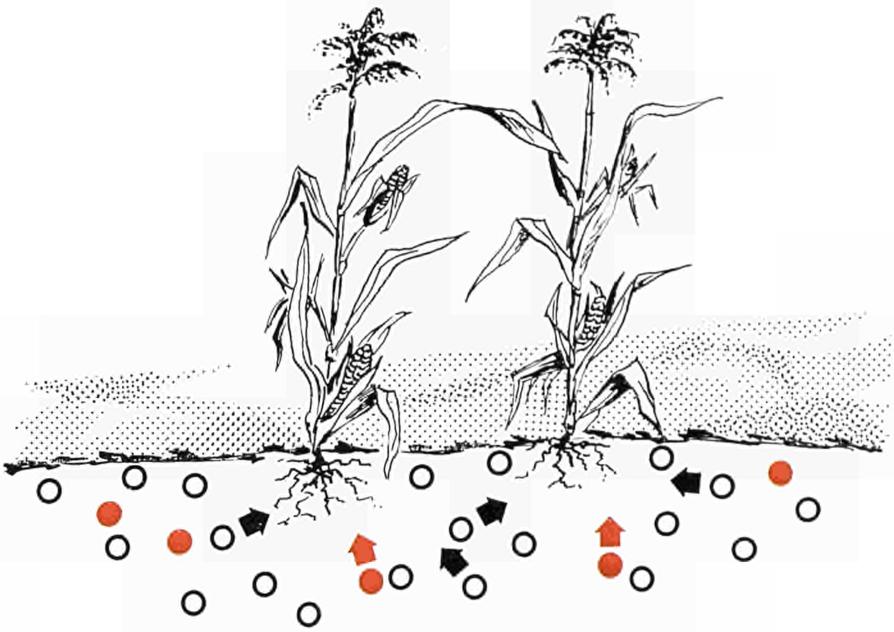
Some mention has been made before of the various factors which govern the extent to which radionuclides can actually be present in the food on our table. The very diversity of these factors makes it difficult to classify them all into separate watertight compartments, but, broadly speaking, four categories emerge.

First, the *physical and chemical properties* of the radionuclides are of importance. Under this heading mention can be made of the physical half-life, the solubility and the valency of the nuclides and the size of the particles in which they are to be found.

Secondly, what can be called the *environmental factors* will exert and influence on the concentrations of the radionuclides: meteorological factors, the movement of surface waters, ocean currents and the nature of the soil. Rain, for instance is a very important carrier of radioactive "fall-out". It has been noted, however, that the greatest concentration of radionuclides is found in the rain coming down in the first few minutes of a shower. Thus there tends to be less fall-out in an area subject to infrequent periods of heavy rain than in an area where frequent showers are the rule, even if the total yearly rainfall, in the first case, is actually much higher than in the second.

Figures 2a and 2b

The addition of lime to contaminated acid soil dilutes the strontium-90 present and favours the uptake of calcium instead of strontium-90 by plants.



The soil is also of paramount importance inasmuch as it is in direct and permanent contact with plants. The degree to which it retains the radionuclides deposited by rainfall will have a direct influence on the contamination of vegetables, cereals, and other plants.

Biological factors are next in line. They affect the uptake and concentration of radionuclides through the medium of the physiological and metabolic processes occurring in plants and terrestrial and marine organisms. As we have already seen in the case of the human body, some nuclides are readily assimilated, others not.

Finally factors connected with *stock-piling, industrial processing and domestic preparation* must be considered. The duration of storage, for instance, will have a direct effect on the amount of radioactivity of food, on account of radioactive decay.

The importance of this factor may be shown by the example that milk powder produced from milk contaminated with iodine-131 (physical half-life = 8 days) is no longer contaminated after about three months of storage.

Reference may be made to the accident which occurred at Windscale in October 1957, (in a reactor of obsolete type which is now no longer operated), when no less than 20 000 curies of gaseous iodine-131, besides lesser amounts of other radionuclides, were released into the atmosphere through the reactor stack. Since the surrounding area, including the pasture land, was highly contaminated with iodine-131, the milk from this production area was temporarily unfit for consumption. It was actually discharged into the sea. However, it is interesting to note that if public opinion had been ignored, this milk could have been earmarked for processing into powder, stored for three months and thus salvaged.

The treatment of food in the factory or simply in the kitchen constitutes the last stage before actual consumption. It is the last hurdle the radionuclides have to pass and it offers the last possibility of decontamination.

A detailed examination of every link in the food chain and of the interplay of all the factors which have just been outlined would fill several volumes. However, a few important aspects deserve consideration among the entire nexus of problems.

Direct contamination

The distinction to be drawn between direct and indirect contamination has already been mentioned.

In the case of *direct* contamination of leaves and flowers, say after a nuclear disaster or in periods of high fall-out, particular attention would have to be paid to the possibility of contamination in the "short" food chain. It is a well-known fact, for example, that the contamination of cereals is important if it occurs during the period before the harvest when the ear is ripening. It will be obvious that in the "short" food chain, most of the environmental factors and biological factors have no chance to come into play. The soil, for instance, which has a selective and discriminative influence on radionuclides, does not figure here as a link in the chain. This means that short-lived as well as long-lived radionuclides have to be given particular attention.

When radionuclides are deposited from the atmosphere on a plant they can be *ab*sorbed, provided they are dissolved by rain, snow or dew.

If the radionuclides are insoluble, or in such a form that they are not dissolved, they may adhere to the leaves and flowers as ordinary dust particles, in other words, they are *ad*sorbed. In the case of vegetables the leaves of which are used as food, rainfall or washing can remove the adsorbed particles wholly or partly. The morphology of the leaf surfaces is important in this respect, since curly or furry leaves will retain these particles more firmly than a smooth, wax-like leaf surface. The smooth leaf of the beet will retain these radioactive particles far less firmly than, say, the potato leaf.

In vegetables with closed heads, for instance cabbage, direct contamination only affects the outside leaves enclosing the head. Removal of these leaves will therefore lead to a considerable reduction in the degree of contamination (see Table III).

Indirect contamination

In the case of indirect contamination, the food chain is more complex because of the intervention of environmental factors, such as the nature of the soil, and biological factors, such as the degree to which particular nuclides are taken up and assimilated by plants and organisms. Strontium-90, caesium-137 and iodine-131 have already been quoted as dangerous radionuclides, because the fission reaction produces them in relatively large quantities and they have, with the exception of iodine-131, a long physical half-life. Shortly after nuclear tests, the concentration of iodine-131 can be quite high. Fortunately, however, the fact that it has a much shorter physical half-life means that, in comparison with the other two, it only raises a short-term problem.

Another reason that was advanced for according these radionuclides special attention was the relative ease with which they are absorbed into the human body. Besides, their biological half-lives are quite long. As could be expected, these last two characteristics do not apply simply in the case of the human body; generally speaking they hold good whenever these isotopes are involved with living matter. Hence strontium and caesium play a leading role in the case of indirect contamination. This is not to say that their journey along the food chain is easy. Even assuming that the soil is such that they are made readily available to plant-roots, a phenomenon of discrimination can be observed, especially in the case of strontium.

Discrimination

There is a certain chemical similarity between strontium and calcium. Since calcium is an essential element in plant and animal nutrition, this produces the result that strontium, if it is available, tends to be absorbed along with calcium. On the other hand the two elements do not have an *identical* chemical behaviour in the various physiological and metabolic processes involved, and there is a discrimination in favour of calcium and hence against strontium.

If we look at this phenomenon in the context of the mechanism of root-uptake of strontium in the soil, we find that the rate at which strontium is absorbed from the soil is inversely related to the concentration of calcium in the region next to the root. Soil calcium so to speak dilutes the strontium concentration, so that on calcium-rich soils there is a comparatively lower uptake of strontium than in soils deficient in calcium. Similarly, dairy cows fed on calcium-rich fodder secrete less strontium into their milk than those receiving fodder which is more deficient in calcium (see Table IV). It has been found that, on an average, only about 1% of the amount of strontium ingested is actually secreted into the milk.

Table II: Fission products of biological importance[5]

Chemical character	Isotopes important on account of yield and half-life	uptake from gastro-intestinal tract to	
		whole body	critical organ
Halogens	I^{131}, I^{133}, I^{135}	1.0	0.3 thyroid
Oxygenated anions	Te^{132}-I^{132}	0.25	—
Alkali metals	Cs^{137}-Ba^{137}	1.0	0.4 muscle
Alkaline earths	Sr^{89}, Sr^{90}-Y^{90},	0.3	0.2 bone
	Ba^{140}-La^{140}	0.05	0.04 bone
Rare earths	Y^{91}, Zr^{95}-Nb^{95} Ce^{141}, Ce^{144}-Pr^{144} Pr^{142}, Na^{147}, Pm^{147}	10^{-4}	3×10^{-5} bone, liver
Noble metals	Ru^{103}, Ru^{106}-Rh^{106}	0.03	4×10^{-3} bone, kidney

Some evidence suggests that a relationship exists between caesium and potassium which is more or less analogous to the strontium/calcium relationship. More research will however be needed before a clearer picture of its actual character can emerge.

Radionuclides in animal products

Livestock consume large amounts of fodder daily; in Holland the average amount of dry matter ingested in a day by a cow is about 15 Kg, or, expressed in terms of the area of pastureland grazed by the cow, about 100 m². This is a relatively large area and, if the pastureland happens to be contaminated, a correspondingly large amount of radionuclides can be ingested. Many of the nuclides are not readily absorbed from the digestive system and are consequently not found in animal products, or only to a very slight extent. As usual, iodine (shortly after nuclear tests), strontium and caesium are the nuclides which cause the greatest concern because they are effectively absorbed, just as much by animals as by man. Among the various common animal products studied in the context of radioactive contamination, milk has undoubtedly been given the greatest attention. Milk is, of course, an important food for young children, who consume it in large quantities daily. Moreover, it is the young who are particularly sensitive to radiation. Radionuclides are however not only secreted into milk (and also, of course, into the urine and faeces) but also in the critical organs of the animals, most of which are potential sources of food for man. Broadly speaking, these critical organs are the same for animals as for man. Hence in the case of meat (cf. muscle in Table II), particular attention is directed mainly to the caesium-137 concentration, in the case of bones to strontium and in the case of the thyroid to iodine.

Radionuclides in marine organisms

The mechanism of contamination of marine and fresh water organisms forms a subject in itself, but it will only be mentioned briefly, especially as fish constitutes a small part of the daily diet in our countries. However, it is just as complex as, if not more than the mechanism of contamination of plants and land-dwelling animals.

An important aspect of this subject is that marine and freshwater organisms are capable of accumulating certain elements, and consequently radionuclides, in concentrations many times higher than in their aquatic environment. In the case of strontium, zinc and phosphorus, for instance, concentrations can be as much as 10,000 times higher. This is particularly true of smaller organisms, such as plankton, which is the ordinary food of the larger organisms.

It remains that, owing to vertical and horizontal ocean currents and other oceanographic causes, radionuclides are extensively mixed with seawater, with the result that their concentrations tend to be low.

The daily diet

A factor which, in a sense, overrides all the other factors affecting the ingestion of radionuclides by man is the daily diet. Eating habits vary from country to country. Moreover, even within a particular country, marked differences in diet exist, depending, for instance, on age group and social level. To take an example, the Dutch consume relatively little meat, but have a diet which is rich in milk and milk products. Consequently, special attention has to be paid to the contamination of milk in this country. On the other hand, in Southern Italy, where relatively little milk is consumed, vegetables and cereals are the foods which draw most attention.

In Lapland a high concentration of caesium-137 has recently been found in reindeer meat. This is due to a considerable extent to strong accumulations on the slow-growing moss used by reindeer as food. As reindeer meat is an important part of the diet, caesium-137 poses particular problems in that region.

Another classical example of this type is the preparation of a special sort of bread made from sea-weed in a small district in North Wales. A check revealed that a relatively strong accumulation of radioactive ruthenium took place in this bread. This product is therefore a potential source of danger to the local population.

It will have become apparent that the study of the radioactive contamination of the food chain is not a simple affair, particularly in the case of indirect contamination. So many factors are interwoven that a large number of experiments are necessary to isolate them and assess their significance. Thanks to the efforts of many experts, much knowledge has been acquired in the past few years, but there are still large gaps in the scientific field to be filled.

One of the more important research contracts concluded by Euratom in the field of health and safety is concerned with the study of the different factors affecting radioactive contamination in the food chain and an assessment of their relative importance. Particular attention is being paid to differences in diet within the countries of the European Community.

Alongside this work of investigation, which is steadily improving our insight into the mechanisms of radioactive contamination in the food chain, another task has to be fulfilled which is very important with regard to the protection of the population: it is the task of checking continuously the extent to which food is actually contaminated. Many countries have launched survey programmes covering this aspect of contamination as well as contamination through air and water, with the purpose of effecting a comparison between the recorded radioactivity and the maximum permissible levels. One of the roles of Euratom is to co-ordinate these programmes and evaluate the recorded results for the European Community as a whole.

Table III: Strontium-89 and strontium-90 concentrations in washed and unwashed kale (December 1957)[6]

	Ca-content mg/g ash	pc Sr^{89}/g Ca	pc Sr^{90}/g Ca
Unwashed kale	165.8	81	48.2
Washed kale	147.5	36.8	12.7

Table IV: Strontium-90 contamination of soil, herbage and milk (May 1958)[7]

Plot	A	B	C	D
Ca-content mg/g soil	34	9	3.5	1.3
pc Sr^{90} per m^2 (0-10 cm deep)	8900	9000	8500	9800
pc Sr^{90}/g Ca				
soil (0-5 cm deep)	4.	33	48	135
soil (5-10 cm deep)	1.4	7.7	18	64
herbage	44	113	134	244
milk	6.5	8.4	11.5	14.6

1. *Physical half-life* (T_{ph}): Used to measure the rate of radioactive decay. The time lapse during which a radioactive mass loses one half of its radioactivity.

2. *Biological half-life* (T_b): The time which the body or a specific organ requires to secrete by means of natural processes 50% of the material absorbed.

3. *Effective half-life*(T_{eff}): Resultant of physical and biological half-lives.

$$\frac{1}{T_{eff}} = \frac{1}{T_{ph}} + \frac{1}{T_b}$$

4. I.C.R.P., Report of Committee II on Permissible Dose for Internal Radiation (1959). Pergamon Press, London.

5. FAO, Radioactive Materials in Food and Agriculture. Report of the FAO Expert Committee, 1960.

6. *Barendsen*, G. W. e.a., Radioactief Strontium in grond, gewassen, voedingsmiddelen en menselijk vet in Nederland. Deel I, Rapport RIGO I (1959) – MBL 4 (1959).

7. Idem, Deel II, Rapport RIGO II (1959) – MBL 5 (1959).

Pre-natal irradiation mutations

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The aim of the agricultural geneticist is to obtain new varieties of cultivated plants having interesting characteristics. He may, for instance, endeavour to increase the output of a plant type or make it more resistant to disease.

Alongside the conventional methods of hybridation and crossing, there is also the technique involving the induction of mutations, i.e. sudden hereditary changes, in living organisms.

Irradiation is one of the ways in which the geneticist can bring about these mutations, and although good practical results have already been obtained by this method, a major effort is now being made in the field of research to secure a further improvement. The author outlines the problems involved and describes the method he has adopted in an attempt to sophisticate this technique.

It is usual practice for our birth certificates to contain the exact date and sometimes even the hour of the first cries with which we announced our official arrival in the world. However, our actual birth took place some nine months earlier and it was at that time that our genotype, i.e. our general hereditary make-up was determined. In other words, it was at that time that the fortuitous encounter between two reproductive cells—on the one hand a male gamete among many others, all different, and on the other the female gamete which was present—resulted in this more or less felicitous association to which we owe our entire genetic heritage and, therefore, not only our physical appearance but also all our psychic powers.

In the case of the higher plants, also, it is recognised that a new generation begins with the germination of the seed, so that there too the genetic characteristics were determined well in advance, at the time of the union of the gametes in the wilting flower.

The zygote and its genetic powers

A new life therefore begins with the formation of the zygote-cell, the first cell obtained from the fusion of the male and female gametes. However, this single cell seems so fragile that we are generally reluctant to regard the birth of a new individual as such until, thanks to the embryo, its main organs can be distinguished and we can thus recognise the particular features of its type in it.

Quite apart from these general considerations which put nine months on our life, it is especially interesting to recall that, while the zygote constitutes the first stage in life, it is its formation and therefore all the preparatory stages prior to its creation which are definitely the most important from the genetic angle.

All the cells in an organism possess the same even number (diploid) of chromosomes throughout the cycle of their life and it is not until the gametes are formed that this number is reduced by half, thus giving birth to reproductive cells containing what is called a *haploid* number of chromosomes. Through this complex mechanism, during which the heredity factors are scattered at random, fusion of the male and female gametes leads to the creation of a new diploid nucleus, the zygote, which combines maternal and paternal potentialities in equal quantities, and then, by being divided up again and again, enables an embryo to be formed.

It is therefore clear that the two gametes which are going to combine, or the zygote cell, contain the entire genetic potential of the new individual who will later emerge. Incredible as this may seem at first sight, the productivity potential of an olive-tree several centuries old was determined in this minute zygote cell as soon as the genetic fusion took place.

The first diploid cell in an organism is therefore always preceded by a haploid stage. In the case of higher plants, the phenomena of chromosomal reductions result in the formation of male and female *gametophytes*. These, the grains of pollen on the one hand and the ovules on the other, mature in very different organs of the plant and must therefore join up again to carry out the act of pollination.

In practice, when the flower opens, the grains of pollen falling on the stigma germinate in the sugar solution secreted by stigmatic papillae. Each grain then forms a pollen tube which extends along the style and thus enables two haploid nuclei to be conveyed to the ovule. When the end of the pollen tube comes into contact with the ovule, it punctures it and bursts in order to release the two male nuclei. These then combine, one with the female gamete to form the zygote and the other with two other haploid nuclei of the female gametophyte to form a triploid nucleus, which after dividing up several times produces albumen. This triploid tissue then acts as a food reserve for the growing embryo. Thus when a fruit ripens we have in each seed a diploid embryo and a triploid albumen. In the majority of cases, the genetic constitution of each embryo will be different from that of its neighbours, since the genes are scattered haphazardly among the gametes during chromosomal reduction.

In the particular instance of perfectly autogamous plants, such as wheat, i.e. plants in which the flowers are always germinated by their own pollen, genetic purification takes place, the plants being termed homozygotes. Since the genes in all the gametes are identical, all the zygotes are obviously of the same genotype and produce identical individuals.

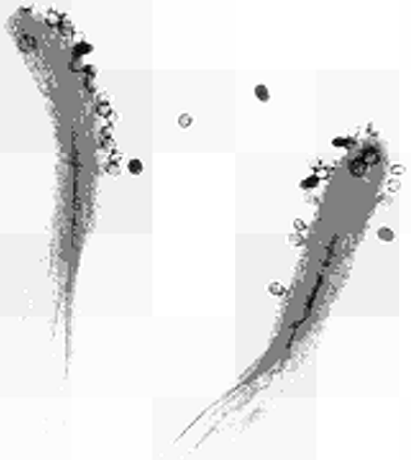
Ionizing radiations in agricultural genetics

It was about 35 years ago that the first research was carried out on the use of ionizing radiations for improving the genetic features of cultivated plants, and since then numerous mutations have been obtained. Several of them have been singled out and are now in use in a number of countries.

In virtually all cases the radiations were applied to the seeds, which are clearly an ideal material from the point of view of facility and variety of treatment.

However, they also have a very serious disadvantage, for, as we have seen above, the seed always contains an embryo formed of a great many cells and which is to all intents and purposes a tiny plant in its own

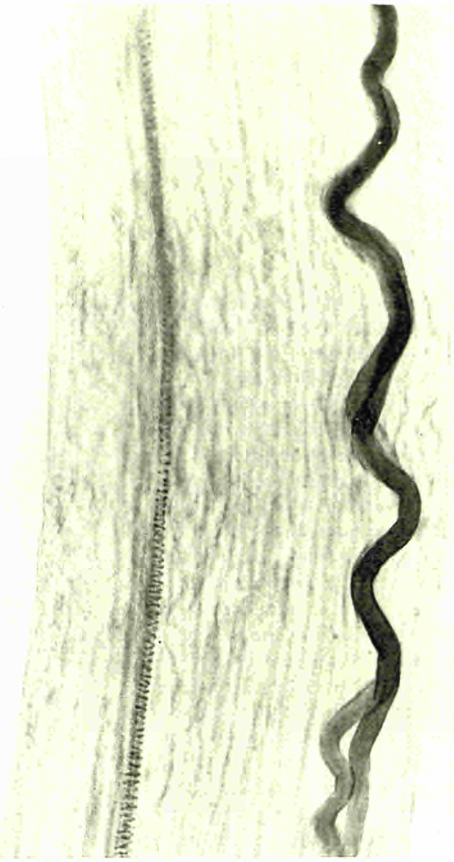
Fig. 1—Pollination



1. The pollen falls on the stigma . . .

2. . . . the pollen grains gradually accumulate and germinate.

1. The pollen grains germinate through contact with the stigmatic papillae . . .



2. . . . the pollen tubes develop in the style . . .

right, with its own rootlet, gemmule and stem. It is therefore obvious that ionizing radiations could only cause localized mutations in one cell or another in this organism, and when the plant matured it would, even under ideal conditions, contain but a mutated sector due to the multiplication of the cell or cells affected by the irradiation. If this mutation affects the cell layers which help in the formation of the gametes, there is some possibility that it may recur in the following generation. If, on the other hand, mutation is concentrated in essentially somatic tissues, such as the root or the stem, it will be impossible to maintain it in subsequent generations. Furthermore, it has been found that there is a kind of rivalry between the cells, as a result of which the normal cells usually prevail against the mutated cells, which is therefore also a contributory factor in the gradual disappearance of the mutations (intrasomatic selection, also called "diplontic").

Under ideal conditions, therefore, irradiation of a seed, i.e., a completely matured embryo, only gives a plant which it is convenient to call a "*chimera*", containing as it does a mixture of mutated and normal tissue.

Avoiding the formation of chimeras

If, on the other hand, we irradiate the plants at the exact moment when the individual gametes are quite distinguishable, or if we can expose the zygote-cell directly to radiations before it begins to split up, there can be no doubt that we shall considerably increase our chances of obtaining mutations which will subsequently become generalized throughout the plant. All the successive divisions of the zygote-cell will result in cells of the same genetic constitution. This would therefore seem to be a means of avoiding the chimera and intrasomatic selection.

In practice, very little experimental work has been done on this type of treatment so far, which is quite surprising since plant material lends itself fairly readily to this type of research.

Fig. II—Fertilization

On Microphotograph No. 3 can be discerned the two gametes combined into a single nucleus, i.e. the zygote. In this it is possible to distinguish the male gamete as being smaller than the female gamete. The large nucleus to the right of the zygote is simply one of the two polar nuclei which, after fertilization and fusion with the other polar nucleus will, after dividing up several times, give the triploid endosperm (a tissue teeming with reserves for the embryo).

3. . . . the male gametes thus reach the ovules, where they combine with the female gametes.

In many of the higher plants, it is in fact easy to observe the phenomena of pollination. Castration and manual pollination can frequently be performed without difficulty and the germination of the pollen and the growth of the pollen tubes in the style can also be followed. Furthermore, the exact moment at which the male gametes enter the ovule and the gametic fusion itself can be observed with the aid of histological cuts made at regular intervals after manual pollination.

The time which elapses between pollination and gametic fusion varies considerably from one species to another (a quarter of an hour in the case of maize and one year in that of certain oak trees), being affected also, although to a lesser degree, by climatic conditions, especially the temperature.

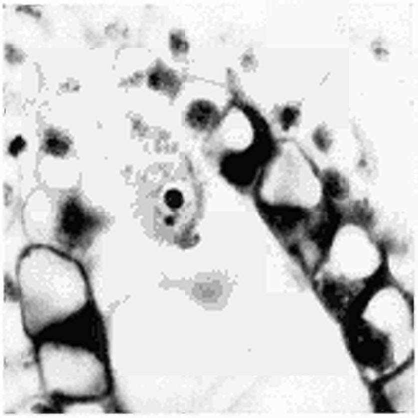
It has been established that ionizing radiations have little influence on the germination of the pollen, the growth of the pollen tubes and the gametic fusion.Certain authors have even found the growth rate of the pollen tubes to increase with exposure to powerful doses of X-rays. The pollen seeds themselves are highly resistant to radiation.

On the other hand, it is a well-known fact that immediately after the gametic fusion the zygote-cell remains in a state of apparent repose in many species. This repose time is also fairly variable, for while it is about two and a half days in the case of the tobacco plant, for instance, it is 55 days in that of the cacao tree.

During this time the first divisions of the triploid endospermic nuclei take place and formation of the albumen thus begins prior to the development of the embryo.

As a result, it is frequently possible to irradiate the plant at the gamete stage between pollination and germination or at the zygote stage between the gametic fusion and the first division.

It should also be noted that after manual pollination the germination process and the further growth of the embryo take place at more or less the same time in all the various ovules germinated. If, for example, we can castrate and pollinate simultaneously a dozen flowers from a tobacco plant, with about 4,000 ovules in each flower, we thus achieve identical growth conditions in 40,000 ovules. By the irradiation of such a plant, at the gamete or zygote stages, an appreciable quantity of seeds which have been subjected to the mutagenous action of the radiations can be obtained a month later. At the same time it enables us to obtain a first post-treatment generation (R1), already quite numerous, and a second one (R2), composed of innumerable plants, which are essential conditions for research into mutated plants. The only plants which can be pinpointed in generation R1 are those having a dominant mutation, while in R2 the descendants of the various self-fertilized R1 plants will cause the appearance, by segregation, of the recessive mutations which had remained concealed during the preceding generation. The advantage of the method lies in the fact that not only does it enable entirely mutated plants to be obtained, but also in generation R2 the same mutation or mutations will be present in all the mutated



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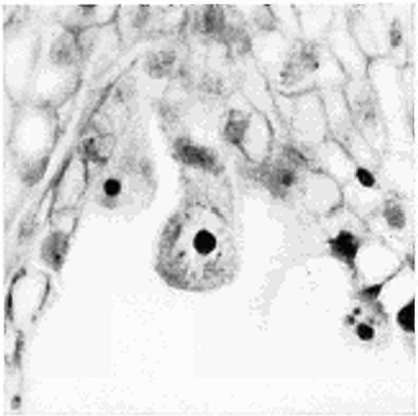

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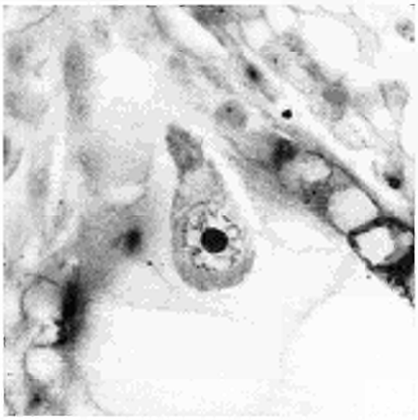

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plants of one line of descent. Thus, if a mutation is of any special interest, there will be no problem in discerning it by carrying out a limited sowing of R1 seeds and then multiplying it by sowing all the available seeds in order to obtain a far more extensive R2 generation.

Retarded mutation

There is, however, one cloud on this otherwise bright horizon—the theory of retarded mutation.

It is a known fact that chromosomes are formed by the juxtaposition of long molecular chains of nucleoproteins. It is clear that ionizing radiations can cause limited injury to one or a few chains only, not the entire chromosomes. In that case it is possible that when the next division takes place, the duplication and longitudinal splitting of the injured chromosome will lead to the formation of a normal chromosome on the one hand and a doubly injured chromosome on the other, the two chromosomes being distributed among the two daughter cells. In this way it is easy to understand that, depending on the extent of the initial injury, the mutation, i.e. the completely transformed gene, will not appear until after several divisions—seven, eight or even more. It is thus obvious that, even after treatment of the zygote, a mutation could only influence one part of the cells and re-form chimeras in generations R1 and R2.

It is equally true that this case must be regarded as exceptional. So far, no research investigation has succeeded in proving the existence of delayed mutation in higher plants; it is probable, however, that such proof will sooner or later be forthcoming.

Fig. III—The zygote

1. After fertilization, the zygote migrates to the upper tip of the embryo sac. At this stage the two gametes are still distinguishable.

2. The zygote is in a state of repose, the two gametes having combined.

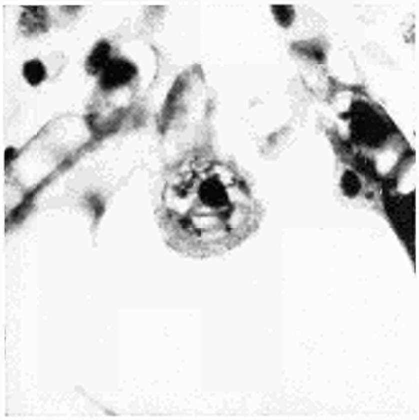
3. First signs of activity; the chromosome fibres appear, this being the "preprophase" stage.

4. Beginning of division: "prophase".
This initial division will result in a bicellular proembryo; the cellular multiplication becomes very rapid.
In the bicellular proembryo, the apical cell (lower parts of microphotographs) in this case divides up a little before the basal cell. It is thus possible to observe the four principal phases of every mitosis.

5. prophase
metaphase

6. anaphase
telophase

7. Four-cell proembryo, also called "tetrad".



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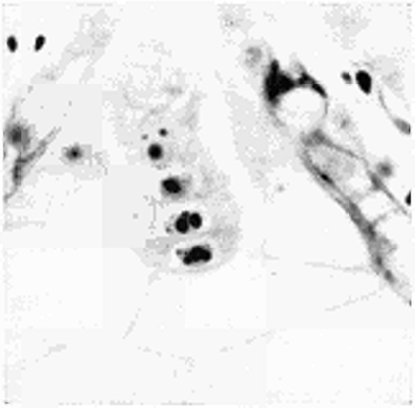

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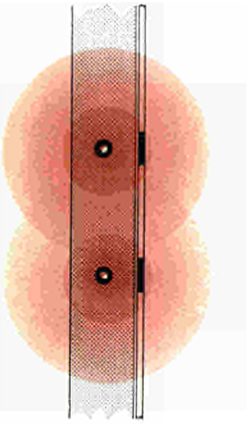


A picture is worth a thousand words

EMILIO LEVI,

Euratom/ITAL (Wageningen) Association

"A picture is worth a thousand words" ... This old Chinese proverb serves here to stress the advantages afforded by autoradiography in botanical research. This technique makes it possible to obtain a visual image of a part of a plant or a complete plant, thus capturing its dynamic metabolism at a given moment.

In the intensive farming which is the rule today, the principal method of increasing output is by the rational use of fertilizers and pesticides. In the case of fertilizers, the efforts are of a positive nature, the aim being to raise the nutritive power of the soil as much as possible, whereas the purpose of pesticides is to destroy the various vegetable (e.g. mould) or animal (plant-lice, colorado beetles, etc.) agents which jeopardize normal development. For thousands of years, man, toiling in his fields, has been pursuing this twin objective by empirical means, and the position may be summed up by saying that although the agricultural methods of yesteryear now seem very antiquated owing to their lack of exactitude, we only apply our scientific knowledge towards improving them. It is for this reason that for several decades now attention has been devoted to the development of a rational use of mineral salts as fertilizers, while pesticides have been in everyday use for almost 20 years. Examples of the latter are the so-called "growth substances", for weeding, and the "systemic insecticides", which, when assimilated by the plants to be protected, poison the insect which attacks, for instance, the leaves.

It should, however, be recognized that in both cases tons of organic compounds and millions of tons of artificial fertilizer are applied every year without our knowing exactly what the mechanisms are by which these elements or substances enter the plants and how they are transported, accumulated and used in the plant metabolism.

Besides, an important new factor has appeared in the biosphere during the last few years in the form of radioactive fall-out following nuclear explosions, which confront mankind with serious problems.

Before we can protect ourselves against these toxic contaminants in full knowledge of the facts, we must, among other things, obtain exact data on the way in which edible plants absorb them into and distribute them over their various organs.

It would take too much time to enumerate the painstaking work accomplished by research scientists since the second half of the nineteenth century which has made it possible to determine the mineral elements required for the nutrition of plants. Major breakthroughs were achieved by Sachs, Knopp, Mazé and Hoagland in particular. Although we are now well acquainted with the list, which may well be complete, of these elements, we are still far from certain of the exact function they perform in the partial or total metabolism of a given plant. It is true that the elements found in fall-out from nuclear explosions are different from those necessary to enable plants to live, but in many cases their physicochemical characteristics differ so slightly from certain essential elements that they are absorbed and used by plants in much the same way.

The use of radioisotopes as tracers

The discovery of the radioactive isotopes of certain elements which are essential to the life of plants has already enabled botanists to use them as tracers for throwing light on a number of basic problems, such as the processes involved in photosynthesis, and has provided them with much more sophisticated methods of detection for tackling problems as yet unsolved in the fields of plant nutrition, phytopharmacology and health protection. The radioactive isotopes of a particular element react in an organism in much the same way as their stable counterparts. It follows that if, for example, a plant is grown in an atmosphere of carbon dioxide which has been made radioactive by the presence of C^{14}, the *quantity* of carbon absorbed by the plant in a given time can be determined, provided that the exact content of this isotope in the gas is known. It is, in fact, sufficient to count the radioactivity transmitted to the plant to enable one to arrive at the desired *quantitative* result. The same result could be obtained by conventional chemical analysis methods,

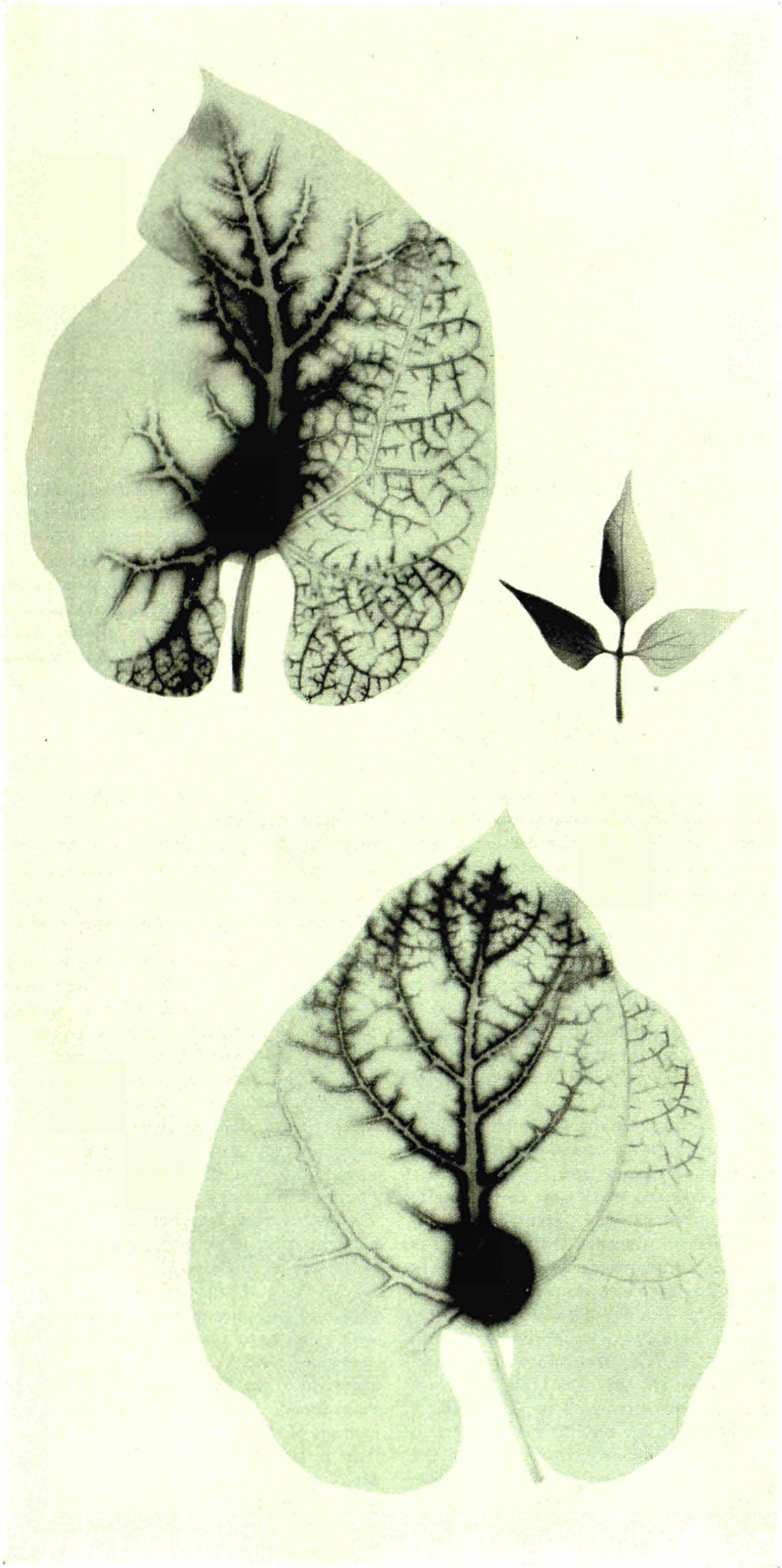


Figure 1.

Pseudo-autoradiographs of the distribution of phosphorus-32 in bean leaves.
The leaves have been dried in the oven at 80°C before exposition. The pictures obtained reveal a preferential concentration of marked phosphorus in certain tissues and its almost total absence in the conductor canals.

but these have the disadvantage of being more protracted and less accurate. However, counting can only be used in practice, *in vivo*, on parts of plants. The normal procedure consists in reducing to powder or solution form parts of or whole plants which have been sacrificed at a given moment and then measuring the radiations emitted in order to determine the quantity present per unit of weight. It is obvious that if these methods can be used for pinpointing *in vivo* the quantitative distribution of elements in whole plants, they will also enable interesting studies to be carried out on the mechanisms which govern the plant world. The same plant could in fact be studied at various different stages in its development. Many research workers are engaged on the perfection of these methods, and in particular those at the Euratom/ITAL Association laboratories.

Autoradiography

Another method of research which the use of radioactive elements has put at the disposal of botanists is that of *autoradiography*, by means of which an image projected by the substance emitting ionizing radiations can be obtained in a photographic emulsion.

The term "autoradiography" was used for the first time in 1924 by Lacassagne, of the Institut du Radium in Paris, but in order to find the true origins of this method we must go back to the year 1896, when Becquerel, without realising it, obtained the first autoradiography from a crystal of uranium potassium sulphate. Becquerel thought the radiations must be due to the fluorescence in the crystal and it was not until Marie Curie's discoveries of 1898 that radioactivity as such was recognized and autoradiography of minerals obtained. The first time the method was used for biological research was in 1908, when, at the Imperial Institute in Petersburg, London obtained a picture of a frog which had been exposed to radium radiations. Although it has been used by certain scientists, the possibilities offered by this method in the field of biology have frequently been neglected in favour of counting, which in theory provides a quantitative representation of the distribution of the radioactive element in the plant or plant section studied. Autoradiography, on the other hand, can provide us with a complete and permanent visual image of a precise moment, or even moments, in the metabolism of a plant, whereas chemical or physical analysis alone could only give a quantitative picture. It is important to note that with autoradiography it is possible to record *all* the radiations emitted during the time of exposure of the object studied, a period which can be extended as appropriate. With counting, on the other hand, it is only possible to obtain absolute accuracy when activity exceeds a certain basic level. Attempts have, of course, been made in autoradiography to determine the quantity of the isotope present in the biological subject by measuring the photographic densities or counting grains or traces. For a botanist, however, a simple, accurate picture of the concentration of a particular element is extremely valuable, especially in studies relating to its distribution in the various parts of the plant after its absorption by the roots or the leaves.

Macro-autoradiographical studies, i.e., of whole plants or organs, are made in the course of investigations into the transportation and distribution of various marked elements in specimens of extremely varied morphology, age and size. Small plants, a complete picture of which could be reproduced on one single film, are ideal, but it is not difficult to cut a plant up into various parts for easier handling and then to put the pictures of the various parts together again. Pictures of roots can be obtained just as easily as pictures of stems, leaves or fruits, and handling problems are thus the only ones that arise.

On the other hand, the use of fine-grained emulsions has resulted in the development of *micro*-autoradiography, by means of which striking pictures of, for instance, histological sections of plant tissues can be obtained.

Interpreting autoradiographical data

Although autoradiography is a valuable technique for research purposes, it must be used in such a way that there is no risk of the results obtained being falsified. Almost invariably this procedure consists of three stages. During the first, which is the period of actual experimentation, the plant is made to absorb, for a certain period of time, the element to be studied. Once this stage has been completed, the tissues must be dried out before the final stage is commenced, in the course of which they are placed in contact with a photographic plate for a variable number of days. The methods at present used, however, vary somewhat from one researcher to another, and, as we shall see, certain contradictions have become apparent; some macro-autoradiographies have yielded surprising results which do not fit in with the hallowed theories of plant physiology. For example, peripheral accumulations were observed in the leaves or at certain points in the stems or even in parts of the plant where they were least to be expected. In some cases the pictures obtained were in marked conflict with the results of similar experiments of shorter duration. A noteworthy instance is provided by the experiments on bean leaves, which established that, according to the autoradiographs at least, the element was no longer present in the conductor vessels, even after a long period of absorption, but was concentrated in the actual tissues of the leaf. Crafts succeeded in proving the fallaciousness of certain results by freezing the plants suddenly with the aid of dry ice. He attributed this phenomenon to a continuation of the metabolism during the period of drying, either in air or in the cabinet. After a number of tests, he came to the conclusion that the plants' metabolism must be halted suddenly by drying them at temperatures below zero degrees centigrade before they come into contact with the sensitive emulsion. It was, however, established that such anomalies had only been encountered when the periods of treatment were less than a few hours.

In the course of experiments carried out under the Euratom/ITAL Association into penetration of the bean leaf, exact pictures had to be obtained of the concentration of the element studied. As we shall see, these experiments resulted in a slightly different interpretation of the phenomena mentioned above. As a result of improvements carried out to the method used hitherto, it proved possible to obtain pictures of substances emitting high-energy β-particles, such as phosphorus-32, which were of a clarity comparable to that obtainable with weak β-emitters such as carbon-14 or tritium. The experimental method adopted consisted in making the plant absorb the phosphorus for periods of 3 to 7 days and then to dry the leaves at 80°C before carrying out the autoradiography. The pictures obtained revealed a new type of anomaly, in particular preferential concentration of marked phosphorus in certain tissues and its almost total absence in the conductor canals (see Fig. 1). However, these anomalies disappeared (see Fig. 3) when plants treated by a low-pressure, low-temperature drying method (lyophilization) were exposed in the same conditions. During the next series of experiments, various intermediate drying formulae were tried out, the leaves being dried out for a variable length of time in the oven before being subjected to lyophilization. On the assumption that the metabolism of certain tissues continues during the drying period in the oven, one would have expected differences in the results according to the length of the drying period; this, however, was not the

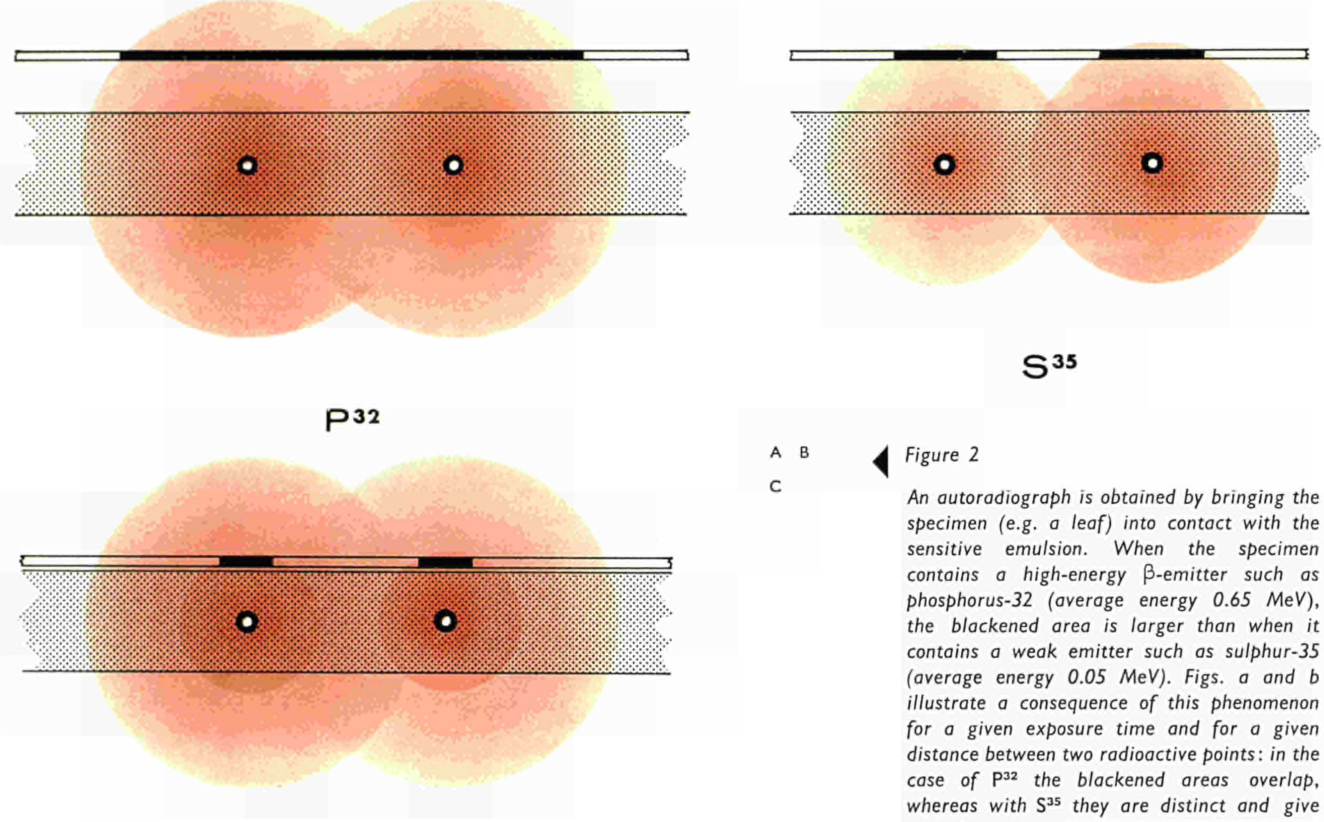


Figure 2

An autoradiograph is obtained by bringing the specimen (e.g. a leaf) into contact with the sensitive emulsion. When the specimen contains a high-energy β-emitter such as phosphorus-32 (average energy 0.65 MeV), the blackened area is larger than when it contains a weak emitter such as sulphur-35 (average energy 0.05 MeV). Figs. a and b illustrate a consequence of this phenomenon for a given exposure time and for a given distance between two radioactive points: in the case of P^{32} the blackened areas overlap, whereas with S^{35} they are distinct and give truer images.

A method of remedying the lack of sharpness in the images of specimens containing high-energy emitters has been developed by Euratom and ITAL under a contract of association. By bringing the emulsion as near as possible to the radiation source and varying the exposure time, the result shown on Fig. c is obtained. (See Fig. 3 for autoradiographs obtained by this method.

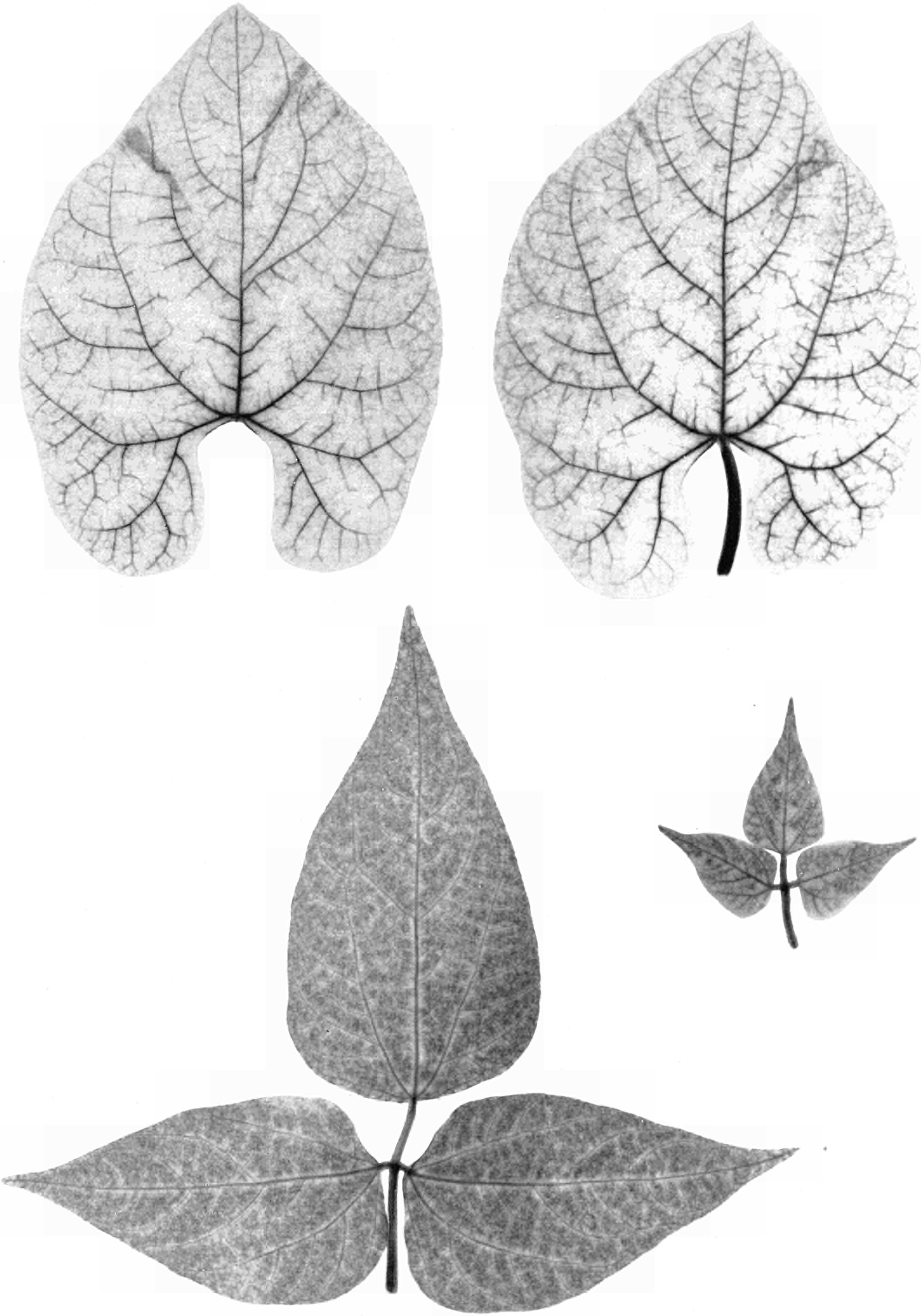
case, no appreciable differences being observed in the results obtained. One was thus forced to conclude that there were other phenomena at work, and further tests did in fact show that it was a purely physical phenomenon, since those parts which dry most rapidly, i.e. usually the finest tissues, become permeable and tend to attract the phosphorus present in solution form in the thicker parts, namely the vessels.

The work of which we have just given some examples and which was carried out in the Euratom/ITAL Association laboratories, has enabled us to develop methods which we trust are reliable. By means of them, it should be possible to obtain authentic pictures of the distribution of the radioactive element applied in all the organs of a particular plant at any given moment. Once the risks of chemical or physical diffusion and the pseudo-radiographical effects are eliminated, autoradiography becomes a sensitive instrument in the hands of the research worker and opens up the way to the subsequent processes, i.e. the counting of well-defined regions of organs, and finally micro-autoradiography, by means of which the function of the cells can be studied. It will thus be possible to endeavour to determine the relationship between the physiology of the cell and the physical or chemical properties of its component parts. Studies have shown, for instance, that there is a *direct* relationship between certain roots and certain leaf regions of one and the same plant, which would seem to indicate that there is a very definite unity of functioning.

As will be seen from the examples quoted above, the use of radioisotopes in agricultural research can provide us with basic information on plant metabolism. There is no doubt that the growing mass of data will contribute to the development of more efficient agricultural techniques than those employed at present, particularly with regard to fertilizers and pesticides, and also to a more thorough knowledge of the distribution of toxic contaminants originating from radioactive fall-out or pesticide residues in edible parts of plants.

Figure 3. Autoradiographs of bean leaves (low-pressure, low-temperature drying method)
1. Autoradiography of the primary leaves of a bean plant.
2. Autoradiography of the first and second trifoliate leaves of the same plant.

The marked phosphorus was applied to the radicular system two hours before the plant was sacrificed. It will be seen that considerable amounts of phosphorus are present in the primary leaves but only in the conductor vessels. Examination of the autoradiograph of the first trifoliate leaf (on the left), however, shows that the phosphorus is distributed in a different way, being retained in the tissues themselves, since the leaf is still in full growth. Very little phosphorus has reached the second trifoliate leaf (on the right) as yet, but it too has been retained in the tissues.



The Use of Radioisotopes in the Chemical

DR. HANS GÖTTE,

Farbwerke Hoechst AG

The world's first atomic pile began to operate in late 1942, and since then we talk of living in the "atomic age". And indeed, when we consider this new development in our history, we are particularly struck by the immensity of the energy contained in the atom and immediately try to think of ways of releasing it so as to produce the electricity which is so essential to our economic progress. There is, however, another side to nuclear energy which it would be a pity to ignore, namely, the production of radioisotopes. These do not require vast power reactors, but can be produced by relatively modest installations, research reactors and cyclotrons. Nor is there any need to release enormous quantities of energy, since the primary intention is to exploit the subtle forces of the rays emitted by the radioisotopes. With the aim of highlighting the importance of radioisotopes in the present-day world and of initiating discussion of the economic and technical problems entailed in their use, the Banque de Bruxelles organized a series of conferences in collaboration with the Euratom Eurisotop Bureau during March of this year. Radioisotopes, or artificial radioelements, are interesting because they are nothing more nor less than unstable atoms emitting either an electromagnetic (γ) radiation or a particle (α or β) radiation, or both together. After the initial paper, which described the methods of producing isotopes, outlines were given of their applications in certain typical fields. Dr. Götte, whose paper is reproduced here, demonstrated the usefulness of radioisotopes in the chemical and pharmaceutical industries.

There is frequently a considerable interval between the researching of basic natural phenomena and their practical utilization. It sometimes happens that just one single advance is enough to set a whole field of study in motion. It was not until the invention of the dynamo, for instance, that electricity entered its prime, although the discoveries and laws associated with the name of Faraday had been known for a long time.

Similarly, the existence of radioactive substances has today been knowledge for some sixty years. However, up to the 1940's the quantities available for the manufacture of luminous paints and for research and medicine were usually of the order of a few millicuries and never more than one curie. The turning-point in the utilization of radioactive substances came with the successful operation of reactors from which any amount of radioactive material could be obtained.

Reactors, radioactive substances and radioactive radiation are so closely bound up with one another today that they must be regarded as a single entity. Among the forms in which this trinity manifests itself in the atoms-for-peace field, it can undoubtedly be claimed that even at this stage radioactive substances confer very appreciable benefits by reason of their widespread use. Whenever the question of their importance is posed, there is the temptation to demand that the answer should enumerate these benefits and evidence their economic advantages. It would be no exaggeration, to continue with the comparison originally chosen, to say that with regard to their versatility—but not their scope—the uses of radioactive substances in research and technology are just as important as those of electricity. It can thus be seen that to put the question in the form indicated above is just as pointless as to attempt to calculate the economic advantages of electricity. Likewise, any attempt to assess their material value in the field of medicine is also difficult, since there is no way of calculating in material terms renewed leases of life or the alleviation of pain, nor can a price-tag be attached to the general benefits of radioactive substances for research purposes.

On the other hand, there is a whole range of special cases in which the use of radionuclides results in economic benefits which can be expressed in concrete terms. However, such figures, extremely useful though they may be, do not provide a complete picture of the value of radioactive substances since they are only taken from a small section of the particular field in which such substances are used. A complete picture can only be obtained if it is realised just how diverse are the uses to which radioactive substances are now being put. It is this factor that enables the value of radioactive substances in research and technology to be assessed, and it is only then that an attempt can be made to formulate any concrete expression of their practical advantages.

Outline of the possible uses of radioactive substances in the chemical and pharmaceutical industry

The use of radioactive substances is based on the following factors:

– On account of their radiation properties, they can be detected with such sensitivity that the presence of individual atoms can be determined.

– The chemical behaviour of the radioactive and stable isotopes of a chemical element is identical. Molecules which contain radioisotopes are therefore no different from those made up of purely stable isotopes.

– The radiations emitted by radioactive atoms have a high energy content and can in many cases penetrate thick and, in particular, opaque layers of matter, behind which they can therefore be detected.

– The radiations emitted by radioactive substances have both chemical and biological effects, which can, for instance, be used for sterilization purposes.

Since the detection of radioactive isotopes is not affected by their chemical and physical state, nor, within certain limits, by substances present elsewhere, radionuclides can be used for the radioactive marking of certain individuals among several of the same type and then for observing the behaviour of all of them on the basis of the marked ones. Not only macroscopic substances such as pieces of carbon, and live animals such as mosquitoes, but also molecules and ions can be marked by this method, the chemical elements in them being marked with radioactive isotopes. The term used to describe these marked substances is radioindicators.

The uses of radioactive indicators range

and Pharmaceutical Industry

from studies of industrial processes and biological problems to microanalysis as applied in chemistry and all kindred fields. It is for this reason that radioactive substances are of particular value in the chemical and pharmaceutical industry.

The best approach in describing the way these indicators work is to consider them in relation to a process-engineering problem. Ten tons of petroleum coke pellets about 1 cm. in diameter are circulated in a petroleum cracking unit by being blown up to a height of 75 m. by a stream of air and then passed through a furnace, where they are brought up to red heat.

The hot coke is then put in a cracking reactor and oil squirted on to it, the desired cracking products being thereby obtained, and the coke cools off and drops down before being blown up again (Fig. 1). In order to operate a plant of this type, it is important to know the speed at which the coke circulates in the gas stream as a function of the air speed. This cannot be measured by conventional methods, but if one of the 10 million odd pellets is marked with a radioactive substance the γ-radiations of which can penetrate the wall of the unit, the marked pellet can be traced externally as it passes the detector and in this way the rotation speed measured.

The same procedure can be used for marking aqueous solutions. One of the problems thus solved relates to the production of nitric acid, which is manufactured by trickling water down an absorption column on to nitrous gases which are forced up in counter-current by a stream of air. Optimum functioning of these columns is only possible if the water throughout the column trickles down over the various trays at the same speed.

For this, the trays are divided up into segments and the water stream fed onto them in such a way that it falls through from tray to tray in the same segment each time. It is injurious to plant operation if the water is allowed to pass through from one segment to another as it falls from one tray to another, but if this does occur, there is no simple way of detecting it. An effective method is by placing an aqueous solution of a radioactive substance on one of the segments in the top tray and then measuring the radioactive content of the corresponding acid as a function of time as it runs off all the segments at the bottom. The result of this experiment is shown in Fig. 2. When the solution was placed in segment 4, a considerable amount spilled over into segment 9 and small amounts of the liquid from segment 4 also passed through to other segments. It was thus observed that some of the acid solution from segment 4 fell through the column at a faster rate than the remainder of the liquid and could therefore not absorb so much of the gas in counter-current.

Information of this nature enables appropriate modifications to be carried out in the design of the trays and their segments, as a result of which the unit can then function faultlessly.

Such tests cannot be carried out by conventional methods, since dyes, for instance, are destroyed by the acid and marking with them is therefore useless.

Another example of the practical applications of radioisotopes is their use as a means of measuring volume. Chlorine and caustic soda are produced from a sodium chloride solution by electrolysis in cells containing 300 to 5,000 kg. of mercury as cathode material, several hundred such cells frequently being found in large industrial plants. Once or twice a year the amount of mercury lost during operation of the unit must be determined. Hitherto this involved emptying the cells and weighing the mercury, an operation which took two or three days, during which time the cell lay idle. For about one week in the year, therefore, the unit could not be used. With the aid of a radioisotope of mercury these losses can be measured in barely an hour by what is known as dilution analysis, and the unit can run continuously throughout the operation. This results in a 2% increase in output.

Radioactive substances can also be used for dilution and mixing processes. In the production of fine-grained substances such as plastic granulates or cement it is important that the new production charges in storage silos be always mixed uniformly with the material present in order to keep the colour and grain distribution even.

Mixing is effected by blowing air up from below and tossing the charge about (Fig. 3). Until recently, it was difficult to determine the point at which a new charge was properly mixed with the material already in the unit. This is now done by adding a few kilogrammes of a granulate marked with a radioactive substance having a short half-life and observing the mixing of the marked material by means of samples taken at the top and bottom. Fig. 3 shows that the sample added is properly mixed with the 60 tons of material in the unit after one hour.

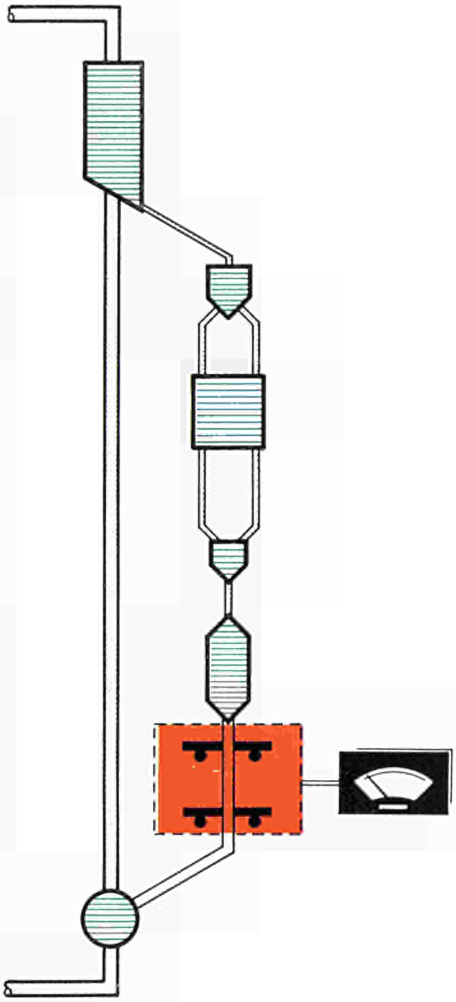


Fig. 1 Schematic diagram of device for determining the period of circulation of coke pellets in an oil-cracking unit

By far the most important uses of radioactive substances have been in the field of chemical analysis. These applications of radioindicators can be divided into three groups—Hevesy-Paneth analysis, the iso-

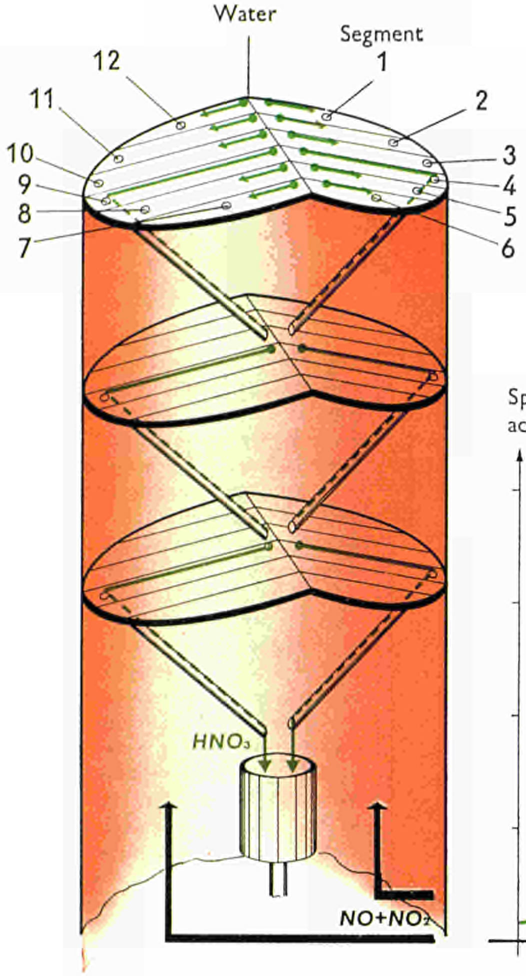
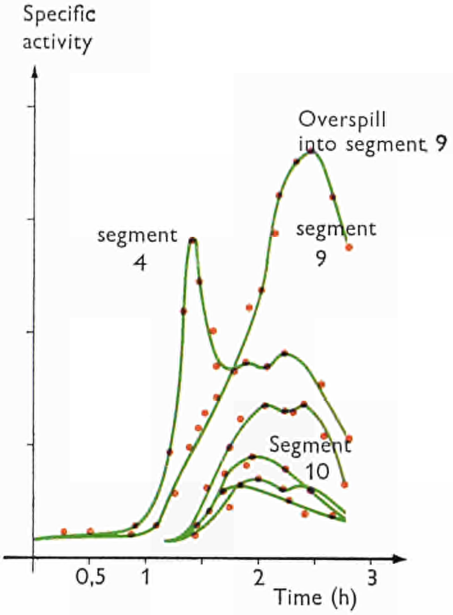


Fig. 2 Absorption column fraction checking



tope dilution method and radioactivation analysis. The first method is based on the fact that a marked substance can also be quantitatively determined in the presence of the same substance in inactive form. Phosphorus-marked phosphate fertilizer can also be used to determine the quantity taken up in one day by a three-week old plant after one dressing, even though phosphate is present in both the soil and the plant at the time of the experiment. No other method of analysis can offer these advantages. It is further possible to determine the chemical combination in which the phosphorus is incorporated in the metabolism of the plant. Hevesy-Paneth analysis is therefore a great help in throwing light on metabolism processes in agricultural chemistry, biochemistry, pharmacology and the areas in which these sciences merge. In view of its high sensitivity, which can reach the values shown in Fig. 4, it is a unique method for the quantitative observation of the fate of trace elements, as in the acceptability testing of plant protectives, insecticides and preservatives. In this way it can be used for supplementing toxicological tests, it being possible, on account of the sensitivity of the method, to handle such small amounts that the toxic or pharmacological effect of the substances examined does not manifest itself immediately; thus the tests are not thrown out of gear by the reactions which might occur owing to toxic effects.

Examples of this have been afforded by two tests, one on a pesticide and one on a drug. The aim of the first was to determine how the tin in a tin-containing pesticide used for the protection of root crops behaves in the organism of mammals, when, for instance, sheep are fed on the leaves of root crops. Fig. 5 gives the percentage amount of tin in the organs of three test animals and their excretions on the 28th, 52nd and 218th days after feeding. It can be seen that only about 0.6% enters the milk, the maximum individual concentration never exceeding 2 microgrammes per litre. It is particularly noteworthy that almost 100% of the amount employed in the test was recovered. When applying the traditional chemical methods, analysts usually have to be content with a recovery rate of 60—70%.

The amounts of tin detected are so small that there is no other way of determining them, not only because such small tin contents cannot be pinpointed by conventional chemical methods but also because the element tin is found in every living organism in concentrations corresponding to those measured. Only with the aid of a marked radioactive isotope of tin can the tin already present be analytically distinguished from that taken up.

The other test related to the metabolism behaviour of a drug. A rat was fed with a pharmacon marked with radioactive carbon and then placed in a vessel, as shown in Fig. 6, through which a stream of air was passed.

After only a short time, radioactive carbon in the form of carbon dioxide was detected in the exhalation of the animal. This means that the pharmacon is absorbed by the organism in the same way as the feeding-stuff administered, the carbon in which is mainly exhaled from the body in the form of carbon dioxide. This experiment cannot be carried out by any other method, since without the aid of radioactive marking there is no way of distinguishing between the carbon taken up from the food and from the drug.

While on the subject, mention should be made of a further use for the Hevesy-Paneth indicator method which has hitherto scarcely been applied at all. In addition to their pharmacological, insecticidal, herbicidal or fungicidal properties, drugs and pesticides are also toxic to humans. Now and again the desired effect, and also the toxicity, is seen to change after the administration of such substances. This suggests that a metabolite is formed which is chemically different from the compound administered. Since the toxicity has decreased, while the desired effect has remained the same or even increased, it is obviously desirable to identify the metabolite so that it can be synthesized and used directly. This can be successfully accomplished if marked compounds are used in the experiment and the identity then determined of the likewise radioactively-marked metabolites formed. As long as data is available concerning the chemical composition of the metabolite and it can be synthetically made, it is easy to identify it with the aid of radiometry. This therefore opens up a wide field of research which might prove of immense value.

Estimating the Value of Radioactive Substances

In conclusion, let us say something more about the economic advantages to be gained from the use of radioactive substances. In this connection, it should not be forgotten that there are several advantages, only one of which can be expressed numerically. This can be seen in Fig. 7, which shows that the only way of calculating economic benefit consists in pinpointing the savings or profits made possible by the use of radionuclides.

This is, of course, easier in the case of the routine technical uses, such as the determination of the amount of mercury, than in such isolated instances as tests to determine the metabolic behaviour of drugs—which, however, does not mean that these latter need not be just as economically valuable. A few years ago figures were occasionally published on the benefits to be gained from the use of radioactive materials, but the specific basis for these estimates in individual cases was not always divulged. During the last few years, the American National Industrial Conference Board (NICB) in particular has embarked upon an economic study based on information received from industrial firms which have used radioactive substances. Fig. 8 is taken from this study.

Estimates have also been made in Britain on the basis of enquiries conducted by the United Kingdom Atomic Energy Authority (UKAEA).

The first and second lines of Fig. 9 show the total savings which were made by American and British industrial companies during the period 1957-58. These figures are five years old and new ones are not yet available. At the present moment, investigations of this nature are being prepared by the International Atomic Energy Agency in Vienna and by Euratom. The results will doubtless point to a considerable increase in the savings effected, for we are at the present witnessing only the infant development of a branch of science that offers infinite possibilities for the future.

Alongside these admittedly critical findings, which include only those savings which can be calculated by the accountant's pen, we have the far more optimistic information for the same period provided by the United States Atomic Energy Commission, while favourable figures have also been released in the Soviet Union. These estimates can be compared with the aid of the figures given in the bottom two lines of Fig. 9.

Such divergent results show how difficult it is to obtain reliable estimates. The greater the role played by research in such findings, the less easy it is to assess any savings made

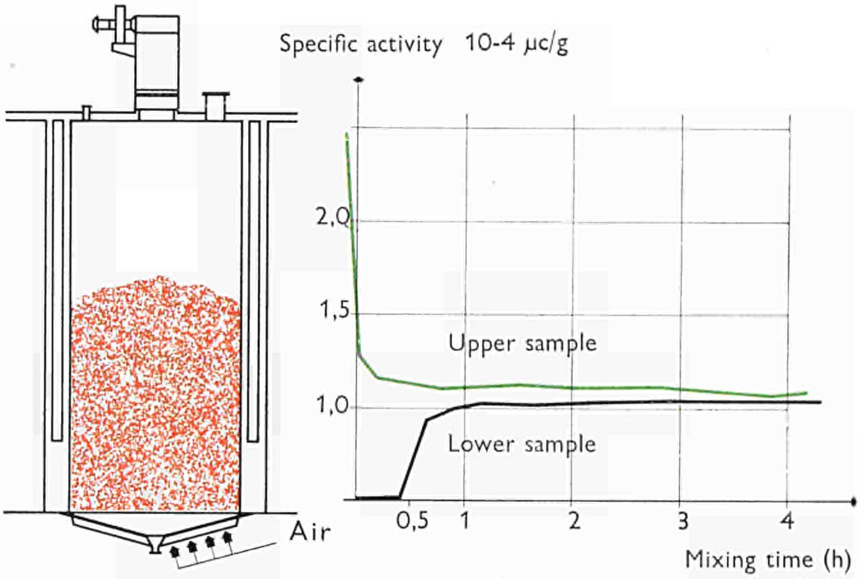


Fig. 3 Determination of time required for thorough mixing of fine-grain substances in storage silos

Fig. 4 Maximum detection response of a radioactive substance

Radionuclide	Detectable with Geiger-Müller Counter		
and half-life	mC	mg	Atoms
Na^{24} 14.8 h	10^{-7}	$1.1 \cdot 10^{-14}$	$2.7 \cdot 10^{5}$
S^{35} 87 d	10^{-6}	$2 \cdot 10^{-11}$	$4 \cdot 10^{8}$
C^{14} 5668 a	10^{-7}	$2 \cdot 10^{-8}$	$1 \cdot 10^{12}$
I^{131} 8 d	10^{-7}	$8 \cdot 10^{-13}$	$3.6 \cdot 10^{6}$

Fig. 5 Results of animal experiment after application of a tin-marked radioactive plant protective

Sn^{113} Balance-sheet of animal experiment

Organs, excretions etc.	Sn^{113} as % of Feed Volume		
	Sheep 28th DAF[1]	Sheep 52th DAF	Sheep 218th DAF
Liver	1.26	1.16	0.17
Blood	0.015	0.001	0
Stomach & intestines	0.9	0.004	0
Other parts	app. 1.7	app. 0.4	app. 0.07
Milk	0.051	0.028	0.050
Urine	app. 0.4	app. 0.55	app. 0.6
Excrement	89.5	93.85	94.6
Total	93.8	96.0	95.5

[1] Day after feeding

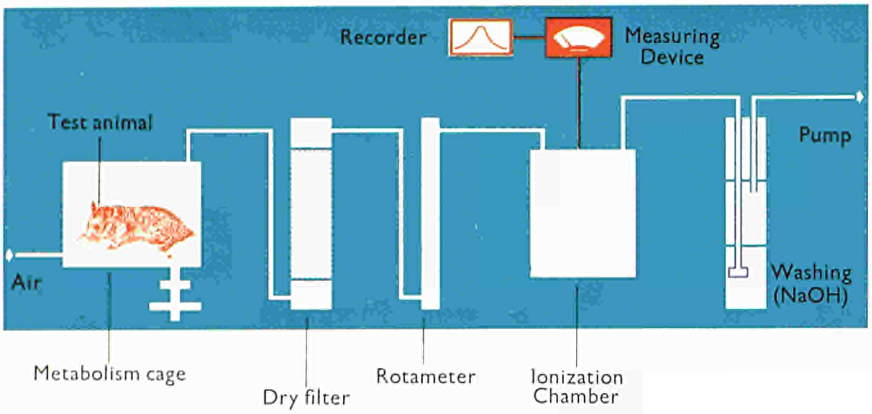


Fig. 6 Experimental device for measuring exhalation activity (Diagram)

Fig. 7 Breakdown by types of advantages from application of radioactive substances

Advantage	Evaluable	Non-evaluable
Material	Savings	All-round progress (e.g. expansion of crop, improvement of tool steels)
	Gain resulting from introduction of new products	
Non-material		Alleviation of pain, lengthening of life span
		Fresh scientific information

Fig. 8 Savings achieved by chemical and pharmaceutical industries in US, 1957/58

Type of industry	Dollar savings from		
	Research	Manufacture	Total savings
Chemical	2,324,469	803,200	3,127,669
Pharmaceutical	813,367	192,750	1,006,117
Total	3,137,836	995,950	4,133,786

Fig. 9 Estimates for 1957/58 of saving achieved by application of radioactive substances

US Calculated on basis of NICB enquiry	Millions of $ 39.113
UK Calculated on basis of UKAEA enquiry	Millions of $ 9.6
USAEC estimates	Millions of $ 500
USSR estimates	Millions of roubles 300-400

possible by the profits obtained from it. The actual advantages can nonetheless be put to good use, especially in the chemical and pharmaceutical industries. One only has to realise what may depend on the findings of a single indicator test. It can provide a pointer as to what proportion of a pesticide used in the spring becomes incorporated during the growth time in the plants which it is used to protect and—if they are used as animal feeding-stuffs—is transferred to meat and dairy products for human consumption. In addition, some data can be obtained as to whether the substance originally used has remained as it was or whether it has changed into harmless decomposition products. Such tests can obviously be decisive in determining whether a particular pesticide can be used or not. If this decision is favourable, the profit from the manufacture and sale of a new product must be weighed up against the research costs, i.e., the tangible benefit must be determined; on the other hand, one should also ascertain the extent to which crop damage can be prevented. This inestimable benefit further represents a material asset which cannot, however, be described as an actual profit. Similar considerations apply in the case of corresponding tests prior to the introduction of new drugs, the advantage here being one which can only partially be expressed in material terms, deriving as it does from the restoration of damaged health and human strength. Any assessment of the statistics in Fig. 9 should be based on the assumption that in both the American and the Soviet Government estimates an attempt was certainly made to include the incalculable benefit in the final result, and it goes without saying that this can be much greater than those advantages on which a price-tag can be pinned.

EURATOM NEWS

Euratom courses at nuclear research centres

The Euratom Commission, in collaboration with the nuclear research centres of the Community countries, has created a number of places for trainees in order to enable students from the Community countries to obtain a better knowledge of the various scientific and technical fields connected with nuclear energy and to become acquainted with nuclear research centres. The Commission also aims thereby at establishing or strengthening relations between higher educational establishments and nuclear research centres in the Community countries.

Thus university and polytechnic students may undergo a period of training in a nuclear research centre, more particularly *towards the end or on completion of their studies*. Preference will be given to candidates who have already obtained an engineering diploma or a degree. Where possible, and provided that they have an adequate knowledge of the language concerned, students will be trained *abroad*, so that they may acquaint themselves with the people and the working methods of another country than their own.

The duration of the course is 2 to 12 months according to the student's circumstances and the training proposed for him.

The course will consist principally in taking part in the current work of the nuclear research centre's permanent teams or studying secondary problems.

Vacancies are available for students of the following subjects:

MATHEMATICS
APPLIED MATHEMATICS
(Especially statistics and programming)
THEORETICAL PHYSICS
EXPERIMENTAL PHYSICS
PHYSICAL CHEMISTRY
MINERAL CHEMISTRY
ORGANIC CHEMISTRY
GEOLOGY
METALLURGY
MECHANICAL ENGINEERING
APPLIED THERMODYNAMICS
ELECTRICAL ENGINEERING
ELECTRONICS
ANIMAL BIOLOGY
PLANT BIOLOGY
BIOCHEMISTRY
BIOPHYSICS
PHARMACOLOGY
DOCUMENTATION

Euratom will refund trainees' travel expenses claimed at the beginning and end of the training period and will grant them a monthly allowance to cover living expenses. Trainees will be covered by insurance against accident and occupational diseases throughout the period.

Application forms can be obtained from
Euratom,
Directorate-General for Research and Training,
51-53, rue Belliard,
Brussels 4.

Applications must reach Euratom at least *three* months before the date on which it is intended to start the course.

Processing of radioactive waste

In the *Journal Officiel des Communautés Européennes* dated 28 July 1963, the Euratom Commission invites interested enterprises and persons to submit proposals for collaboration under its programme relating to the processing of radioactive waste. It specifies in detail the various points on which it would particularly like to receive proposals, the field concerned being the processing, treatment, evacuation and storage of radioactive waste, without precluding the possibility of any other proposals being examined.

A total budget of $ 4,500,000 has been earmarked for work in this field in the Community's second five-year programme. A total of $ 1,300,000 is to be spent by the Commission during the period 1963-1964 on this part of the programme, a statement on which is shortly to be issued by the Scientific and Technical Committee.

Euratom to undertake research on radioactivity is the sea

The Euratom Commission plans to negotiate a 3-year association contract with the Italian Nuclear Energy Authority (CNEN) for research into radioactive contamination of the sea. The aim is to find out to what extent the introduction of radioactive materials into the sea will affect underwater life. The absorption, accumulation and loss of radioisotopes by marine organisms will be examined and studies will be carried out on the effects of radioactive contamination on the biological equilibrium of the sea.

EURATOM NEWS

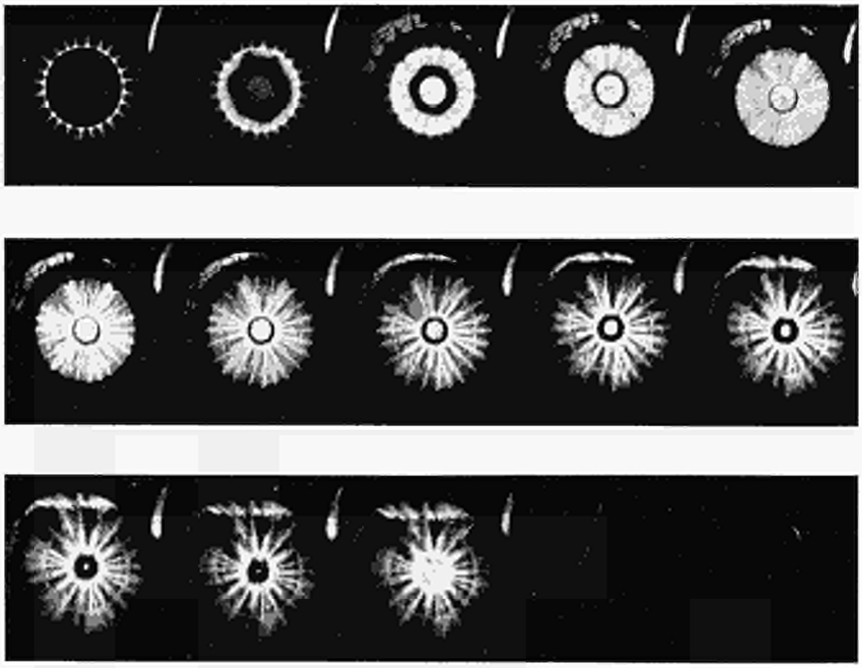
Research on nuclear fusion

A new approach is investigated in Frascati

In the summer of 1960 a small group of Euratom scientists, working in the Italian nuclear centre in Frascati within the framework of an association between Euratom and the Comitato Nazionale per l'Energia Nucleare (CNEN), started research on controlled thermonuclear fusion along completely new lines.

The experiments built at Frascati are conventional insofar as they are based on the confinement of "plasma" by means of magnetic fields. What can be considered as relatively novel about the Frascati scientists' approach is the way in which they have tackled the instability problem, which has hitherto plagued all attempts to exploit this principle efficiently: instabilities start mixing up the plasma and the magnetic field so rapidly that there is no time for enough nuclear reactions to set in. The quality factor of any type of magnetic field confinement is the product τn, where n is the plasma density and τ is the mean life-time of the confinement. The critical value of this product for a deuterium-tritium reactor is of the order of 10^{14}. A device capable of achieving $n \tau > 10^{14}$ at the necessary high temperature of 130 million °C or more will produce fusion output which is larger than the input required to heat the plasma. The basic idea behind the research carried out in Frascati consists in trying to approach this limit by increasing the density n, rather than by increasing the confinement time τ. In other words, it has been decided that, if a magnetic field confinement can be used at all, one should be content with short confinement times during which instabilities cannot mix up the magnetic field and the plasma.

In order to explore this possibility, three experiments have been designed: MIRAPI (minimum radius pinch), MAFIN I and MAFIN II (magnetic field intensification). MIRAPI involves the generation of a hollow cylindrical shell of plasma which is made to implode towards its axis. In the MAFIN experiments a metallic shell is made to collapse and compress a cylinder of preheated plasma. MAFIN II is perhaps the most unusual inasmuch as a H.E. charge is the primary source of energy.



MAFIN II fusion experiment. History of a typical implosion seen by a high-speed cinecamera (one shot per millionth of a second). First picture: ignition of the 24 detonators located on the outside of the H.E. charge. Pictures 2-5: radial progress of the detonation wave. Remaining frames: the metal liner is hit and collapses. Maximum compression of the plasma is reached in frame 12, after which expansion and disassembly follow.

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topi radioisotopen ship propulsion schiffsantrieb propulsion navale propulsione navale scheepsvoortstuwing biology biologie biologie biologia biologie medicine medizin médecine medicina geneeskunde health protection gesundheitsschutz protection sanitaire protezione sanitaria bescherming van de gezondheid automatic data processing automatische information information automatique informazione automatica automatische verwerking van gegevens insurance versicherungswesen assurances assicurazione verzekeringen economics wirtschaft économie economia economie education and training ausbildung enseignement insegnamento onderwijs en opleiding power reactors leistungsreaktoren réacteurs de puissance reattori di potenza energie reactoren nuclear fusion kernverschmelzung fusion nucléaire fusione nucleare kernversmelting radioisotopes radioisotope radioisotopes radioisotopi radioisotopen ship propulsion schiffsantrieb propulsion navale propulsione navale scheepsvoortstuwing biology biologie biologie biologia biologie medicine medizin médecine medicina geneeskunde health protection gesundheitsschutz protection sanitaire protezione sanitaria bescherming van de gezondheid automatic data processing automatische information information automatique informazione automatica automatische verwerking van gegevens insurance versicherungswesen assurances assicurazioni verzekeringen economics wirtschaft économie economia economie education and training ausbildung enseignement insegnamento onderwijs en opleiding power reactors leistungsreaktoren réacteurs de puissance reattori di potenza energie reactoren nuclear fusion kernverschmelzung fusion nucléaire fusione nucleare kernversmelting radioisotopes radioisotope radioisotopes radioisotopi radioisotopen ship propulsion schiffsantrieb propulsion navale

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