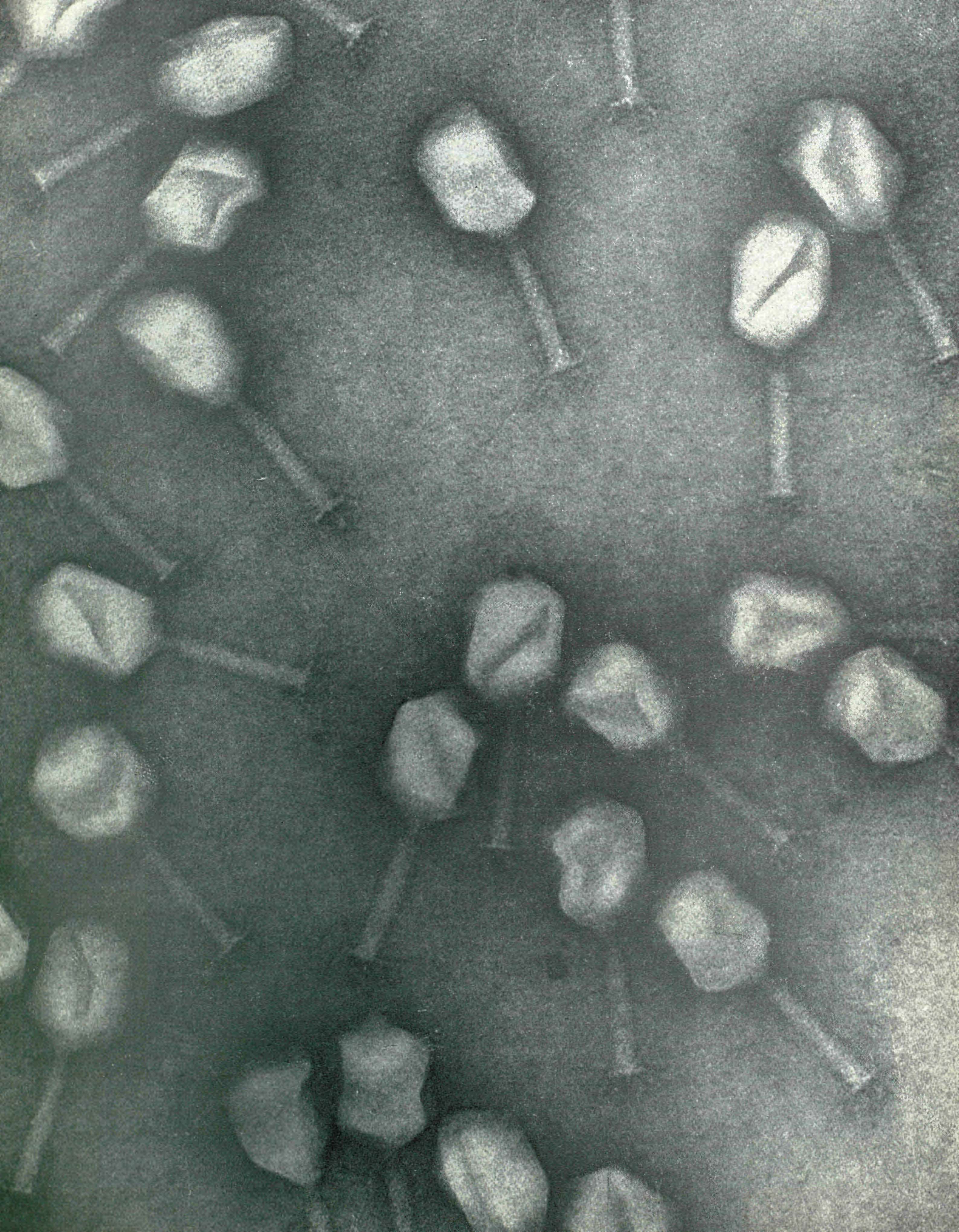
euratom

bulletin of the european atomic energy community

december 1966 vol. V no. 4



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

Published and edited by

Euratom, Dissemination of Information
Directorate, 51-53 rue Belliard, Brussels 4.
Telephone: 13 40 90

1966-4

Contents:

Obrigheim nuclear power plant granted Joint Enterprise status; Gundremmingen nuclear power plant goes critical; AVR reactor goes critical; Highly satisfactory results from operation of Dragon; Power reactors in operation, under construction and planned in the Community; Development of thermal insulation concrete; Course in molecular biology and radiobiology; SENA reactor goes critical; Irradiation techniques in the wood-processing industry; Second international conference on methods of preparing and storing labelled compounds; Measurement of the fissile-material content in irradiated fuel elements; A neutron source based on fission products.

Subscriptions:

For details on how to subscribe please see order form facing last page.

◀ *Bacterial virus T_2 magnified 200,000 times (by courtesy of Prof. J. A. Cohen,* Laboratorium voor Fysiologische Scheikunde, *Leiden)*

Cover: Snapshot of a technologically important phenomenon: boiling (see *p. 117)*

Picture credits: Pages 118-123: Gesellschaft für Kernforschung, Karlsruhe; page 128: Alain Perceval, Paris.

Quarterly

Five editions:

English, German, French, Italian and Dutch

Yearly subscription rates:

United Kingdom 18/-; United States $ 3.50;

Basic rate:

Europe: 125 Belgian Francs

Other countries: 175 Belgian Francs

Single copies:

United Kingdom 6/-; United States $ 1.–

Printed in the Netherlands
by A. W. Sijthoff, Leiden

euratom

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

1966-4

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).

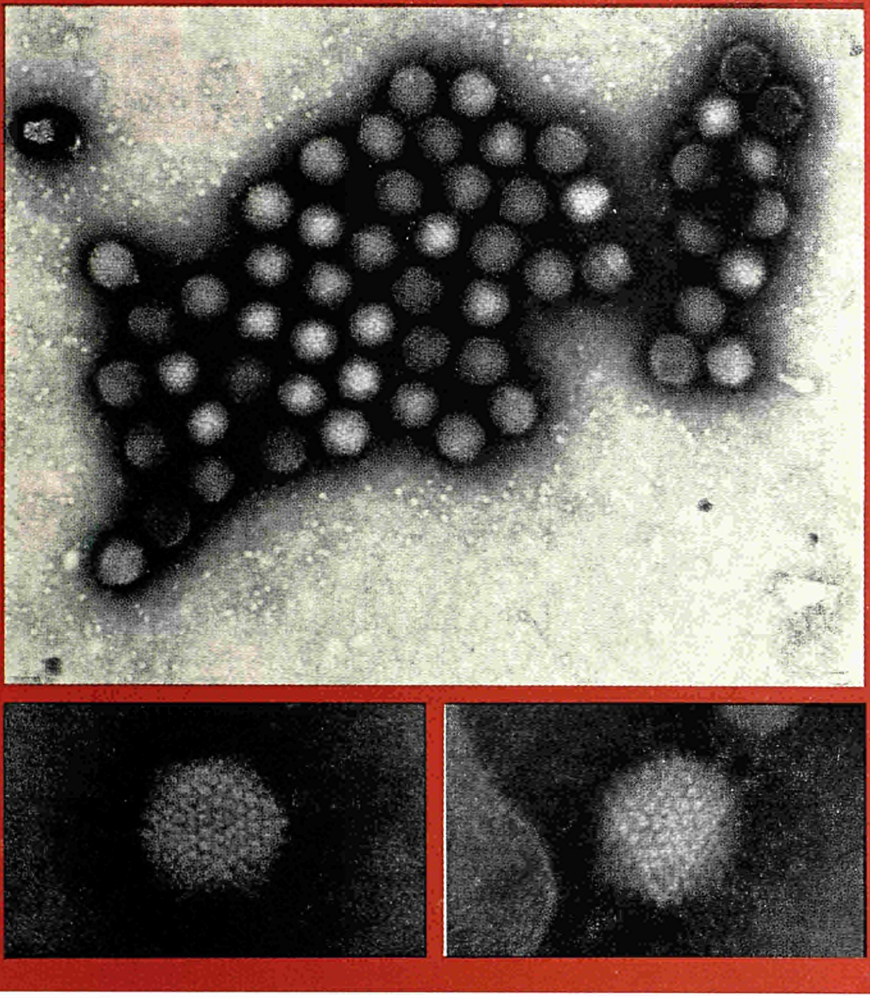
The most spectacular advances of our age are associated, on the whole, with our improved control over inert matter: the new machines and new processes which are the fruit of fundamental and applied research are gradually transforming our existence.

But what of our control over living matter? Here too research is opening up a host of new possibilities, but a different attitude toward the question of their exploitation can be clearly detected. One symptom of this is the relative modesty of individual research projects in medicine and agriculture, for instance, when they are compared with the massive efforts devoted to nuclear and space technology.

And yet the beneficial impact which biological research can have on our existence is potentially at least as powerful. The work which culminated in the large-scale availability of penicillin is one of the most striking examples.

However, the idea of conceiving applied biology as a branch of technology is not one which will find ready acceptance. Manipulation of the life processes, although it is commonplace, after all, in agricultural research, is an activity which a kind of instinct warns us to regard with especial circumspection. There are even signs that the biologists themselves may be afraid of shedding full light on their discoveries, lest they fall into the hands of apprentice sorcerers.

On the other hand, as Dr. Appleyard points out in his article, biology is irresistibly becoming a field for really big projects. Is it not wiser, therefore, to bring out all the major issues into the open and face them fairly and squarely?



Some examples of the vision of very small things afforded by electron microscopy. The larger picture shows Adeno 12 viruses magnified 112,000 times. In the smaller electron micrographs, which use a magnification of × 385,000, the individual facets of the virus are clearly visible (by courtesy of Prof. J. A. Cohen, Laboratorium voor Fysiologische Scheikunde, *Leiden).*

Towards the

The life sciences are today in the middle of an extraordinary and revolutionary ferment, largely because of the impact upon them of physics and chemistry, which have brought them entirely new coherence, new freedom, new potentialities and opportunities. If we see this in the general context of the state of scientific research in the mid 20th century, we can derive some conclusions to guide our present and future plans for biological, medical and agricultural science in Europe.

Doing away with mysticism

Physics and chemistry could not, of course, have revolutionised biology if they had not first undergone their own revolution. In fact, thanks to the work of Röntgen, Einstein and Planck, of the Curies, of Rutherford and Bohr, of Hahn and Strassmann, of Frisch and Meitner, of Fermi, of Chadwick and of many others, these sciences have in the last sixty or seventy years stood the world of physics on its head, shaken it and remade it—by rigorous thought and experiment and by a refusal to admit mystery.

Many inhibitions were thus removed: no longer was life considered as a mystery beyond scientific investigation. At the same time there overflowed into biology new machines and men with a new way of thinking.

The invasion of physics and chemistry

A striking feature of some of the imports from physics and chemistry was their remarkable simplicity: for example the ability to count accurately the smallest living things, or the ability to identify one molecule or group of molecules by its radioactivity.

There came also less simple physicochemical devices, such as the separation of viruses or cell constituents or even important molecules by the elegant use of simple criteria like weight, density, specific electric charge or adsorption, or the vision of very small things by electron microscopy; and finally others, altogether more complex, such as X-ray or neutron diffraction studies of macromolecular structure.

The consequence has been a series of astonishing discoveries, almost unbroken since 1934, when Avery, MacLeod and McCarty first showed that the principle capable of bringing about heritable transformation of pneumococcus cells was a pure chemical: desoxyribonucleic acid. These discoveries have included the complete and detailed description of the physico-chemical structure of genetic material as well as an outline of the elaborate scheme by which it

biology of tomorrow

RAYMOND K. APPLEYARD, *Director of Biology Services, Euratom*
(after an address prepared for delivery at the foundation of the Medizinisch-Naturwissenschaftliche Hochschule *in Ulm, Germany)*

and its intermediates and derivatives control the life-processes of the living cell.

We have learned how the genes duplicate, how their instructions to the rest of the cell are relayed by messenger and decoded, and some groups are investigating the many ways in which the cell interprets these instructions; while others are busy cracking the code itself in terms of detailed chemical sequences or taking apart the synthetic factory of the ribosome to see how it operates.

Molecular biology

Taken all in all, every advance in biological research for about thirty years seems to confirm that by far the most fruitful and successful scientific hypothesis about life is one already defended by many great pioneers: that it can be described and explained in physico-chemical terms. It is these terms that molecular biology is now seeking to elucidate.

Interdisciplinary co-operation

However, the developments of the last decades totally contradict any superficial notion that one can just bring the physicist or the chemist into biological research as a kind of superior technician or technologist. He is indeed a very nice chap and he will indeed make new instruments and materials for you. Unfortunately, if you use his instruments and his materials and his ways you will get results in his terms and in the end you will have to adopt his thinking. The only proper and final relationship is actually one of free and equal intellectual intimacy.

A twofold merger

The success of this intellectual cross-fertilisation has engendered a new outlook and brought about a twofold merger. No longer are the life sciences a mystery apart: they are inextricably welded into one with the physical sciences. Nor are the individual branches of life science any longer separated as they once were. On the contrary, they have at last a common body of central theory, knowledge and experiment about the basic mechanics of the life process which only diverges in the separate branches as more detailed investigation proceeds.

To my mind, this twofold merger enables us to re-draw the ontogenetic tree of natural science, in a very interesting way, starting from the elemental symbols and the simplest building blocks of nature and proceeding by increasing levels of organisation through chemicals and cells to the community of interacting human brains—the most highly organised system we know, and one to whose successful operation we should now pay more conscious attention.

We should not be too modest to say that, if the basic symmetry of the building blocks of the natural world are revealed by high-energy nuclear physics, certainly the most elegant superstructure and the most beautiful convolutions of which they are capable have been worked out by Nature in living things; and if space research teaches us—at great expense — about the starry heavens, I imagine most of us would as soon understand ourselves and our rôle here on earth.

The merger of subjects and more especially the newer body of central theory and knowledge grounded in physics and chemistry should also instil a new facility and coherence into the teaching of the biological subjects, for it gives us a new skeleton on which to hang the flesh of factual knowledge. But this it will only do if we now put it consciously to work.

New patterns of ideas

An extraordinarily important feature of this double merger of the life sciences both between themselves and with physics and chemistry is that it permits quite new and freer patterns of ideas and convergences of thoughts and efforts.

Consider, for example, "sickle-cell" anaemia. At one pole, this disease is a serious practical medical problem, especially in some regions of Africa. At another, it is a striking example of a basic genetic phenomenon: the wide spread of the mutant gene responsible for the disease appears to be due to the increased resistance to malaria which it confers on those individuals who carry it together with one normal gene. At a third, it can be seen in the light of new knowledge about the physics and chemistry of the molecule which is at the moment beginning to reveal general laws; both the "sickling" and the malaria resistance would seem to reflect a change in the amino acid sequence within the hemoglobin molecule, which thereby becomes insoluble. From medicine the problem; from chemistry the method; from physics the explanation; to medicine and fundamental genetics the profit.

Or consider the way in which the composition of the circulating blood is rigorously stabilised by great—if variable—reserve capacities in the body (and which incidentally may limit its usefulness as a simple indicator of radiation damage). To understand this we must find out more about the different kinds of stem cells which exist and shed light on their growth and their interactions. But the activities of these stem cell pools govern adaptation to many environmental factors, from infection to pollution or climate; a full investigation is therefore going to require the co-operation of a correspondingly wide group of specialists. There will, I am sure, emerge a whole new pattern of thinking extending very far.

The transforming power of the new biology

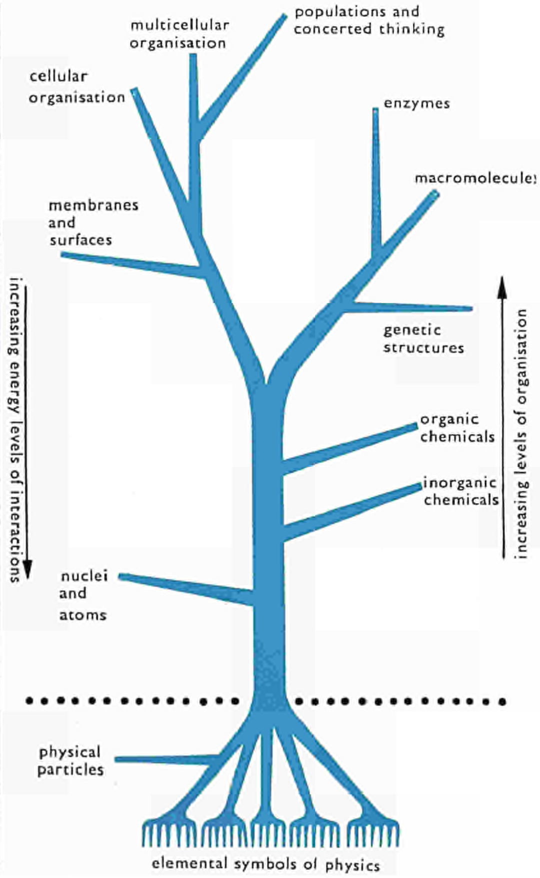
The explosive advance of the last decades has brought to the life sciences more than a new cohesion both among themselves and with physics and chemistry. It has brought alarming new possibilities to transform ourselves and our circumstances. Most of these come from our remarkably increased power to manipulate cells, viruses and subcellular processes.

For instance, Spiegelman last year succeeded in the indefinite replication of a bacterial virus—a living thing—by a cell-free preparation in a test tube. At the level of the haploid cell, such as the well known bacterium E. coli, several hundred distinct biochemical markers are known and can be manipulated, for example by switching the apparatus regulating the production of one enzyme to the control of another, or "persuading" the cell to make up to 2% of its total protein in the form of one particular enzyme, as Jacob and Monod have done. We have yet to exploit these capacities. Cells of several plant species can be cultured as clones in vitro and later redifferentiated into whole plants. Even mammalian cells can be cultured in vitro and in quite large quantity. If ever genetic stabilisation of such clones can be achieved we shall be within sight of a new and extremely exciting range of products: selected natural or modified antigens, antibodies, enzymes and other proteins, messengers and so on.

Reaching beyond the cellular field, let me only allude briefly to the prospects of molecular exploration of the transformation of animal cells to malignancy by viruses such as polyoma; of the molecular exploration of morphogenesis and embryology when once it is allied to our new extensive knowledge of the association, in anything up to 1% or more of live births, between diseases or other serious disabilities and chromosome abnormalities; of the possibilitie which may be opened to surgery by the storage of cells and organs if we can learn to control secondary disease and to master the genes of man responsible for tissue transfer incompatibility.

To take a more practical example: the speed of selection and build up of cattle stocks (and Europe is shifting from vegetable toward animal foods) is limited by the rate at which cows can bear calves. But today twinning can be induced by selected chemical agents; and modern techniques of ovule transplantation show promise of entirely revolutionising a serious problem of rapidity of economic adaptation. It is all a long way beyond Jacob's attempts with sheep, recorded, appropriately enough, in the book of Genesis.

To-day's tree of science?



Social theory of research: the rôle of governments

All of the developments I have mentioned—the intellectual ferment, the merger of disciplines, the larger coherence, the new patterns of ideas and research, the new opportunities—must of course be seen against the socio-economic background of our times.

Scientific research means many things to many men; and I believe it no disadvantage that one and the same research project may mean his intellectual life to the man at the laboratory bench, the realisation of some of his ideas to his professor and economic or social advantage to his financial sponsors. But whatever it means to those who practise it, it always represents to Society a partial use of its disposable surplus—be it in brains or in money.

Among the many ways in which this disposable surplus may be used by a Society—some good, some bad, some amusing, some not, research, although a form of labour, has this peculiar quality of capital investment: that it leads in due course to a larger surplus, some of it available for more research. It is surely this autocatalytic action that has brought research progressively out of the small private back room to become a very significant element in the social economy.

Now today governments, acting for Society, have so widened their field of action and so greatly increased their competence that, whether they and we like it or not, one of their more exacting rôles is a rather tight crontrol over part of Society's surplus and consequently, over part of its scientific research. This must, I think, be admitted as right and necessary and as a permanent, if relatively new feature of scientific life.

The scale of research

The increasingly conspicuous success of the autocatalytic process has brought to research greatly increased scale and means, so that today we are talking about a far from negligible fraction of Society's surplus.

Measured as a percentage of the whole gross national product, the investment in the future made through research represents perhaps 1-2% for a number of West European countries, perhaps as much as 3-4% for the U.S.A. Expressed as an annual outlay, it represents today over 3,000 million dollars in the Community of the Six.

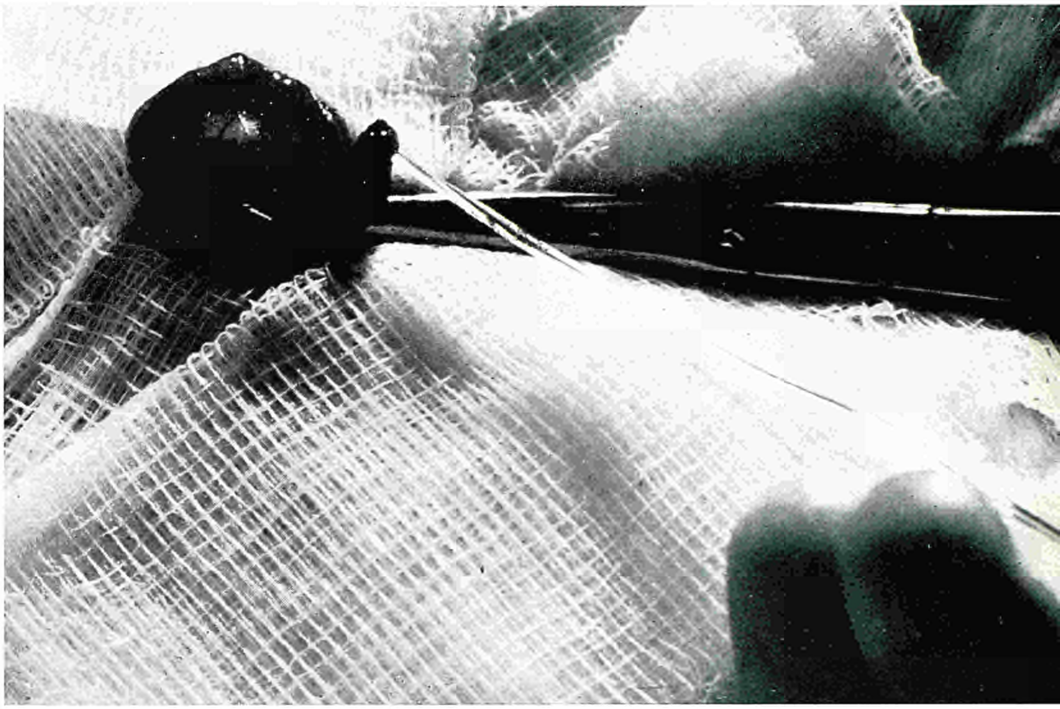
Professionalism in research

Such vast expenditure on scientific research has brought with it other recent and conspicuous changes. Research has become a real career in itself. The long line of great amateurs, Aristotle, Leonardo, Leeuwenhoek, Kepler, Harvey and so on have had to give way to the spiritual descendants of Archimedes, probably the first clear-cut professional governmental director.

Not only has research in all areas become an affair of professionals, but it is often dominated by one-hundred-per-cent research institutes. Although the need for close contact and relationship between teaching and the most advanced research was never more necessary, even the university group risks finding itself relatively handicapped by its partial commitment to teaching, at least in the most highly competitive and rapidly advancing fields. Notable exceptions are and surely will be those able to gather and maintain a large group among whom some can devote themselves almost entirely full-time to research, others can be almost full-time teachers and others in between, the same individuals even varying the ratio during their careers.

What can we deduce from all this about the future of the life sciences and about our own responsibilities now to prepare for that future?

If we accept that governments will set



The specialty of Dr. E. S. E. Hafez, of Washington State University, is producing multiple births in livestock. For Dr. Hafez, centuplets are routine.

Normally, a cow's ovary releases one egg at a time, just as the ovary of a woman does. As a result, though a cow is born with thousands of incipient eggs in its ovaries, it can give birth to no more than 10 or 12 calves in its lifetime.

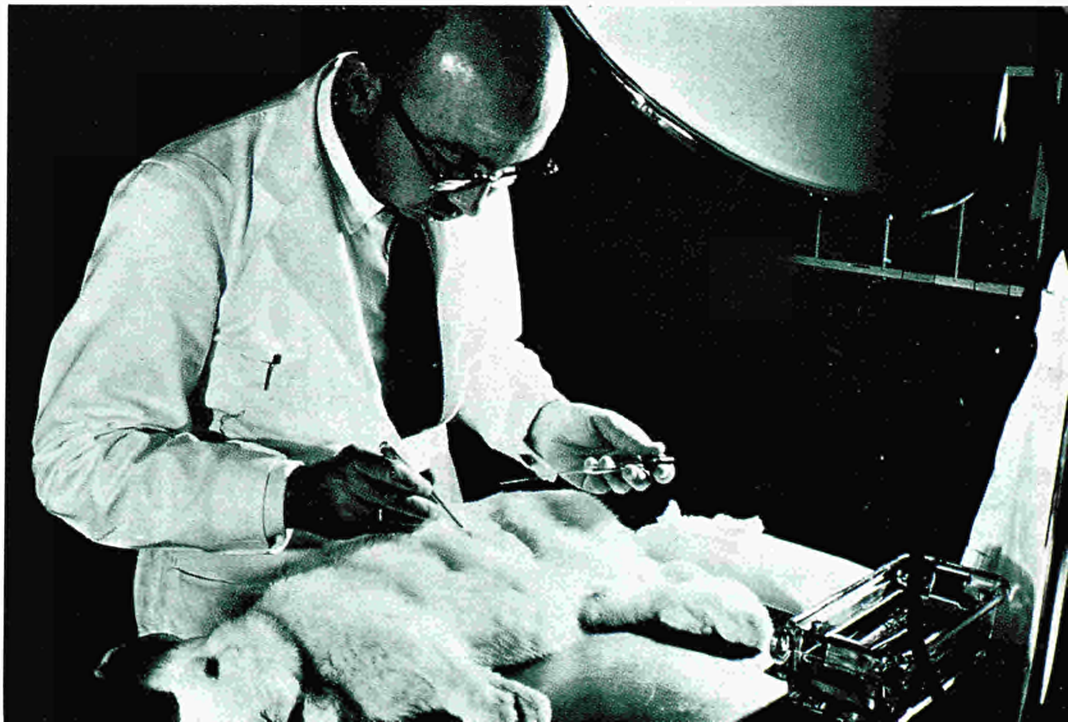
But Hafez, through the use of two sets of hormones, can now make a cow's ovaries release ripe eggs in quantity. After his cows undergo multiple ovulation, he artificially inseminates them, fertilising as many as 100 eggs in each animal.

Several days after the mass conception, he flushes out the tiny embryos. These can then be implanted in the uteruses of other cows.

If no mishap occurs and if the receiving uterus has been properly prepared with hormones, the implanted calf will go through a normal gestation period and be born as if it were the foster mother's own—but with the genetic qualities of its true parents.

As an interim measure, the embryos can be transplanted into smaller animals such as rabbits, where they continue to grow normally for up to 14 days before being put into other cows.

Thus a whole herd of pedigreed cattle could be transported easily and cheaply across oceans inside a single rabbit. (Photographs by courtesy of LIFE International, C 1965, Time Inc.)



Dacus oleae Gmel, *better known as the olive-fly. This fly lays its eggs in olives and the larvae which develop render them unfit for consumption or for the production of oil. It is estimated that the olive-fly accounts for the destruction of one third of the annual crop in the Mediterranean region. Large scale sterilisation of males by radiation is one method of fighting this pest which is being considered in the European Community.*

general trends by the scale of their allocation of resources for research, it is the duty of us all to see that this task of allocation is well done; and if we begin by looking at what has been done, we shall see a remarkable anomaly: there are many statistics available, but they all say the same thing, and one illustration may speak for them all.

Are the life sciences underprivileged?

Take the economies of the six member countries of Euratom. The relative importance, in terms of turnover, of agriculture, medicine and electrical energy production in them is very roughly 3:2:1, agricultural production amounting to some 25,000 million dollars per year. We have already noted that the overall ratio of research expenditure to gross national product is some 2%. But in the case of agriculture, the money spent on research and development is equivalent to only about 0.5% of annual turnover; for medicine the corresponding figure is about 1.5%; whereas for electrical energy production, the size of the nuclear research component alone is some 10 to 20% of a total gross production very little or none of which is nuclear.

Yet the aim of most of this nuclear research and development work is no longer to learn how to make a reactor work, but merely to reduce cost margins. In other terms, its leverage on the economic future of the industry it serves is much lower than it used to be.

In the light of the examples we have already discussed, I cannot believe that the transforming power of biological research is any less than that of nuclear research. It is not even necessary to look into the future to see this: it is enough to consider the results of the discovery of penicillin or the production of maize in America at a labour cost of only 7 man-seconds per kg. Moreover, if we look outside Europe to a larger and hungrier world whose needs we disregard at our peril, the relative importance of food and health and of all development work that pertains to them becomes overwhelming.

Perhaps this distortion—I think the word is not too strong—in the patterns of research expenditure is purely historical, reflecting in large measure a now obsolete estimation of the transforming power of the biological sciences. If so, we may suppose it will be corrected. In that case, we must on the one hand accept responsibility for seeing that the necessary decisions are made in full and objective knowledge of the potentialities of our field. On the other, we must recognise that a massive expansion will itself bring specific difficulties to the life sciences.

Perhaps the most serious difficulty is the Community's available supply, not of financial resources, but of trained brains, where the "production cycle" is very long.

Supplying trained brains

If it were realised, for instance, that the strength of a region in molecular biologists or in medical ecologists should be doubled by 1986 or even 1996, it would not be too early to make the appropriate decisions here and now: the teaching institutions must be located or set up, the teachers found, the students selected, taught and allowed to develop into experienced research workers: twenty or even thirty years is not too long.

But is it really possible to see clearly so far ahead? All we can lay down with certainty is that today's pattern of training will determine the pattern of research twenty years from now and the results which will be produced in thirty years' time. Nevertheless, it is this planning for expansion, together with the merger of disciplines which we believe the key to progress, that has already led us in Euratom to increase the opportunities for young research workers to master a second discipline: in particular for young chemists or physicists to learn a biological trade.

Inevitability of big projects

We must, moreover, face the inevitable fact that expansion means much more "big science" in biology than hitherto, and consequently much more programmed research and big projects; one of the first examples is to be found in America, where the Russells have bred over a million mice in their approach to the problem of radiation genetics of mammals.

Others will certainly come: a centre to breed pathogen-free monkeys in Europe has been suggested and is certain to be considered. A reasonably favoured method of controlling some of our worst insect pests like the olive fly *dacus oleae*, which is such a scourge in the South of Europe, is by the release of irradiated males. For a limited experiment of this kind in Florida, it was already necessary to convert an aeroplane hangar into a fly factory to produce a total of 3,000 million sterile males at the rate of 100 million per week; the cost of the project was $ 10 million. I cannot resist the temptation to feel that the large scale production of flies might be a very entertaining topic for some optimisation-minded and original engineer. Nor would any list of potential big projects be complete without mention of such tasks—already under way—as computer analyses of the national vital statistics of whole countries.

But the big projects will not all be confined to a simple centre; some, in order to gather enough relevant talent, will be geographically dispersed networks of related programmes. Our Euratom research programme on the haematopoietic system and on bone marrow transplantation is typical of this kind. It involves five contracts and six research groups in four different countries. It costs altogether, with the contributions of our partners, about 900,000 dollars per year and some 50 research workers participate. And even this quite massive effort does not exhaust what is being done in the six countries.

The big project raises many questions. As has been said of international organisations, it is hard to start, hard to control and hard to stop. Above all, I believe it must be correctly and closely related to the body of permanent non-project research institutions so that both gain in strength from each other by ready transfer of skills and men: so that university teaching and research benefit from the special facilities of the project and the project can enjoy the co-operation of the best brains of the university.

We need to accept—and to teach—that a man may spend a few years seconded to a project, and a few years doing a little teaching and much research, and at the end of it be a better man to do much teaching and little research in the warmest and most academic phase of his life. Only so can we combine the professionalism and overall purposefulness that we need in research with the close relation between research and teaching that we need in biology.

Basic versus applied research?

It is not only in the big projects but throughout that we shall have to watch the correct balance and relationship between so-called applied and so-called basic research. I believe this distinction, in its simple and naïve form, to be quite dangerous: it is certainly not quite exact.

Mainly because of the complexity both of living materials and of our knowledge about it, a man attacking a fundamental problem will nowadays often have to make a new advance of practical and technological importance to succeed; while a man attacking a superficially simple or apparently trivial practical problem may suddenly find a yawning gap in really basic knowledge right at his feet—and succeed in leaping the chasm.

In addition, an increasing proportion of research falls into neither the applied nor the basic category but into the third and intermediate class of oriented research, which sheds light upon a given group of practical problems rather than just attacking them head on.

The trouble with the old distinction is that it represented—and represents—a separative distinction, between the academic and the project research, between the university and the fieldworker, which restricted and slowed down the interchange of ideas and people between the one class and the other. I personally would prefer to distinguish free or pioneering research, susceptible of turning up entirely new areas, phenomena or principles; main-line or programmed research which proceeds on established lines to attack an established area; and exploitation or project research—the follow-up of breakthroughs when they are made. If this last were specially funded, and perhaps specially honoured, we could at least be sure of putting to practical use such discoveries as are made, and as quickly as possible; in contrast to our old European tradition which so often left the exploitation to others.

Necessity of team work

It is an old truism that all living material is very complex. The problem is that today we know far more about each aspect of the complexity than we did and we have far more sophisticated technology to manipulate it. One result is that what we might call the fun period, in any field, when exciting new discoveries can be made with just two water baths and a refrigerator, has been greatly shortened or has even vanished altogether.

But a more important one is that any spearhead of research is now backed by a tremendously complex battery of techniques—techniques of immunology, electron microscopy, separation, chemical analysis or synthesis, the ubiquitous tracer in an ever-widening range of molecular situations and so on.

Consequently, in competitive research—and all research is a competitive activity—the individual research worker is far more expensive to maintain: he now costs about 25-30,000 dollars per year in Europe; and, because he cannot be a specialist over the whole range of techniques he needs, he has to be part of a team. This team, ideally, will change all the time, will usually be, in fact, a series of *ad hoc* teams for successive individual problems, reflecting the way in which the new coherent matrix of biological science spawns new *ad hoc* patterns of thought and progress, as well as new *ad hoc* relations between breakthroughs and their exploitation.

Indeed virtually all the research I have cited has been or must be executed by shifting multidisciplinary teams of this kind, in which it is usually quite impossible to say beforehand whose training will make the crucial contribution. That a startling proportion of modern front-line research is carried out like this, especially in the U.S.A., may be seen from statistics such as the following: in last year's *Journal of Molecular Biology* 80% of the papers were by more than one author and 37% were by more than two. And over 40% of the papers carried notifications of change of address.

From monovalence to omnivalence

This frequent need of the *ad hoc* group, the temporary team or combination to force a particular barrier is peculiar to the complexities of biological research and is absolutely essential to its effective and economical prosecution: it is just waste of an expensive man not to back him up properly. The logic of this may be expressed in the following manner: the single individual is usually limited to one competence: he is *monovalent*. For nearly any problem he will need to call on other expert knowledge. The larger group may have several specialities: we may call it *plurivalent*. But it still cannot live by itself, for it must often call upon other skills. And a university centre or whole research establishment may have nearly all the skills it wants at any time: it is *multivalent*. If it could have all the skills it would ever need in complete depth all the time, one might call it *omnivalent*.

I believe this way of looking at things brings out a final group of real requirements for our planning in Europe.

The network of the biological sciences

First, the largest institute needs to be prepared, for the sake of its own programmes, to co-operate with others in a wider network. It cannot stand alone.

Second, we must try to bring the large number of intelligent and useful research workers who try to do good work in monovalent or plurivalent groups into correct relationship with appropriate multi- or omnivalent centres so that they are not unnecessarily held up and so that their full potential is realised.

I think we should insist that where public support creates a multi- or an omnivalent institute, that institute reserves some places, some facilities, some effort for cross-linkage with the mono- and plurivalent groups of its area.

The organisational forms and methods for this have, as far as I know, yet to be fully

An adult Macaca speciosa *monkey receiving an intramuscular injection. It is desirable to use monkeys as experimental material when the aim is to obtain results which can be readily transposed to human beings. This applies, for instance, to the acquisition of data on bone marrow transplantation, a promising method of treatment for victims of irradiation accidents. These monkeys should ideally be as free of infections as possible, in order to reduce to a minimum the incidence of post-irradiation complications due to these infections.*
The creation of an European centre in which pathogen-free monkeys would be bred is likely to be seriously considered.
(Photograph by courtesy of TNO, Radiobiologisch Instituut, *Rijswijk, Netherlands).*

explored. But I am certain that advanced attempts at such exploration must be pushed forward.

For efficient progress in the life sciences, just because living things are so complicated, there must be a maximum of crossfeeding of ideas, information and practical help in which all are both givers and receivers, and in which *ad hoc* research teams appear and dissolve again with the problems that brought them together—not even necessarily or always geographically. That is the meaning of a research community—and that, I firmly believe, is what we must promote in the life sciences or we shall come to a dead loss here in Europe.

In conclusion, I would suggest equally to those who govern and to those who direct: to give the life sciences the resources appropriate to their new transforming potential; to insist upon recognition of the physicist, the chemist, the clinician, the geneticist, the fundamental as well as the applied research worker, the teacher, the investigator and many others as all equally valid partners in the new science; not only to mount and maintain a healthy basic research effort, but extend it by supplying the necessary means and incentives toward rapid exploitation of its findings—an extension which will necessarily include the mounting of big projects; to insist upon a maximum freedom of movement of men and ideas and upon all institutes playing, even if only for their own sakes, a full rôle of mutual help within what I have here called the network of the biological sciences. (EUBU 5-15)

Euratom safeguards

FERNAND SPAAK, *Director for Safeguards, Euratom*

What is the Euratom safeguards system? What, indeed, is meant by the expression "safeguards" as used by the various international bodies concerned?

We may say at once that this expression does not cover health protection or nuclear safety measures and that the two concepts must be kept entirely separate to avoid the misunderstandings that sometimes occur.

Nuclear materials proper, i.e. natural or depleted uranium, enriched uranium, uranium 233, plutonium and thorium, are outside the ordinary range of materials. They are not only rare, but also economically and politically important and, in some cases such as plutonium, very dangerous to use or handle; as for their military significance, it does not need to be stressed. A check must therefore be kept on their utilisation; this is what a safeguards system is for.

Throughout history, governments have striven to subject certain materials, of various kinds but all falling roughly within the compass of the above criteria, to measures of control governing their production, use, and movement—measures which sometimes amounted to a monopoly. It could scarcely be otherwise with nuclear substances, when once atomic energy began to move out of the laboratory stage or the pilot installation on the industrial scene.

The United States, because of their considerable lead in this field, were the first to act, immediately setting up a safeguards system which was gradually extended to those countries with whom they later signed co-operation agreements providing for uranium or plutonium supplies.

The object was to enable the supplier state to ascertain that the materials delivered were in fact used for their avowed purposes, in other words, that they were not being diverted to non-peaceful purposes.

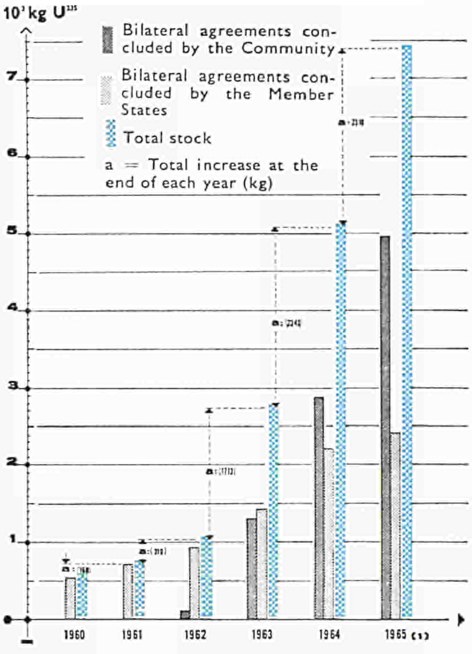
Our six member states, by signing the Rome Treaty setting up the European Atomic Energy Community and assigning it the task, set out in Article 1, of fostering progress in the nuclear field, conferred on it the duty of "guaranteeing, by appropriate measures of control, that nuclear materials are not diverted to purposes other than those for which they are intended".

Thus, every one of our states relied on Euratom and its executive organ, the Commission, to apply these safeguards at a Community level. So, as early as 1958, Euratom set up the first multi-national safeguards system in the world and was thereby able soon afterwards to give non-member countries (the United States, the United Kingdom and Canada), with whom the Community signed co-operation agree-

Table 1: Growth of numbers of nuclear facilities subject to Euratom safeguards

31.12.1960	111
31.12.1961	127
31.12.1962	134
31.12.1963	155
31.12.1964	168
31.12.1965	192
30. 6.1966	202

The increase from 31.12.1960 to 30.6.1966 is 82%.



(1) The data for 1965 are provisional

Figure 1: Growth of enriched uranium stocks in the Community (in kg uranium 235)

ments, the peaceful-use guarantees linked with the supply of the materials needed to carry out its research and development programme; it was thus in a position to ensure compliance with these guarantees within Community territory by means of its own officials instead of inspectors appointed by the non-member supplying country.

The aims and means of the Euratom safeguards are detailed in Chapter VII of the Treaty.

Like most texts dealing with this subject, the Treaty provisions on control are extremely clear and concise: nine articles in all, on four pages. The obligations laid on the enterprises concerned must indeed be unequivocally defined and leave nothing open to argument or interpretation. Moreover, the managements of these facilities must have the assurance that they will not be subjected to undue interference in the running of their business and that the system leaves no room for discrimination.

The aims? To ensure that ores, source materials and special fissile materials are not diverted from their intended uses as stated by the users, that "the provisions concerning supplies are observed", i.e. that all shall have equal access to resources, and lastly to verify the fulfilment of any special undertaking concerning safeguards entered into by the Community in its agreements.

The means? In the first place, the Commission's safeguards services must be adequately informed on all nuclear installations operating on Community territory. Article 78 therefore requires that "anyone setting up or exploiting facilities . . . shall declare the basic technical characteristics of such facilities". For this purpose the Commission, on 18 February 1959, adopted Regulation No. 7, which specifies the various information required (plan, description of technical processes, measuring and checking methods, amounts of material used, output capacity, main uses and, for reactors, power delivered, length of use, consumption of materials).

The Commission is not required to approve these plans; it simply notes that such and such a plant is or will be operating under such and such conditions.

Approval is only required in special cases, for instance when the facility has to use materials of American origin supplied under the Euratom/United States Agreement for Co-operation.

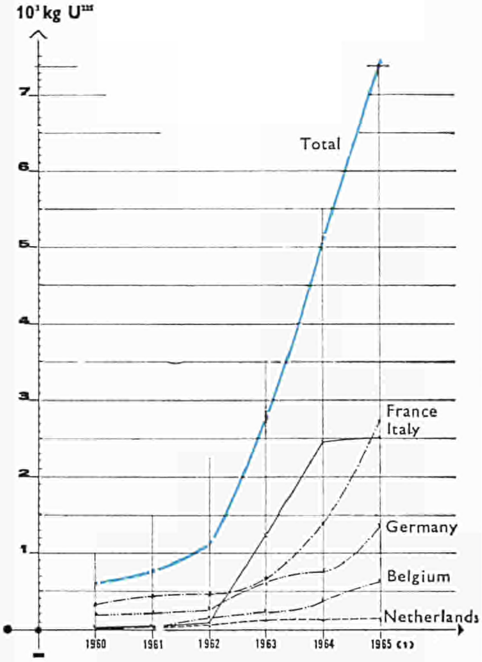
On the other hand—and this is an exception—the Commission must approve the technical processes to be adopted in irradiated-fuel chemical processing plants; for it was recognised that the Commission could not efficiently inspect these plants, which are dangerous to enter and highly complex, until it had secured firm assurances as to the chemical manufacturing processes.

Next, the Commission must periodically be sent "operating records", giving a certain number of accounting details concerning the nuclear materials used, produced or transported. These data, examined, processed and analyzed, enable a general account to be kept of all materials subject to Euratom safeguards. This accounting in itself provides an automatic check on the statements submitted by both the shippers and the receivers of such materials.

The Council of Ministers approved the regulation drawn up by the Commission on 12 March 1959 to implement this system. This Regulation No. 8 brought into force a system of immediate, monthly or quarterly returns, as the case might be, to be completed and produced under the responsibility of each installation.

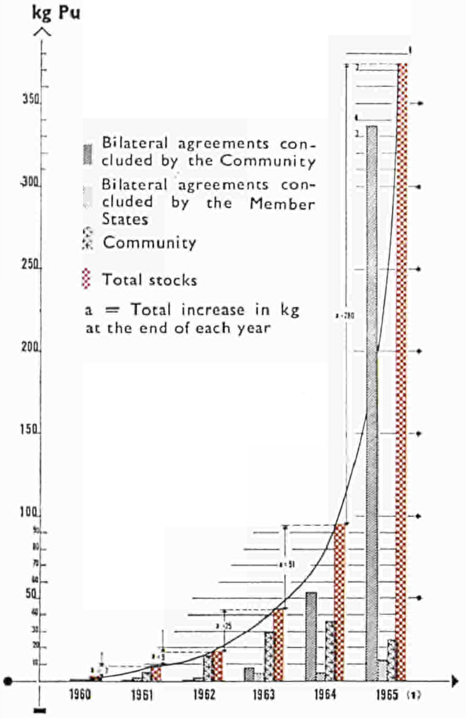
These returns are not statistical data, but actual materials balances and inventories similar to those drawn up, for economic management purposes, by most commercial or industrial establishments.

We come now to the last, though not the least, means of control. The Commission, quite naturally, must be able to ascertain,



(1) The data for 1965 are provisional

Figure 2: Breakdown of enriched uranium stocks by country (in kg uranium 235)



(1) The data for 1965 are provisional

Figure 3: Growth of plutonium stocks subject to Euratom safeguards in the Community (in kg plutonium)

through spot checks by its inspectors, that the information submitted is correct and that the safeguards requirements imposed are fully observed by the facilities. The inspectors, Community officials recruited by the Commission from nationals of the six member countries, hold extremely wide powers. They have free access at all times to all nuclear facilities and to all and any items of information they may require.

The obligations implicit in the safeguards system are liable to entail infringements on the part of the facilities it governs. For this reason a set of sanctions has been laid down, ranging from a warning to the enterprise to the withdrawal of materials.

We hope we have given a sufficiently clear, though summary, notion of Euratom's safeguards system to allow of dealing now with the more practical aspects—in other words, what exactly has been done and how.

The Directorate for Safeguards and Controls, set up in 1958, soon got under way in mid-1959 after the issue of the two regulations Nos. 7 and 8. A general inventory of installations was drawn up and the operating records began to arrive in quantity. By the start of 1960 the Commission possessed an initial statement of account of the Community's materials.

At the outset of the same year, the Commission appointed the first inspectors and at once sent them on their rounds to the Community facilities.

There was a very long row to hoe in the six years that followed: the nuclear installations considerably increased in number and in size, while the nuclear materials subject to control grew in quantity and diversity. Non-member countries supplied larger and larger amounts of highly enriched uranium and of plutonium, materials which could be directly diverted to military ends. These deliveries are still necessary, until such time as the Community can produce these materials unaided to develop its projects. Euratom's safeguards system has had to adjust to the new problems thus created and find the most suitable methods to maintain its efficiency, so vital to the smooth operation of the supply-line.

Table I and the graphs in Figs. 1 to 4 give an idea of the pattern of development.

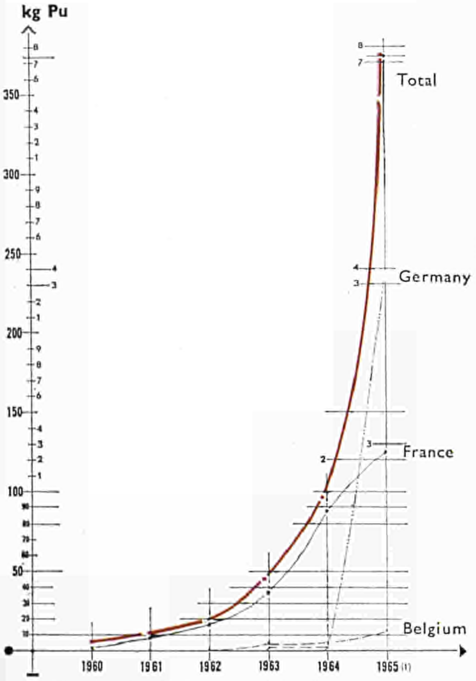
The increased activity shown by these curves inevitably raised a number of administrative, technical and even scientific problems. The staff of the Directorate for Safeguards, which at present has nine inspectors, is being reinforced, if only because irradiated-fuel reprocessing facilities have come into operation.

As to improvement of its technical methods, Euratom has sometimes devised its own solutions, sometimes relied on the know-how of its foreign partners and, in particular, has called on the long experience of the United States Atomic Energy Commission.

Six years of intensive operation have brought Euratom's safeguards service a wealth of experience which it hands on willingly to its partners and even to international control bodies such as the International Atomic Energy Agency.

Safeguards are being increasingly applied, to nuclear materials throughout the world. All effective safeguards systems, be they for disarmament or for non-proliferation purposes, will entail the application of control methods similar to those developed by Euratom.

By their compulsory and comprehensive application throughout the Community to all nuclear materials intended for peaceful purposes, Euratom is already making a positive contribution to these great problems of international life. The object of the Euratom safeguards system is admittedly not to prevent the six Community countries from pursuing military programmes; but it is already acting as a means both of making it impossible for materials earmarked exclusively for peaceful uses to be switched over to military programmes and of preventing such programmes from being carried out in secret. (EUBU 5-16)



(1) The data for 1965 are provisional

(2) The Italian and Dutch stocks do not exceed 1 kg

Figure 4: Breakdown of plutonium stocks subject to Euratom safeguards, by country (in kg plutonium)

What is boiling?

RENÉ MORIN, *Heat Exchange Department, Ispra Establishment, Euratom Joint Research Centre*

Boiling is an everyday phenomenon, and one harnessed since remote ages by the housewife as well as the engineer. Old prints show the alchemist amidst his retorts, and boiled eggs can scarcely be said to be a recent invention!

It was so familiar, in fact, that no systematic study of the phenomenon had been undertaken until the past few years. It needed the emergence of new devices such as jet engines, rockets and nuclear reactors, to reveal the extent of our ignorance and spark off a major research effort. These machines supply a great deal of power within a small compass and the performance of the fluids which they use must be pushed to the limit. In view of the promise displayed by boiling liquids, the next step was obviously to investigate their efficiency in these limit conditions.

Despite the many studies under way (1500 reports on boiling have appeared each year since 1960), understanding of the basic mechanisms involved is progressing very slowly. This is due to the intrinsic complexity of the phenomenon, readily apparent from the following considerations:

— the fluid in question constitutes a heterogeneous mixture of liquid and steam;

— the steam bubbles seem to form in an irregular manner;

— the appearance of the phenomenon changes according to the conditions, for example according to the quantity of heat supplied.

By this very complexity acts as a spur, impelling the specialist to seek fresh experimental and analytical methods, and to rediscover the pioneer spirit in a young science with a vast and still-growing field of application.

Evaporation and boiling

First of all, *evaporation* should not be confused with *boiling*; they are two distinget modes of vaporisation, marking the transition from the liquid to the gaseous state.

Evaporation is the transformation of the liquid into vapour by an imperceptible process which takes place on the *free surface* of the liquid: it is in this way that swamps dry out in summer and that wet objects become dry. The pace of the phenomenon is governed by the amount of vapour present in the atmosphere above the liquid: water cannot evaporate, for example, in an environment with 100% humidity.

Boiling, on the other hand, is characterised by the formation of steam bubbles *within the mass* of the liquid. This mode of vaporisation is governed by the pressure to which the liquid is subjected: boiling occurs when the temperature of the liquid reaches a certain value, fixed for a given pressure, called the saturation temperature. If the pressure drops, this temperature drops too, so that while at sea level water normally boils at 100°C, it will boil at the summit of Mont Blanc at 84°C. The degree of humidity plays no part in this process.

Two comments are called for before we examine in detail the mechanism of heat transfer during boiling.

Firstly, boiling occurs, as we have seen, at a fixed temperature for a given pressure. There is thus no danger of temperature differences and hence of thermal stresses in the boiling apparatus.

Secondly, a great deal of heat is always necessary to evaporate a liquid. For example while 1 calorie is required to heat 1 g of water through 1°C, 540 are required to vaporise 1 g of water at 100°C. The process of vaporisation thus consumes a considerable amount of heat. Furthermore water has one of the best performances in this respect (it is bettered only by sodium, 1 g of which requires 900 calories in order to

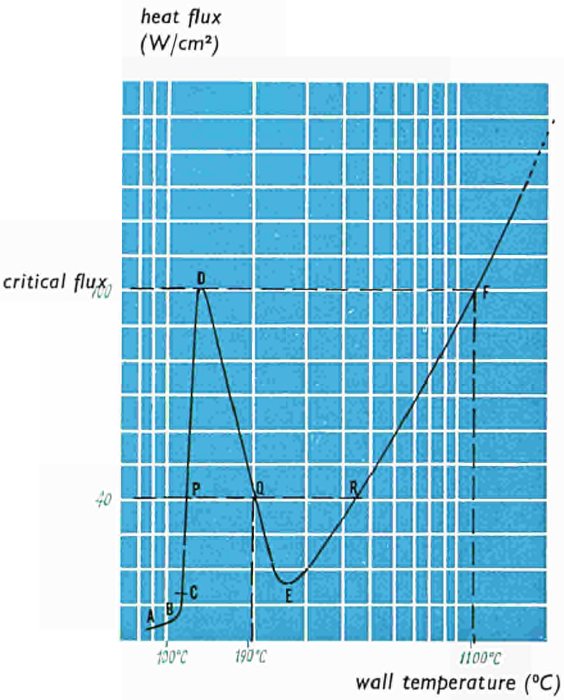


Figure 1: Nukijama curve
zone AB—natural convection
zone BC—surface boiling
zone CD—nucleate boiling
zone DE—transition boiling
zone EF—vapour-film boiling

be vaporised at atmospheric pressure). It will incidentally be noted that it is this property which enables water to act as regulator of the climate: it absorbs heat by evaporation during the hot hours, and then gives it up again by condensation (opposite process to vaporisation) during the cold hours. In the desert the days are torrid and the nights glacial because of the absence of water. By the same token, maritime climates are temperate.

In order to understand boiling, it is necessary to distinguish between the following forms:

— *vessel* boiling, in which the liquid remains stagnant in a receptacle (e.g. a locomotive boiler, or simply a pan of water on the fire);

— *convection* boiling, where the fluid circulates in a heated duct (e.g. a channel of a boiling-water reactor).

VESSEL BOILING

The existence of several vessel boiling systems was revealed for the first time by the Japanese Nukijama in 1934. He used a platinum wire heated directly by an electric current and placed in a vessel containing water.

He noted for each test the following quantities:

— the thermal flux on the wire (i.e. the quantity of heat supplied to the wire divided by the wire surface);

— the wire temperature.

These two values are sufficient to characterise an experimental point which can then be plotted on a graph. The set of representative points constitutes the well-known Nukijama curve (Fig. 1).

Five zones are distinguishable therein:

zone AB : natural convection,
zone BC : surface boiling,
zone CD: nucleate boiling,
zone DE : transition boiling,
zone EF: film boiling.

The different regions will be studied in turn, beginning with the simplest or most familiar.

Nucleate boiling (zone CD)

In nucleate boiling, the most common form, the mass of the liquid must be at saturation temperature. In these conditions, steam bubbles form on the heated wall, then escape to burst on the free surface of the liquid.

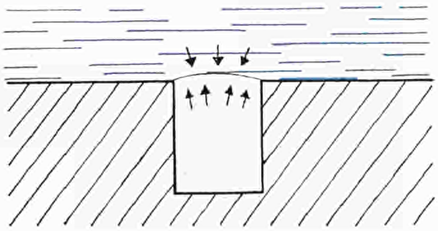
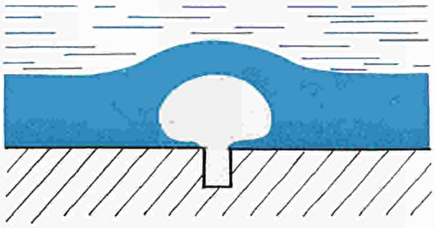


Figure 2: How a bubble is formed.
The diagram represents a nucleation centre, i.e. a small cavity (a few microns in diameter) in the heated wall. A bubble forms when the gas (or water) pressure in the cavity is sufficient to overcome the capillary forces acting on the interface.

More accurately, the bubbles form at preferential locations on the wall called "nucleation centres". These correspond to small cavities containing gas or steam. When the wall temperature rises the gas pressure in the cavities increases. The bubble forms when the pressure is sufficient to overcome the capillary forces acting on the gas/liquid interface (Fig. 2). This bubble remains attached to the wall until it reaches a critical size determined by the laws of dynamics. But whence comes the heat necessary for its growth? Following experiments on water a new theory, which has recently been corroborated elsewhere, was put forward by the Ispra Heat Exchange Department.

A superheated (i.e. at a temperature above boiling-point) layer of liquid having a depth of about 0.1 mm covers the heating wall. This superheat is necessary

Figure 3: How a bubble grows.
The same cavity as in Fig. 2. The wall is covered with a layer of superheated liquid (full colour section) which the bubble manages to lift.



to produce nucleate boiling by enabling the gas confined in the nucleation centres to overcome the capillary forces. This hot liquid is lifted up by the bubble during its growth (Fig. 3).

Under the bubble itself a thin liquid film remains (only a few microns — Fig. 4). The heat of the wall is then conducted across this film and supplies it with the energy necessary for gradual vaporisation. According to this theory the wall directly supplies much of the heat needed to form the bubble (70 to 80% for water at atmospheric pressure), the remainder deriving from the hot liquid surrounding the bubble.

At atmospheric pressure and in water, the bubble escapes when it attains a diameter of about 2 mm, (after a lifetime of 5 to 10 millisecs), taking with it a thin film of superheated water. This skin either vaporises, thus helping to swell the rising bubble, or mingles with the colder water through which it is passing. The disturbance zone thus created around a bubble is about 1.5 times the bubble's diameter (Fig. 5).

All in all, these mechanisms explain the good heat exchange achieved during boiling. The bubble actually extracts heat from the wall by pumping it across the underlying liquid film; it carries the water heated by contact with the wall into the liquid mass; lastly, it helps to create turbulence.

In a given cavity and for a given heat flux, the bubbles are generated at a fairly steady rate.

If the flux is stepped up, the time between each individual bubble diminishes until it finally becomes zero: there are then two successive phases — first the bubbles coalesce, and secondly columns of steam appear (Fig. 6). At the same time, the number of nucleation centres increases, the smaller cavities progressively coming into play as the water temperature by the wall rises. When the flux is high enough, the whole heating surface is covered with columns of bubbles (point D on the Nukijama curve).

The size and number of nucleation centres on the wall strongly affect the phenomenon, as the following experiment shows.

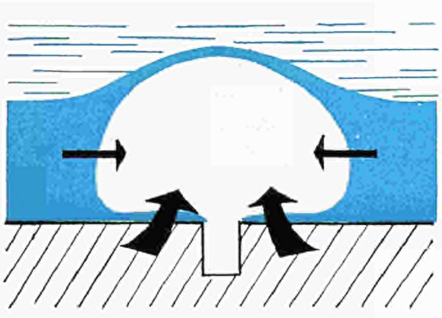
If the lower end of a glass test-tube containing water is heated, there comes a time when the bulk of the contents is expelled (Fig. 7). The explanation is as follows: since there are practically no nucleation centres, the water becomes strongly superheated, at least at the lower end of the tube. When finally a steam nucleus forms on the heated wall, the superheated part of the liquid is rapidly vaporised, causing violent expulsion of the tube's contents. This is not a rare phenomenon with boiling liquid metals, where the superheat necessary to activate a centre of a particular size is much greater than that for water — 4 times greater for potassium and 9 times for sodium.

Steam-film boiling (zone EF)

In this type of boiling there is a stable film of steam between the heating surface and the liquid (Fig. 8). The interface is wavy and bubbles escape at the bellies of the waves. The bubbles thus appear in lines separated by intervals of half a wavelength. In order to form an idea of steam-film boiling, it is enough to observe a small drop of water falling on a very hot metal plate: it rolls about and evaporates very slowly, thus showing that an insulating steam-film has formed between the drop and the plate. This phenomenon is well-known to laundresses, for example, who use it to check that the smoothing iron is hot enough.

A similar phenomenon occurs when a piece of metal previously raised to a high temperature is quenched in water. It remains red for some time: it is insulated by a steam-film. The temperature gap between wall and liquid is in general very wide and heat exchange occurs through radiation and conduction within the vapour layer.

Figure 4: How a bubble grows—continuation. The bubble continues to grow. A large part of the heat (denoted by the arrows) necessary for the formation of the bubble comes directly from the wall by conduction across the superheated water film between wall and bubble.



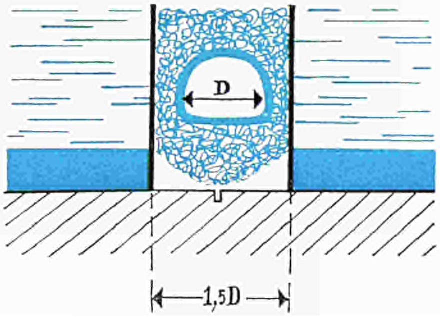
Transition boiling (zone DE)

This is the least-known field, being the most difficult to obtain experimentally and to explain. An attempt may be made to achieve transition boiling by applying a heat flux (e.g. by electric heating) to a surface. Let us refer again to the Nukijama curve (Fig. 1). Suppose the heat flux is 40 watts/cm². A priori it will then be possible to obtain any one of the points P, Q or R. In fact, the experimental evidence is that either P (nucleate boiling) or R (vapour-film boiling) will be obtained, according to conditions, but never Q (transition boiling). In another experiment where the wall is maintained at about 190°, the only possible operating point is Q. Therefore in order to study transition boiling it is necessary to raise the wall to a temperature lying between 125 and 250°C for water at atmospheric pressure.

It is not easy to impose a wall temperature. It is usually obtained by heating the inside of the test-tube, which is immersed in boiling water, by a supply of steam at its condensation temperature. Condensation is the inverse phenomenon of vaporisation, so that each gram of vapour liberates, in the process of liquefaction, the calories absorbed by a gram of liquid in vaporising. Condensation thus makes it possible to supply heat at constant temperature.

Transition boiling is characterised by an unstable vapour-film in violent motion. When liquid comes into contact with the

Figure 5: The bubble breaks away from the wall, disturbing the liquid in a cylindrical zone with a diameter about 1.5 times that of the bubble.



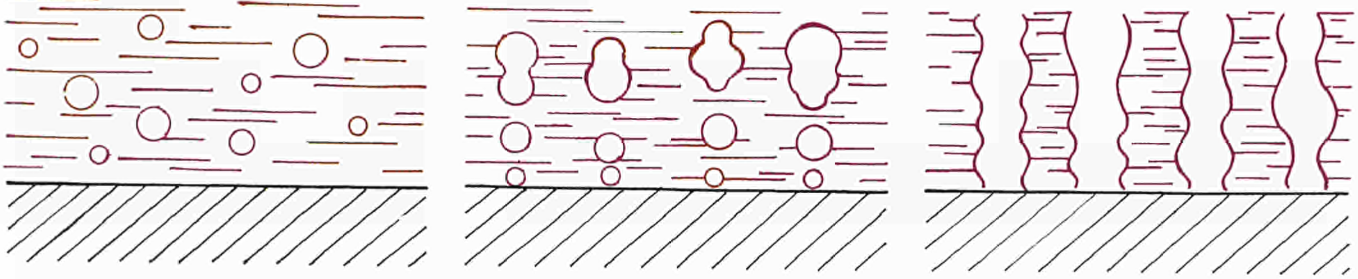
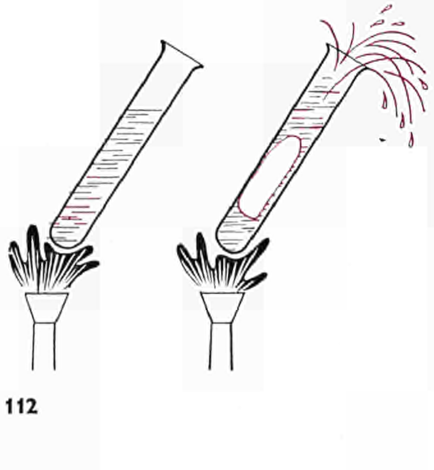


Figure 6: The stages of nucleate boiling. First diagram, left: the bubbles remain separate. As the heat flux reaching the wall gradually increases, the bubbles are first observed to merge together (second diagram), then regroup two or three at a time, and finally form steam columns (third diagram).

Figure 7: Boiling in a test-tube. In a glass test-tube there are no nucleation centres. If the bottom of the tube is heated the water becomes strongly superheated. When finally a steam nucleus forms on the wall, rapid vaporisation ensues, causing the violent ejection of the contents.



hot wall it vaporises suddenly, causing a sort of explosion. The wall temperature then undergoes substantial and abrupt local variations (Fig. 9).

Natural convection and surface boiling (zones AB and BC)

In this zone the water bulk is below saturation temperature. When the wall is below saturation temperature, heat exchange takes place by natural convection.

As soon as the wall temperature exceeds saturation temperature by a given margin, "surface boiling" takes place. Depending on the relative temperatures of the wall and the water content, one of the following phenomena may take place (Fig. 10):

—no bubbles are detectable, even with an ultra-fast camera; however pulsating hot water columns form at certain points on the wall: this phenomenon is attributed to the formation of evanescent microscopic bubbles, the interfaces of which act as membrane pumps;

—bubbles appear on the wall, but disappear before they can detach themselves from the wall surface;

—bubbles form on the wall, escape, and then are absorbed in the cold water some time before reaching the free surface.

Bubbles are formed according to the same laws as those applying to nucleate boiling. Account must be taken, however, of the condensation which occurs at the top of the bubbles when they reach the cold water layers.

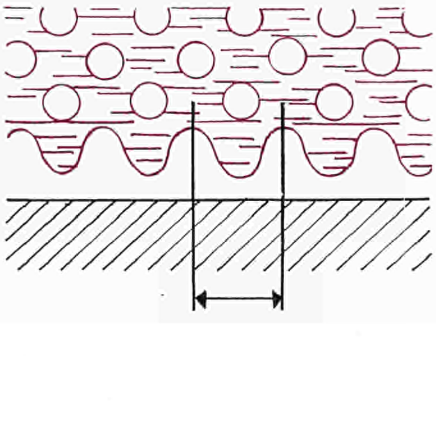
This type of boiling cannot be observed in a vessel except as a transient phenomenon. In fact the heat from the wall heats up the liquid, eventually establishing nucleate boiling.

Boiling crisis (point D)

The boiling crisis is a very important phenomenon from the practical angle. If one starts with nucleate boiling and increases the heat flux on the wall, the representative point shifts on the Nukijama curve until it reaches the point D. A further flux increase makes it jump sharply from D to F. If the wall can withstand the high temperature at point F, vapour-film boiling begins. Otherwise the wall is destroyed by so-called "burnout".

The flux corresponding to point D is called the critical flux (or burnout flux) because it corresponds to a crisis, a deterioration in the heat exchange process. The mechanism governing the vessel boiling crisis has not yet been clarified and many theories have been advanced. It may be assumed in simple terms that at point D the nucleation centres become so numerous that they cover practically the entire surface (Fig. 11). Above each centre, as has been seen, there is a steam column. If the flux rises, more and more steam will be produced in each column and its speed will increase. However, between the steam columns the water must be able to reach the wall in order to cool it and to feed the steam columns. A time will obviously come when the steam will be travelling at such a rate as to prevent the water from making contact with the wall, at least locally. The wall will then overheat: this is known as the boiling crisis.

Figure 8: Film boiling—a stable process



The above analysis of the phenomena described has been deliberately simplified. In order to have an idea of the complexity of vessel boiling it is as well to know some of the parameters involved, such as the type of fluid employed; nature and amount of any additives; pressure; the character, thickness, dimensions, surface state and mode of heating of the wall, etc.

The quality of the heat exchange between a fluid and a heating or cooling wall is indicated by a number called the "heat exchange coefficient". This figure, expressed in watts per square centimetre per degree Centigrade (W/cm^2 °C), represents the heat flux passing between the two media for a temperature gap of 1°C between fluid and wall. It is obvious that the greater this figure, the better the exchange. The value of nucleate boiling can easily be judged from a simple example. The heat exchange coefficients of boiling water in a vessel at atmospheric pressure are as follows:

—in natural convection (zone AB): approx.	0.2 W/cm^2 °C;
—in nucleate boiling near point D:	5 W/cm^2 °C;
—in vapour-film boiling (zone EF), at a wall-temperature of 950°C	0.05 W/cm^2 °C.

These values can be compared with the heat exchange obtained in forced convection in a tube of diameter 2.5 cm in which water at a temperature of 30°C circulates at a speed of 1.50 m/sec, i.e. 0.55W/cm^2 °C. If this last value is taken as the unit figure, the heat exchange is ten times better in nucleate boiling than in the crisis range, and ten times worse in the vapour-film boiling zone.

Vessel boiling has been most explored, firstly because it does not require costly experimental facilities and secondly because it enables the experimenter to form an idea of the basic mechanisms involved in convection boiling, the type most commonly employed in industry.

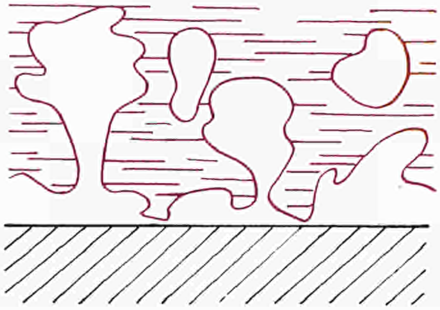


Figure 9: Transition boiling—an unstable process

CONVECTION BOILING

Suppose water is circulating upwards in a vertical tube the wall of which is heated by nuclear reaction or by an electric current. If the inlet temperature is below saturation temperature, heating of the liquid by forced convection will first of all be observed. After a time boiling will begin, and if the tube is long enough, all the water will finally be vaporised.

The novel feature of this type of boiling is that the liquid is forced to travel at a certain rate and that it carries off the steam formed. Various types of flow, or "flow regimes", are obtained, depending on the relative quantities of steam and liquid present in the channel.

A diagram of the various systems (almost as well-known as the Nukijama curve) is given in Fig. 12.

The following will be found in sequence:

zone ab: the liquid alone,
zone bc: surface boiling,
zone cd: nucleate boiling,
zone de: slug flow,
zone ef: annular flow,
zone fg: the liquid-deficient region,
zone gh: superheated steam.

Surface boiling (zone bc)

This phenomenon resembles vessel surface boiling. The average fluid temperature in a plane perpendicular to the tube axis is below saturation temperature, but the fluid in contact with the wall is somewhat above this temperature. Evanescent bubbles then form on the wall. In proportion as the mass of the water becomes heated along the channel, the maximum diameter of the bubbles increases. A moment comes when they are released from the wall to be subsequently absorbed by the cold liquid.

Nucleate boiling (zone cd)

Nucleate boiling occurs when the mass of the liquid attains saturation temperature. The bubbles are entrained by the flow. Their formation is governed by the same basic laws as apply to vessel boiling, but with

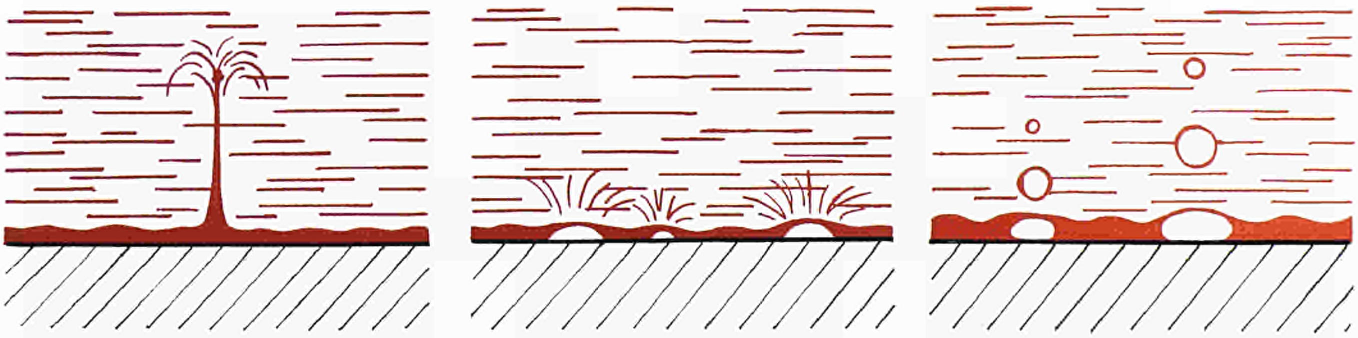


Figure 10: Surface boiling. Surface boiling changes as the temperature of the liquid rises: first jets of hot water are projected into the cold liquid (first diagram, left); then bubbles form, swell and collapse without leaving the wall (second diagram); finally (third diagram) the bubbles break away from the wall to condense in the cold liquid.

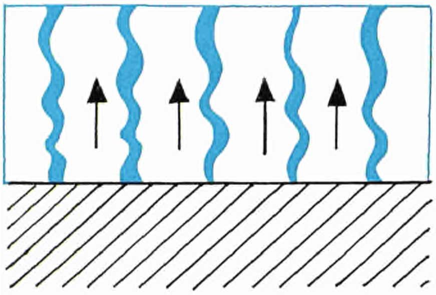


Figure 11: Vessel boiling crisis. The diagram shows in a highly schematic form the rising vapour columns separated by descending streams of liquid.

the additional influence of the speed of the fluid in the tube. In particular, their diameter at the time of escape is less than the critical vessel-boiling diameter.

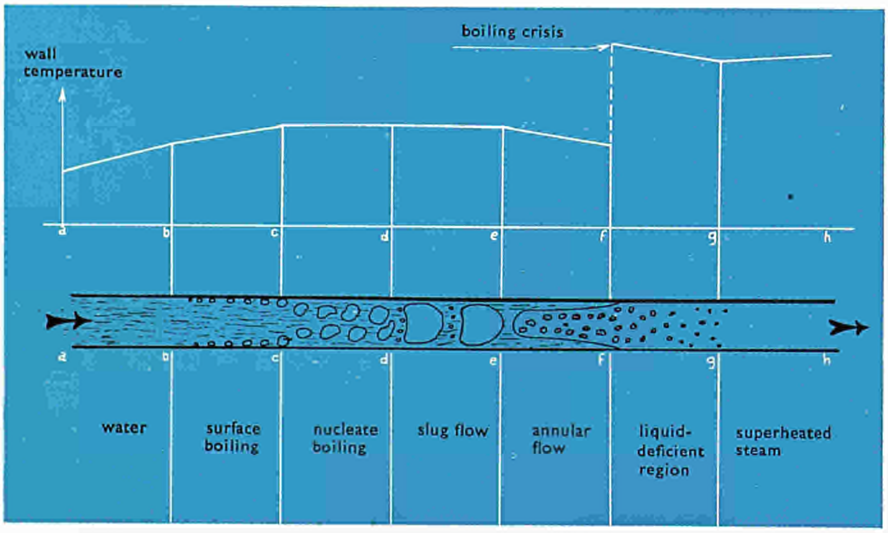
As with vessel-boiling, some superheating of the water near the wall is needed in order to activate the nucleation centres. This is a point which requires close attention, particularly when sodium or potassium are used. As has been pointed out, these substances require massive superheating in order for the first bubble to appear. As they are also good heat conductors the temperature of the liquid in the forced convection zone is almost uniform in a plane perpendicular to the channel axis. It is therefore necessary to superheat the whole potassium or sodium mass to produce boiling. Once the bubbles start to appear, they grow explosively to a large size in the superheated liquid, and disturb the flow. Countermeasures can be taken however by inducing the formation of artificial nucleation centres of adequate diameter.

The transition from nucleate boiling to annular flow (zone ef) may occur directly or via the intermediate stage of slug flow, according to conditions.

Slug flow (zone de)

This type of boiling is characterised by large bubbles (or slugs), the base of which is more or less flat and the top dome-shaped. These slugs are separated by liquid which may or may not contain small-diameter bubbles (Fig. 13).

Figure 12: Wall temperature pattern of a heating tube as a function of the type of boiling



This phenomenon, a source of instability in boiling channels, has not yet been very thoroughly explored. Yet it is perhaps not so very different from an ordinary traffic-jam.

Annular flow (zone ef)

In this zone the bubbles merge to form a continuous steam flow within a liquid sheath adhering to the wall (Fig. 14).

The steam, which circulates more rapidly than the water, causes ripples on the water surface. There are two types of wave, the first resembling a sea-swell, and the second a breaker or comber which is crested with steam carrying droplets of liquid with it: this is a fog.

The heat exchange takes place by the following process:

—conduction across the liquid film on the wall, then evaporation on the interface; this mechanism is akin to that postulated for bubble formation;

—in some instances, nucleation on the wall, with entrainment of water droplets superheated by the steam core (Fig. 14).

When the liquid has evaporated completely, there remains only the steam core containing water droplets; this is the *liquid-deficient region* (zone fg). The wall temperature rises, the droplets which impinge upon it being no longer sufficient to cool it. With continued heating the droplets evaporate and only the *superheated steam* remains (zone gh).

In a boiling channel the inlet liquid is generally subcooled, i.e. to a point below saturation temperature. Conditions at the outlet vary greatly according to the setup. For example, in a pressurised-water reactor (operating pressure 140 atmospheres), the water issues in the subcooled state, but surface boiling is accepted, and sometimes even a degree of nucleate boiling in the hottest channels. In boiling-water reactors (operating pressure 70 atmospheres) nucleate boiling occurs at the channel outlet, but recent designs even provide for annular flow.

Fog-cooled reactors (of the *CIRENE* type, developed by the *CISE*) operate with annular flow over a major section of the channel,

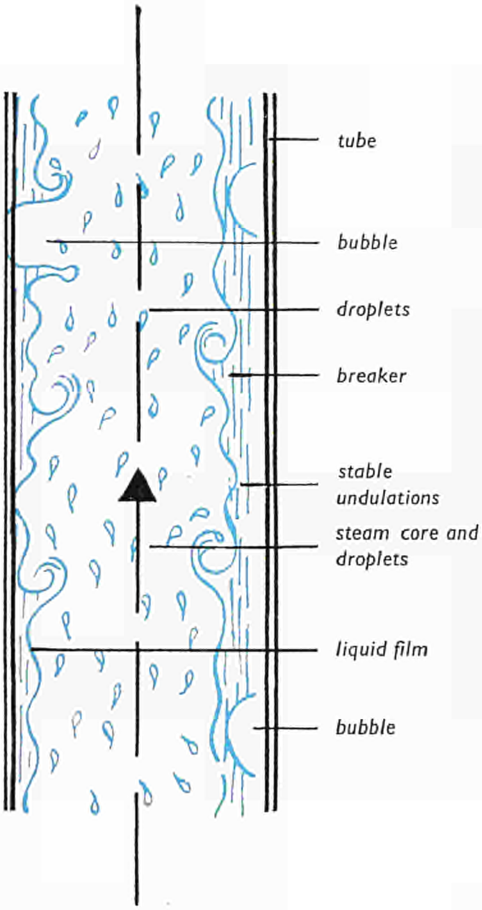


Figure 14: "Annular" flow

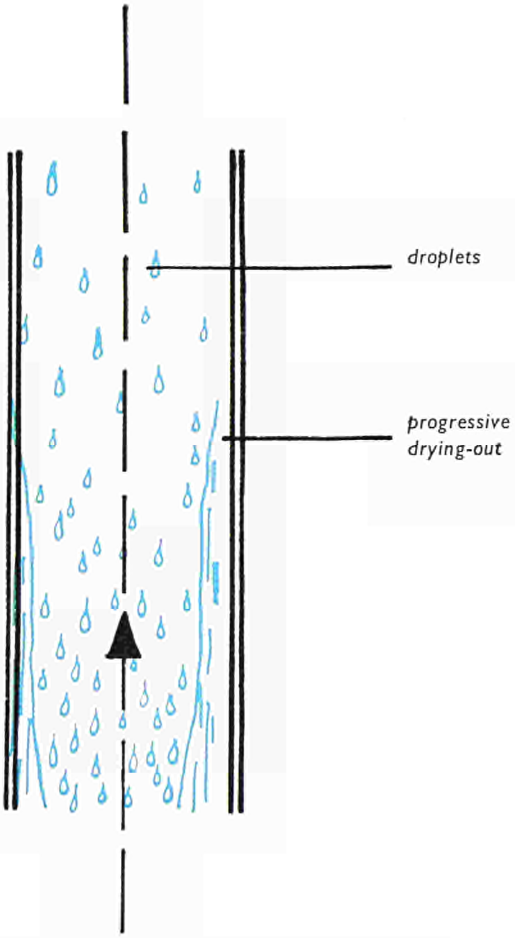
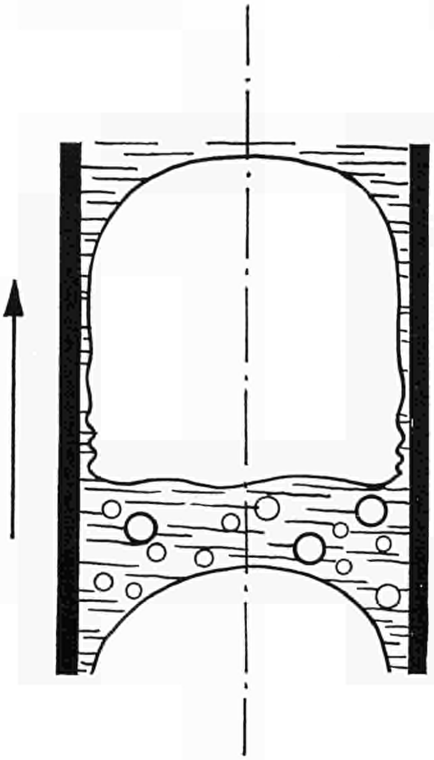


Figure 15: The boiling crisis in annular flow

Figure 13: "Slugs"



hence their name (i.e. *CISE* reattore a nebbia = *CISE* fog reactor).

In "once-through" industrial boilers, the steam is superheated at the outlet.

Considerable progress has been made with this type recently and it is being used in conventional thermal plants.

Boiling crisis

In a similar manner to that observed with vessel boiling, the heat transfer conditions may deteriorate for certain values of heat flux applied to the wall. Depending on the speed and temperature of the inlet liquid, the pressure of the system, and other factors, the crisis may occur in any of the following regions: annular flow, slug flow, nucleate boiling, surface boiling.

We cannot yet claim to have arrived at a complete grasp of various types of crisis which occur, although some attempts have been made, without any great measure of success as yet, to formulate empirical laws, or correlations, intended to give some guidance to designers. The reason for the difficulty is that the mechanisms involved are very numerous and the parameters to be considered vary from case to case. A couple of examples will suffice to illustrate this situation.

When there is enough steam in the channel the flow is annular. If the heat flux is gradually stepped up, a moment comes when the liquid film on the wall at the channel outlet becomes too thin to wet the entire surface. At this point the wall has wet and dry patches, which can lead to very wide temperature fluctuations. This is the start of the crisis. A further flux increase raises the surface temperature and the amplitude of

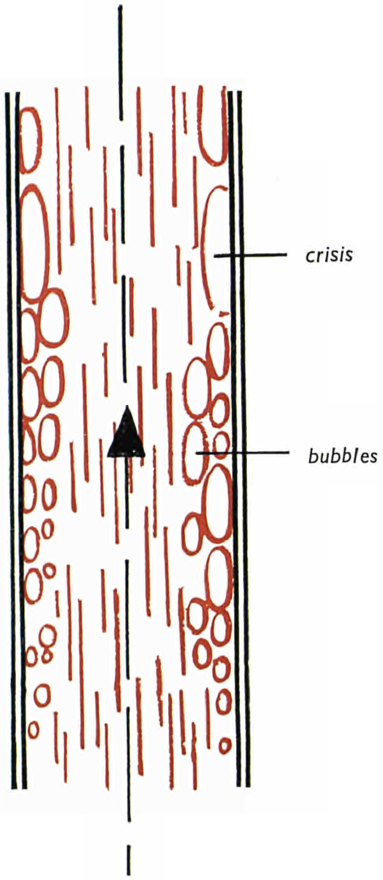


Figure 16: The surface-boiling crisis

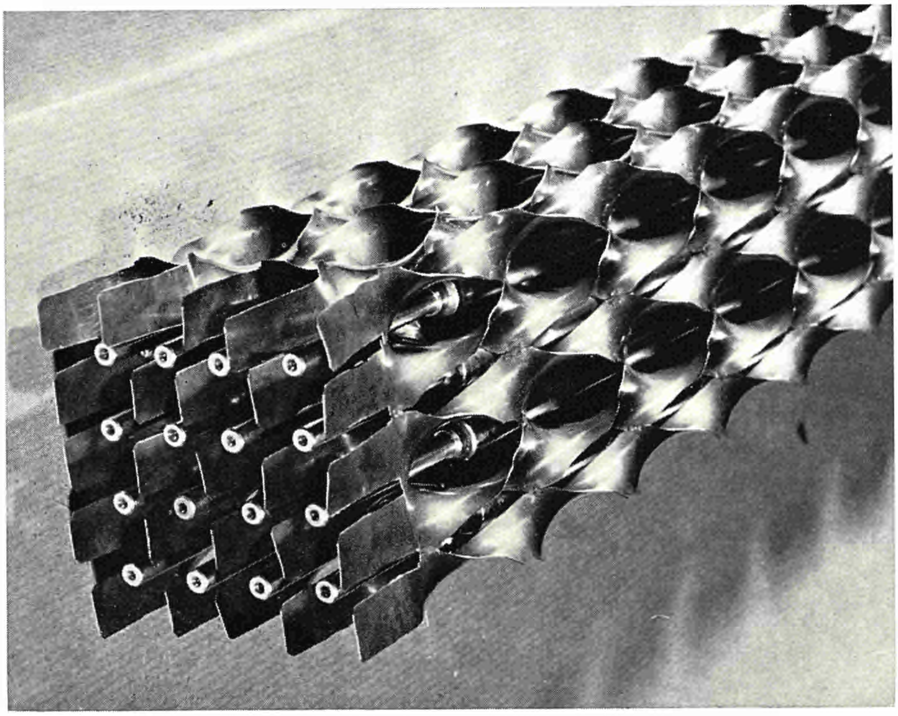


Figure 17: Mockup of fuel element for boiling reactor equipped with twisted tapes. This method makes it possible to achieve critical fluxes two or three times higher than with straight flow (SNECMA, *France*).

Figure 18: Strioscopic photographs obtained during the lifetime of a bubble in surface boiling.

Strioscopy makes it possible to "see" the temperature gradients: the white lines represent isotherms.

Photo 1: A bubble has just formed on the wall.
Photos 2 and 3: The bubble has broken away from the wall. In traversing the colder zones it recondenses.
Photo 4: The condensation cycle ends abruptly: there is an implosion which causes a characteristic jet of hot water—the so-called "nuclear mushroom". It will be noted that the perturbed zone is relatively narrow, of about the same diameter as the bubble; outside this zone the thermal layers are stable.
These photographs were taken from a film made by Mr. Bähr(Heat Exchange Service, Ispra).

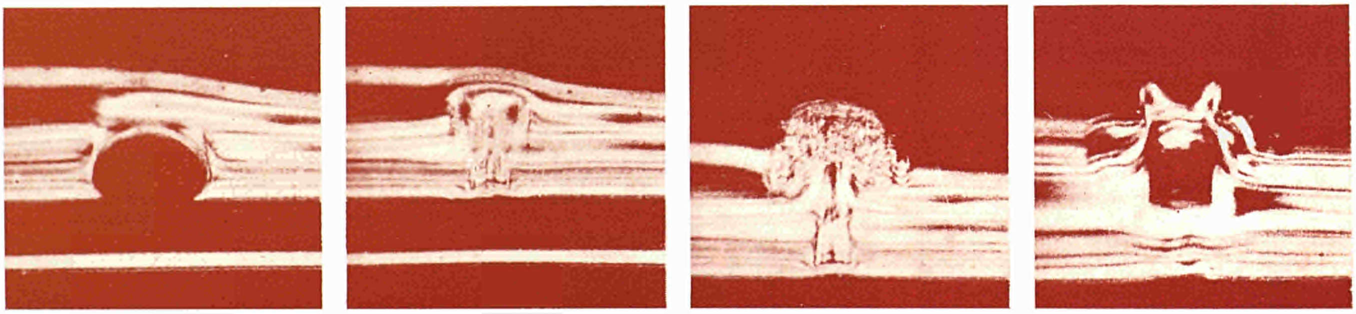


Photo 1 *Photo 2* *Photo 3* *Photo 4*

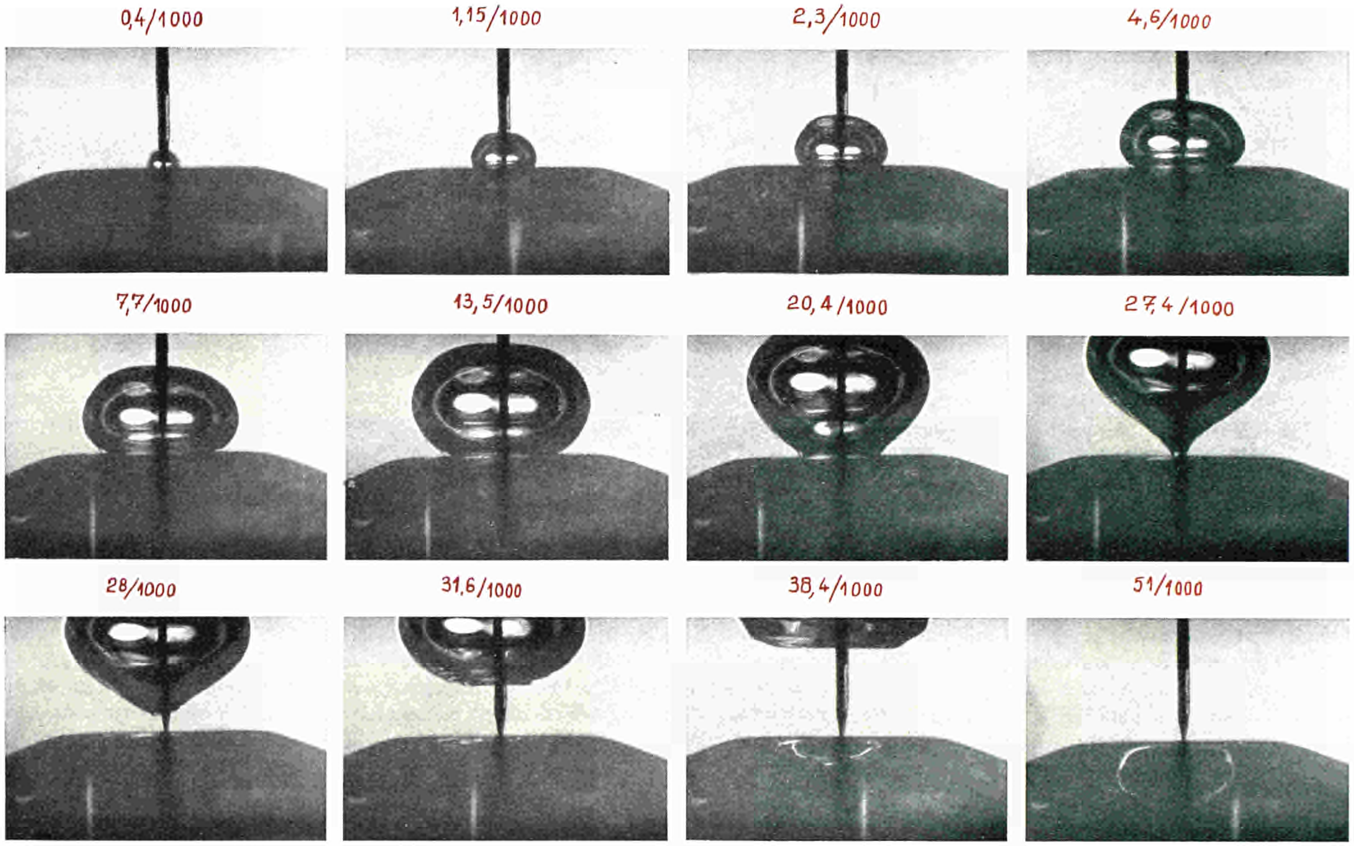


Figure 19: Film of the genesis of a bubble (taken with an ultra-high-speed camera). The fluid temperature above the nucleation point was measured at a distance of 10 microns from the wall. The luminous spot on the film indicates the temperature variations at the measurement point. At the point of time when the bubble is formed the water is superheated (first picture: the luminous spot is on the extreme right). When steam surrounds the measuring thermocouple, the temperature reading is near the saturation temperature.
Camera speed: 3,000 frames/sec.

the fluctuations, normally without causing the destruction of the channel.

If on the other hand the water at the channel outlet is subcooled, the phenomenon follows a different pattern. There is, as we have seen, a surface boiling, the bubbles disappearing in the core of cold water. At a high heat flux the steam barrier near the wall may be enough to prevent contact between wall and water. The phenomenon which then occurs is similar to the vapour-film effect in vessel boiling: the resultant poor heat exchange gives rise to the boiling crisis. A further flux increase leads to the destruction of the heating wall (Fig. 16).

Certain techniques make it possible to hold off the boiling crisis by avoiding steam build-up near the wall. One example is turbulent flow, which was intensively studied by *SNECMA* under Euratom contract. Spirals known as "twisted tapes" placed in the channel axis impart a cork-screw motion to the liquid-steam mixture (Fig. 17). The effect of the corresponding centrifugal force is to concentrate the water on the wall and the steam in the channel axis. This acts as a safeguard against the boiling crisis in any flow regime.

Furthermore, certain wall configurations can be used to stabilise the liquid film in annular flow, for example transversal or longitudinal corrugations of a given height and spacing (developed by *GeCo*, United States, and *Thomson-Houston*, France, respectively).

Those who hoped to receive a simple and comprehensive answer to the title of this article will perhaps be disappointed. Boiling is a highly complex phenomenon, whose mysteries we have barely started to unravel. But at all events we have seen that it is a most vital phenomenon; the game is therefore worth the candle. (EUBU 5-17)

STARK

The "Fast Breeder Project" is currently the most important central research project of the Karlsruhe Nuclear Research Centre. Fast breeders are the reactors of the future; whereas with the present-day "thermal" reactors it is for the most part only possible to utilise the U 235 isotope, which occurs in natural uranium to the extent of 0.7%, the fast breeders enable energy to be produced from U 238 and thorium, large quantities of which are available, and thus constitute a practically inexhaustible source of energy. A number of countries are now working on the development and testing of these reactors. Euratom has been participating in the Karlsruhe project since 1963 under a contract of association.

Work on the "Fast Breeder Project" began in 1960. The first task was to clarify the fundamental physical and technical principles of fast-breeder construction and operation. The problems of reactor physics and safety were uppermost and it was accordingly decided to build three research plants, *SNEAK*, *SUAK* and *STARK*, in which to carry out the necessary experimental work for the solution of these problems. In addition, in 1964 the Karlsruhe Nuclear Research Centre began its participation in the *SEFOR* experimental reactor in the United States. Side by side with this Southwest Experimental Fast Oxide Reactor, which serves mainly for studying problems of stability and safety in fast reactors, the Karlsruhe fast zero-energy assembly known as *SNEAK* ("Schnelle Nullenergie-Anlage Karlsruhe") has pride of place. This is a fast zero-energy reactor in which various fission-zone assemblies can be built up to simulate power reactors and used for the determination of reactor-physics and safety data which can then serve as a basis for the design of power reactors. The Karlsruhe fast subcritical assembly, designated *SUAK* ("Schnelle Unterkritische Anordnung Karlsruhe"), is used for measuring various reactor-physics parameters such as the neutron life and the neutron spectrum in fast subcritical assembly models.

The Karlsruhe Fast-Thermal Argonaut Reactor, or *STARK* ("Schnell-Thermischer Argonaut Reaktor Karlsruhe"), differs from the abovementioned fast assemblies. It is a coupled reactor with two fission zones, one thermal and the other fast, which, being interlinked and interdependent through the exchange of neutrons, together form a critical assembly. *STARK* was born as the result of the extension of the Karlsruhe Argonaut Reactor, in accordance with the plans devised by a team of scientists at the Nuclear Research Centre's Institute for Neutron Physics and Reactor Technology, which included K. H. Beckurts, W. Häfele, H. Meister and K. Ott.[1] In this way it was possible to construct in a short time and at no great cost a reactor which, from the operation and safety point of view, has all the characteristics of the uncomplicated and safe Argonaut reactor, and in addition possesses a fast fission zone with a neutron spectrum similar to that typical of fast reactors.

The possession of a fast fission zone is very important for the tasks that *STARK* is required to perform. *STARK* serves for the development of measuring techniques and apparatus for studies on fast reactors; it enabled a start to be made, years before the completion of *SNEAK*, on the preparation and testing of the experiments to be carried out in this important research installation.

STARK first went critical on 24 June 1964. Until recently, the *STARK* working programme was determined by the preparatory work for the *SNEAK* experiments, but after the commissioning of *SNEAK*,

---

[1] H. Meister, K. H. Beckurts, W. Häfele, W. H. Köhler, K. Ott: "The Karlsruhe Fast-Thermal Reactor Concept", KFK 217 (1964).

The Karlsruhe Fast-Thermal Argonaut Reactor (Schnell-Thermischer Argonaut-Reaktor Karlsruhe) and its task in the Fast Breeder Project of the Karlsruhe Nuclear Research Centre

CHRISTIAN BRÜCKNER, STARK *Reactor Group, Karlsruhe*

the accent has been on activities relating to the study of the *STARK* "coupled system" as such.

Physical problems in fast-breeder development

Any nuclear reactor is an installation in which the fission of atomic nuclei, initiated by neutrons but also producing neutrons as well as fission fragments and energy, can take place in a self-sustaining chain reaction. In a "critical" reactor the number of disintegrations per unit of time and, consequently, the neutron population are constant and their magnitude determines the reactor power. A state of equilibrium exists: of the neutrons generated during a fission event, on the average exactly one initiates a further desintegration.

The nuclear fuels used in reactors must therefore fulfil the following condition: for every neutron absorbed, the number of neutrons η generated through fission must be sufficient to cover all the neutron losses that occur as a result of absorption in other parts of the reactor and of escapes from the fission zone (normally about 20%).

The quantity η depends on the nature of the nuclear fuel and on the energy of the neutrons absorbed. In figure 1, η is shown as a function of the neutron energy for natural uranium, uranium 235 and plutonium 239.

It can be seen, for example, that in the case of natural uranium the minimum value of η that is necessary to maintain the neutron balance is attained only at very low ("thermal") neutron energies. It is only in thermal reactors that natural uranium can be used as fuel; in these reactors moderating substances such as water, heavy water or graphite ensure that the neutrons generated lose their kinetic energy before they initiate further fissions as low-energy thermal neutrons.

On the other hand if highly enriched uranium or plutonium is used, it is possible to build "fast" reactors in which the nuclear fissions are produced by non-moderated fast neutrons. The high value of η in the fast-neutron energy range, particularly in the case of plutonium, not only allows the neutron balance to be maintained in the normal manner, but also leaves a sizeable surplus of neutrons for the conversion of "fertile" into fissile material by neutron bombardment.

Two main conversion processes are known: after neutron capture thorium is transformed into fissile uranium 233, and uranium 238 into plutonium 239. The work at Karlsruhe is based on the latter transformation:

uranium 238 + neutron → uranium 239
——— β-decay ——→ neptunium 239
——— β-decay ——→ plutonium 239

Thus besides the fissile material (plutonium 239), fast reactors will contain as the fertile element uranium 238, from which more plutonium 239 is produced through conversion. The high η value of plutonium in the fast-neutron energy range not only enables the consumption of fissile material to be made good in these reactors by conversion of the fertile element, but even makes it possible to "breed" a surplus of plutonium, which can subsequently be used for the initial charging of newly constructed reactors.

The initiation of nuclear fission by high-energy fast neutrons means that the neutron energies in a fast reactor are considerably higher than in a thermal one. Consequently, the parameters required for the design of a fast breeder have largely to be determined afresh; this applies particularly to the fission cross-section in the fuel, which determines the probability of fission-initiating neutron capture, and to the absorption and scattering cross-sections in the fuel, fertile material, construction materials and coolant, all of which depend on the energy of the neutrons.

The hard-neutron spectrum is characterised by the extremely short life of the neutrons released in the fissions. Whereas in a thermal reactor the average time that elapses between the generation and the absorption of the neutrons in the fuel is one-thousandth of a second, in a fast reactor it is only a ten-millionth part of a second. It is easy to see that this is bound to affect the time-behaviour and, consequently, the safety of the fast breeder; indeed, the rate at which the neutron population and the power of a "supercritical" reactor increase depends not only on the "reactivity", i.e. the amount of the departure from equilibrium, but also on the average neutron life, that is to say the time that elapses between two successive generations of fission events: the shorter the average neutron life the faster the rates of increase are likely to be.

Now fortunately not all the neutrons are "prompt", i.e. released immediately after the fission process; a small proportion are "delayed" neutrons which are emitted later—sometimes minutes after the relevant fission events — on the radioactive decay

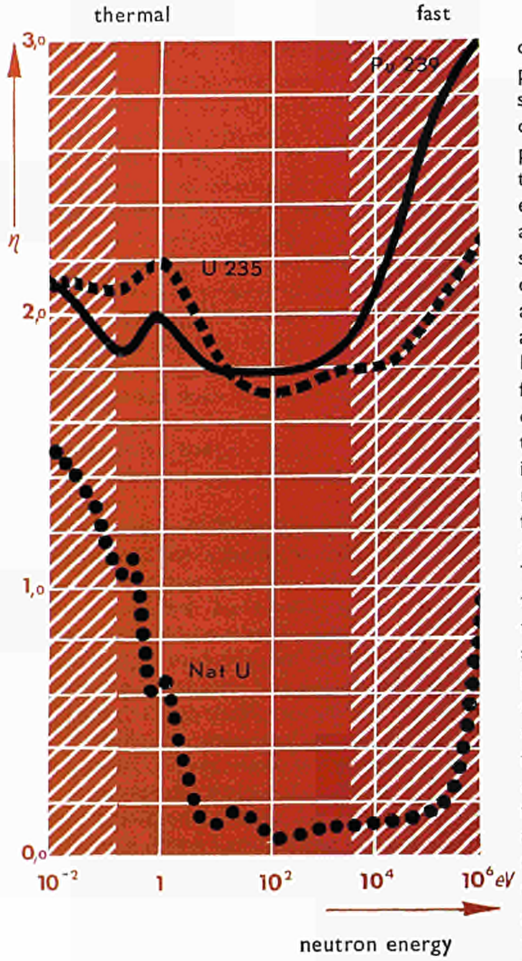


Fig. 1: Number of neutrons generated (η) for every neutron absorbed in natural uranium, U 235 and Pu 239, as a function of the neutron energy.

of certain fission fragments. (The actual proportion of delayed neutrons depends solely on the nature of the fuel; in the case of plutonium it is 0.22%). Despite the small proportion of delayed neutrons, the long time-lags result in a very substantial lengthening of the average neutron life (up to about one-tenth of a second) and hence in small rates of power increase both in supercritical fast reactors and in thermal reactors, as long as the delayed neutrons are making a necessary contribution to the neutron balance. If, however, the reactivity of a fast reactor exceeds the proportion of delayed neutrons, i.e. if the prompt neutrons alone are able to determine the power increase, their extremely short life gives rise to very sharp power increases, at rates far above those likely to occur in thermal reactors.

This peculiarity of fast reactors underlines the importance of giving meticulous attention to safety aspects in their development and necessitates a search for entirely new methods of reactor stabilisation. In the design and construction of a fast breeder every effort must be made to ensure that the positive reactivity changes that can occur in normal operation or during malfunctions remain small and, in addition, to give it characteristics which enable it to counteract rapid power increases without the intervention of a control and shut-down system. This auto-stabilisation works provided that, during power and temperature increases, sufficiently powerful effects are produced to reduce the reactivity, i.e. to give the reactor a "negative temperature coefficient of reactivity". The power reduction must take effect extremely rapidly. The effects known from thermal reactor practice are generally too slow.

Consequently, in fast-breeder development great attention has been paid to the Doppler effect, of which little notice had previously been taken. This effect, which acts with the required rapidity, is based on the change that occurs in the neutron-capture probability as a function of temperature, both in fissile and non-fissile nuclei.

It is exceptionally difficult, however, to acquire the necessary knowledge for the design of a fast breeder as regards the neutron cross-sections in the fuel, fertile material, construction materials and coolant in the fast-neutron energy range, the magnitude of possible reactivity perturbations and that of stabilising effects, particularly the Doppler effect. The usually very complicated energy-dependence of the effective cross-sections in the energy range concerned calls for onerous theoretical and experimental studies, which include the development of novel techniques for measuring fast neutron spectra.

But it is above all essential to possess pilot installations in which the characteristic features of fast reactors can be simulated. This is the reason for building zero-energy reactors or reactors of the *STARK* type.

Construction and characteristics of STARK

STARK came into being through the extension of the Karlsruhe Argonaut reactor, which is shown in cross-section in figure 2. The Karlsruhe Argonaut reactor is a heterogeneous thermal reactor with an annular fission zone which contains 20% – enriched uranium as the fuel and light water and graphite as the moderators. The fission zone is located between two coaxially mounted aluminium tanks with respective diameters of 61 and 92 cm. The inner tank is filled with a graphite core and the annular fission zone is surrounded by an external graphite reflector. The whole is enclosed in a shield of concrete blocks.

The 24 fuel elements are composed of individual plates containing as fuel uranium oxide (U_3O_8) clad with aluminium. Unoccupied spaces between and next to the fuel elements are filled with graphite spacers. The height of the fission zone is 61 cm. The annular zone is filled with moderating water, which circulates in a closed system.

Start-up and control are effected by means of six regulating elements with cadmium plates; these are distributed around the outer aluminium tank and are movable in the vertical plane. For the monitoring of the reactor there are six neutron-measurement channels, five of which are incorporated in a safety system. Two channels equipped with BF_3 counter tubes are used when the reactor is started up; the other four channels contain ionisation chambers and serve for power monitoring during operation. The Karlsruhe Argonaut reactor was operated at power levels of up to 10 watts.

The most important modification in the extension of the Argonaut reactor into the coupled fast-thermal Argonaut reactor was the replacement of the inner graphite core by a "fast" fission zone containing uranium metal the enrichment of which can be varied.

Figures 3 and 4 give an idea of the construction of *STARK*. The annular "thermal" fission zone of the Argonaut reactor is unchanged; it has merely been provided with an annular aluminium container of its own. The outer reflector and the concrete shielding are likewise unchanged.

The fast fission zone, which is now located in a central vessel mounted inside the annular tank, is formed by a lattice arrangement of 37 fuel capsules in which natural uranium in the form of square platelets is contained inside square-section tubes of special steel. The average degree of enrichment can be varied by mixing natural uranium and 20%-enriched uranium; in addition, by inserting filler materials it is possible to adjust the fast-neutron spectrum of the fast fission zone. This zone likewise has a height of 61 cm. It is entirely enclosed in a thick jacket of natural uranium which protects it against thermal neutrons from the annular zone. This is surrounded in turn by a graphite jacket which links it to this annular thermal zone. The octagonal internal cross-section is shown clearly in figure 4.

The central position of the fast zone is equipped to receive a pile oscillator for measurements on material specimens. Special fuel capsules, into which measuring devices or irradiation samples can be inserted, provide further facilities for experimentation.

Since the ingress of water or other liquid moderators into the fast zone would result in a dangerous increase of reactivity (water ingress is the "maximum hypothetical accident" in the *STARK* reactor), complete protection against leakage is essential. This is ensured by two sealing systems: firstly, the heads of the fuel capsules are sealed with rubber discs against each other and against an aluminium plate which covers the natural-uranium jacket; secondly, the central vessel, which projects an appropriate distance upwards, is sealed with a rubber sleeve against the rotating cover which forms part of the upper shielding. An important factor for the experimental work is the presence of plugs in the cover to ensure that objects inserted in the fast zone remain accessible.

STARK is equipped with the same monitoring system as the Argonaut reactor and likewise has control and shut-down elements with cadmium plates on the outer wall of the annular vessel; it has, however, 12 of these elements, twice as many as the Argonaut, and the area of the plates is increased by 50% so as to obtain a higher reactivity value for the shut-down system. Furthermore, the fast zone is equipped with a shut-down rod consisting of a fuel capsule, which can be lowered out of the fission zone, and a "follower" containing boron carbide. In order to increase the intrinsic safety of the reactor, the moderating water is kept at a temperature of 80°C during operation by means of an electric heating system in the water circuit.

With its "thermal" annulus and its "fast" central core, *STARK* thus has two fission zones, each of which in itself is decidedly subcritical: only together are they capable of forming a critical assembly. The "coupling" between them is effected through the exchange of fast neutrons: each zone contributes to the neutron economy of the other and hence to the number of fission events.

Just as the construction and operation of the annular zone in *STARK* are the same as in the Argonaut thermal reactor, so too is its neutron spectrum completely identical

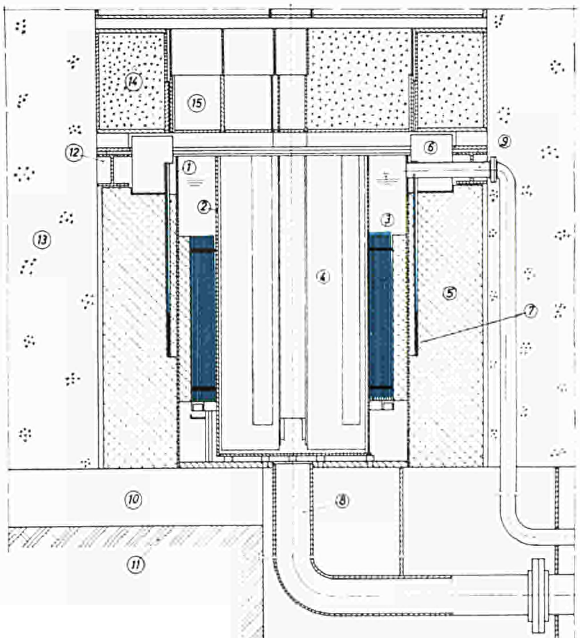


Fig. 2: Vertical cross-section through the Karlsruhe Argonaut Reactor

1. *Outer aluminium tank*
2. *Inner aluminium tank*
3. *Fuel elements*
4. *Inner graphite core with experimentation channels*
5. *Graphite reflector*
6. *Control-plate drive*
7. *Control-plate (inserted)*
8. *Water feed line (also fast drain line)*
9. *Overflow*
10. *Channel for start-up source*
11. *Foundation*
12. *Structure*
13. *Biological shield*
14. *Annular cover*
15. *Rotating cover*

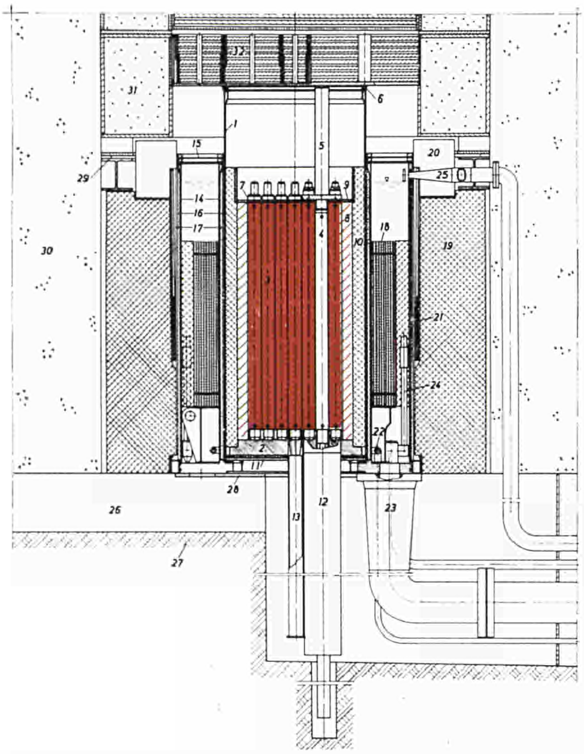


Fig. 3: Vertical cross-section through the STARK reactor

Fast zone
1. *Central aluminium vessel*
2. *Lattice plate*
3. *Fuel capsules*
4. *Control element*
5. *Guide tube for control element*
6. *Seal on tank*
7. *Seal on fuel capsules*
8. *Natural-uranium jacket*
9. *Cover plate*
10. *Graphite jacket*
11. *Boral plate*
12. *Guide tube for control-element drive*
13. *Extension for pile oscillator*

Thermal zone
14. *Annular aluminium vessel*
15. *Cover with rupture disc*
16. *Thermal insulation layers*
17. *Air cooling gap*
18. *Fuel elements*
19. *Graphite reflector*
20. *Control-plate drive*
21. *Control-plates (inserted)*
22. *Ring line for water feed*
23. *Fast drain line*
24. *Middle overflow*
25. *Upper overflow*
26. *Channel for start-up source*

Supporting structure and outer shielding
27. *Foundation*
28. *Bed-plate*
29. *Structure*
30. *Biological shield (concrete blocks)*
31. *Ring cover*
32. *Rotating cover*

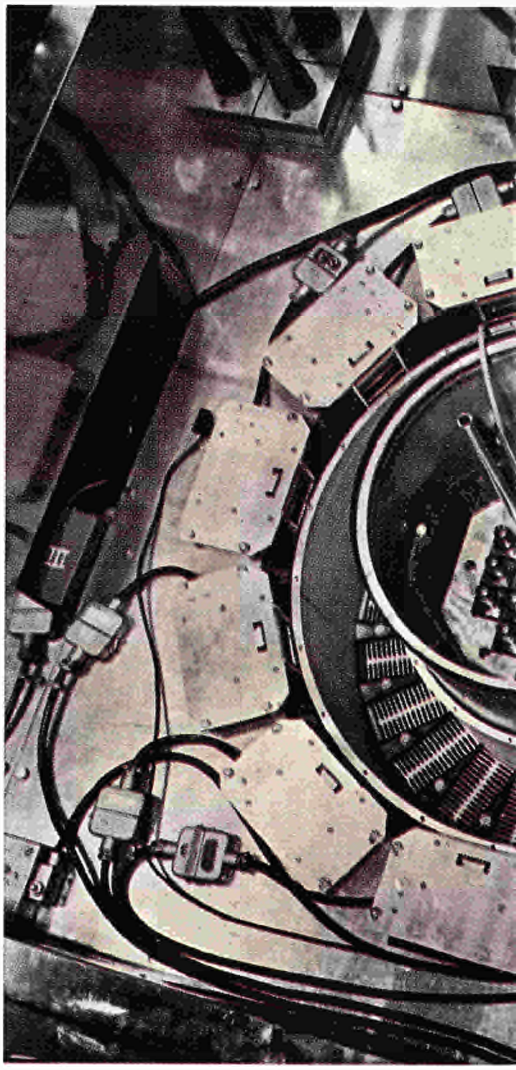
with that of a thermal reactor. The fast neutrons escaping from the fast zone lose their energy for the most part in the graphite jacket, but at the latest immediately on entering the annulus in the moderating water. Consequently, the fissions in the annular zone are initiated almost exclusively by thermal neutrons; the average life of the prompt neutrons is about 1.3×10^{-4} sec.

The energy distribution of the neutrons in the fast zone is determined by the compact structure and the material composition. The use of metallic uranium and the absence of moderating substances result in a hard neutron spectrum resembling that of fast reactors. The natural-uranium jacket prevents penetration by slow neutrons from the thermal zone. It allows only fast neutrons to pass through and acts as a converter: some of the thermal neutrons absorbed in it split U 235 nuclei and are thus, as it were, converted into fast neutrons. Hence only fast neutrons initiate the fission processes in the fast zone. The life of the prompt neutrons in that zone is around 10^{-7} sec.

For the fuel mixture inserted in the fast zone an upper limit is fixed such that the contribution of the fast zone to the total power of the coupled system, and consequently to the neutron economy, cannot exceed a certain maximum value. In the fuel charges loaded into *STARK* to date, this maximum permissible value for the power contribution has been about 33%. The fast fission zone therefore remains heavily dependent on the neutrons entering it from the thermal zone; its "link" with the thermal zone is a very close one, as is clearly illustrated in figure 5. Since at least two-thirds of all the fission events in the entire system are "triggered off" by thermal neutrons, the average life of the prompt neutrons in *STARK* is also determined predominantly by that of the thermal neutrons. The actual value is 0.7×10^{-4} sec., which is approximately the same as in purely thermal reactors.

As regards its time-behaviour *STARK* is still a thermal reactor; it can be controlled with the same simple regulating system as the Argonaut.

Important safety features are likewise preserved in this way. As we know, the Argonaut reactor has great inherent safety. Should a power excursion occur in the event of an accident, the moderating water heats up very rapidly and is expelled from the fission zone owing to the formation of steam on the walls of the fuel-element plates (i.e. the reactor is "shut-down"), so that energy release ceases before the fuel melts or any other damage can occur. In the *STARK* reactor the close coupling and the limited power contribution of the fast zone ensure that the latter zone is likewise protected by this mechanism in the event of power excursions: any power increase in the fast fission zone is directly associated with an increase in the thermal zone, but under accident conditions this would so quickly result in a shut-down that at no point in the fast zone could the temperature reach the melting point of the fuel. Furthermore, the shut-down process is accelerated by the high temperature of the moderating water. This ensures that in the event of a power excursion the



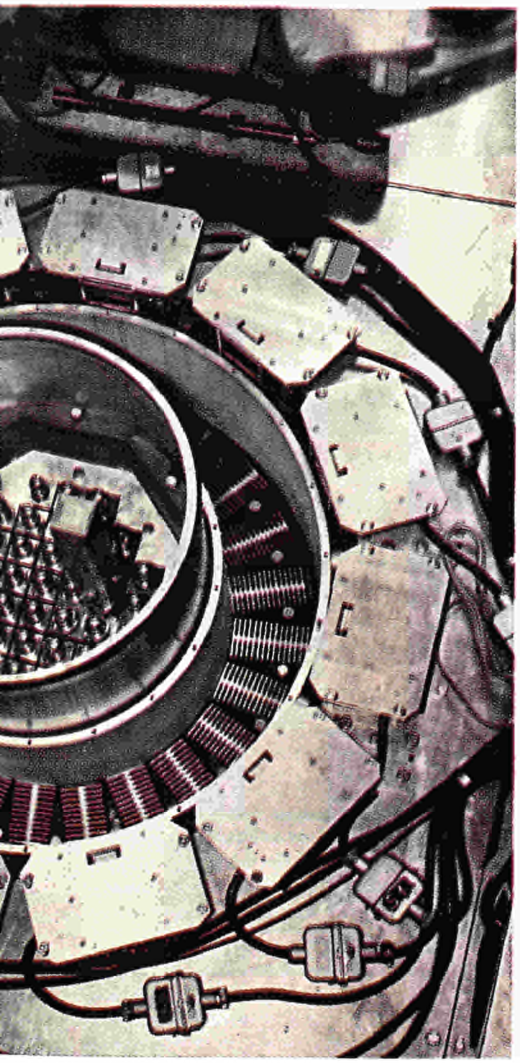


Fig. 4: Topside view of STARK

moderating water very soon reaches boiling point.

Studies carried out in STARK

Ever since it was commissioned *STARK* has served for the execution of a highly diversified experimentation programme. A three-stage variation of the fuel charges, which primarily affected the power contribution and neutron spectrum of the fast fission zone, provided an opportunity of conducting the experiments under different conditions.

For the initial charging of *STARK*, only natural uranium was loaded into the fast zone, the power contribution of which was consequently very small. For charges 2 and 3, and finally for charge 4, the average degree of enrichment was progressively increased and the power contribution of the fast zone eventually brought up to the maximum value of 33%. The principal data are shown in detail in Table 1.

The various studies carried out in *STARK* fall into three main groups, namely investigation of the neutron spectrum in the fast fission zone, determination of the average prompt-neutron life in the coupled system, and finally, the study of effective cross-sections and reactivity effects in the fast zone. It was a question of ascertaining the suitability of known measuring methods for application in fast assemblies and of developing new techniques and preparing them for application in *SNEAK*.

For the spectrum measurements the devices used include various types of fission chambers and threshold probes. Fission chambers are, of course, detectors which contain fissile material and register neutrons via the fission events they initiate. Since neutrons of different energies possess different fission capacities in the individual fissile materials, it is possible to obtain information on the neutron spectrum by using chambers loaded with different substances.

The use of threshold probes is based on a similar principle: the fast fission zone is charged with materials in which neutrons can initiate nuclear reactions, but only if their energy lies beyond a certain "threshold"; radioactive substances are formed, from whose activity the reaction rate can be determined and thus information obtained on the neutron spectrum. Thanks to the availability in *STARK* of a pneumatic shuttle system it was even possible to employ probes with very short-lived daughter products. Measurements were successfully carried out in the energy range which is of particular interest in connection with fast reactors, i.e. from under 100 keV down to 10 keV.

The results are integral data on the neutron-energy distribution in the fast zone. They constitute the principal basis for the testing of theoretically determined spectra and the postulated energy-dependent neutron cross-sections. It is planned to carry out more ambitious measurements, using He^3 spectrometers, recoil proton counters and semi-conductor detectors, in the very near future.

The neutron-life measurements in *STARK* were centred mainly on "statistical" methods. These methods are based on the fact that the neutrons in a reactor do not originate independently of each other but stem from associated chains of fission events, the regular sequence of which is determined partly by the average life of prompt neutrons. Consequently, the neutrons registered, for example, in a neutron detector during a given time interval must be related with a certain degree of probability to the neutron which that same detector, or another one, observed at the beginning of the time interval, and conversely allow a determination of the prompt neutron life ("Rossi-α-experiment", "probability analysis"). The same applies to the impulse-rate variations measured in two detectors ("frequency analysis of the reactor noise").

From the experiments in *STARK* it can be concluded that the two-detector measurements ("cross-correlation measurements") in particular can be used successfully on fast systems. Thus all three of the above-mentioned methods are now proven and ready for use in the *SNEAK* experiments.

The study of the effective cross-sections and reactivity effects are carried out with the aid of a pile oscillator at the centre of *STARK*'s fast fission zone. With the reactor critical, various samples of the materials to be investigated are moved by means of this oscillator in a rectangular pattern between the centre of the fission zone and an external position. From the resulting power fluctuations the reactivity equivalent of the sample can easily be determined, and from this it is possible to ascertain the integral effective cross-section of the material in question at the neutron-energy distribution in the fast zone. Here again the special significance of the result is that it provides the basis for the testing of theoretically determined spectra and effective cross-sections.

The same procedure can be used for measuring the "Doppler effect" in the fast-neutron spectrum; two samples of the fissile material or other neutron absorber (e.g. uranium 238) to be studied, which are identical except for their temperatures, are subjected to oscillatory exchange in the fast fission zone. The "Doppler coefficient" can then be determined directly from the reactivity equivalent of the sample exchange.

With the commissioning of *SNEAK* some of the above-described studies in *STARK* have been terminated. Others, especially spectrum measurements, are being continued. The main object is the further development of neutron-spectrum measuring methods. In addition more emphasis will be placed in future on the study of *STARK* characteristics, especially the time-behaviour of the fast-thermal coupled system. (EUBU 5-18)

Fig. 5: Pattern of the chain reactions in the STARK *coupled reactor*
1. Thermal fission zone
2. Graphite jacket
3. Natural-uranium jacket
4. Fast fission zone

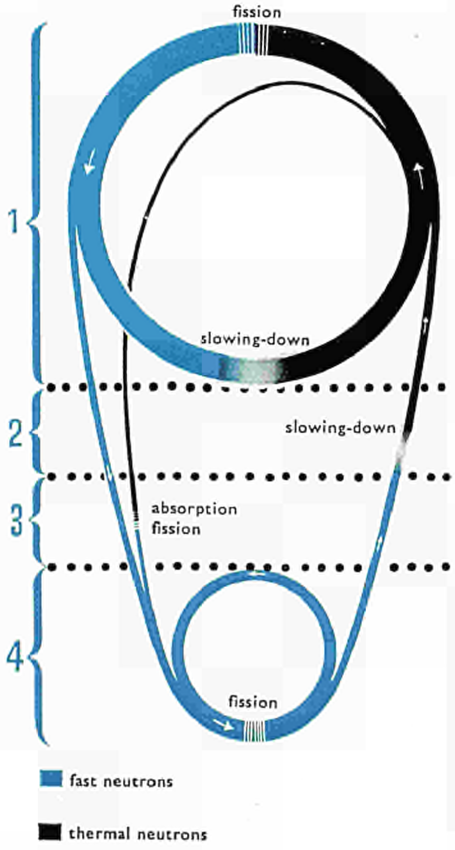


TABLE I: *STARK* fuel charges to date

Charge N°	Fuel quantity in thermal zone	Fuel quantity in fast zone	Average fuel enrichment in fast zone	Power contribution of fast zone*	Remarks
1. (24-6-1964/23-3-1965)	7.58 kg U^{235}	7.92 kg U^{235}	0.72%	1.8%	Fast zone charged with natural uranium only
2. (1-4-1965/23-12-1965)	6.79 kg U^{235}	45.66 kg U^{235}	7.06%	8.9%	Simulation of a vapour-cooled fast core by insertion of 1.67% Vol polypropylene
3. (10-1-1966/9-2-1966)	5.75 kg U^{235}	87.56 kg U^{235}	10.36%	19.4%	
4. (from 16-2-1966 onwards)	4.58 kg U^{235}	107.56 kg U^{235}	13.57%	29.2%	

* Without natural-uranium jacket

EURATOM NEWS

Obrigheim nuclear power plant granted Joint Enterprise status

The Euratom Council of Ministers, meeting on 28 July 1966, granted the Obrigheim nuclear power plant in Baden-Württemberg, Germany, the status of a Joint Enterprise within the meaning of Chapter V of the Euratom Treaty.

At the Commission's request the Council granted the Joint Enterprise *Kernkraftwerk Obrigheim GmbH* certain of the advantages specified in the Treaty. These relate primarily to tax and import-duty concessions. The plant will be equipped with a pressurised-water reactor with a capacity of 300 MWe. The main contractor for the construction of the plant is *Siemens-Schuckert*. Sub-contracts for some of the supplies will be awarded to firms in the European Community.

The Enterprise undertakes to pass on the know-how acquired during construction and operation of the plant to Euratom, who will make it available to all interested parties in the Community.

Gundremmingen nuclear power plant goes critical

The Gundremmingen nuclear power plant, situated about 60 miles from the Bavarian capital, Munich, went critical on 13 August 1966.

This plant, which has a net capacity of 237 MWe, is equipped with a boiling-water reactor. It was built by *AEG*, *International General Electric* and *Hochtief AG*, for *Kernkraftwerk RWE-Bayernwerk (KRB)*.

The plant, which comes under the Euratom/United States joint programme, has the status of a Joint Enterprise as provided in the Euratom Treaty, and as such enjoys certain privileges as regards taxes and import duties. In addition, the Community is participating in the costs to a maximum amount of 8 million dollars.

AVR reactor goes critical

The 15 MWe high temperature reactor of the *Arbeitsgemeinschaft Versuchsreaktor GmbH (AVR)*, a joint subsidiary of 15 municipal electricity undertakings, went critical at Jülich for the first time on 26 August 1966.

The reactor, which was built by the *Brown Boveri & Cie/Krupp* Group, is of the high temperature gas-cooled type and uses spherical fuel elements 6 cm in diameter (see *Euratom Bulletin*, June 1965 – Vol IV n° 2 – "Energy from pebbles").

It is the first member of the *THTR (Thorium-Hoch-Temperatur-Reaktor)* reactor family, which is the object of a research and development programme being carried out by the *Jülich Nuclear Research Establishment* and *Brown, Boveri & Cie/Krupp* in association with Euratom.

Highly satisfactory results from operation of Dragon

The high-temperature experimental reactor *Dragon* (*OECD* Nuclear Agency project), which went critical in August 1964, reaching half-power in June 1965 and full power in April 1966, was shut down in September 1966 in accordance with the operating programme, for a detailed examination of its components after several months of operating at full power.

The results of full-power operation of this reactor are highly satisfactory. The release rate of fission products, both gaseous and solid, lies between one ten-thousandth and one hundred-thousandth; the activity of the primary circuit helium amounts to less than 100 millicuries; helium leakages have been only about 6 kg a month; and reactor availability has been well over 90%.

As to the post-irradiation examinations, which are still in progress, they have already revealed, for instance, that even after a burn-up of over 20.000 megawatt-days per metric ton, the fuel elements are quite undamaged; no corrosion, strain or cracking has been detected.

As also scheduled on the operating programme, a blower and a heat exchanger were dismantled. The exchanger shows an activity of only 0.5 curies, which means that it can be handled without special precautions, and the blower has likewise a very low activity, 100 millicuries only. These figures are very reassuring, especially as regards reactor maintenance.

It should also be mentioned that during the full-power operating period the gas temperature at the core outlet was successfully kept within the region of 830°C, i.e. 80°C higher than the temperature originally planned.

EURATOM NEWS

Power reactors in operation, under construction and planned in the Community

(Status as at 12 September 1966)

1. The total net electric capacity of the nuclear power plants in operation, under construction or planned is 8,331 MWe, broken down as follows:

	Country	Operational	Critical	Under construction	Planned	Total MWe
a) *Proven-type reactors*						
Gas/graphite						
Chinon 1 (EDF1)	F	70	—	—	—	70
Chinon 2 (EDF2)	F	200	—	—	—	200
Chinon 3 (EDF3)	F	480	—	—	—	480
St. Laurent 1 (EDF4)	F	—	—	480	—	480
St. Laurent 2 (EDF4 a)	F	—	—	515	—	515
Bugey (EDF 5)	F	—	—	540	—	540
G 1 Marcoule	F	3	—	—	—	3
G 2 Marcoule	F	40	—	—	—	40
G 3 Marcoule	F	40	—	—	—	40
Fessenheim 1	F	—	—	—	700	700
Latina (SIMEA)	I	200	—	—	—	200
		1033	—	1535	700	3268
Boiling-water						
KRB (Gundremmingen)	D	—	237	—	—	237
KWL (Lingen)[1]	D	—	—	173	—	173
VAK (Kahl)	D	15	—	—	—	15
Garigliano (SENN)	I	150	—	—	—	150
GKN (Doodewaard)	N	—	—	52	—	52
		165	237	225	—	627
Pressurised-water						
KWO (Obrigheim)	D	—	—	300	—	300
SENA (Chooz)	F-B	—	—	266	—	266
Trino Vercellese (SELNI)	I	257	—	—	—	257
		257	—	566	—	823
b) *Advanced converters*						
Heavy-water						
MZFR (Karlsruhe)	D	50	—	—	—	50
KKN (Niederraichbach)	D	—	—	100	—	100
EL4 (Brennilis)	F	—	—	73	—	73
BR3 (Mol)	B	—	—	10	—	10
		50	—	183	—	233
High-temperature						
AVR (Jülich)	D	—	15	—	—	15
Sodium/zirconium hydride						
KNK (Karlsruhe)	D	—	—	20	—	20
Nuclear-superheat						
HDR (Kahl)	D	—	—	25	—	25
		50	15	228	—	293
c) *Type not yet decided*						
NWK (Stade, Elbe)	D	—	—	—	600	600
Preussen-Elektra (Höxter, Weser)	D	—	—	—	600	600
RWE-Badenwerk/Elektrowatt (Hochrhein)	D/CH[2]	—	—	—	300	300
Geesthacht (Schl.-Holstein)	D	—	—	—	20	20
ENEL (?)	I	—	—	—	600	600
EBES (Antwerpen)	B	—	—	—	600	600
INTERCOM (Huy)	B	—	—	—	600	600
		—	—	—	3320	3320
TOTAL		1505	252	2554	4020	8331

[1] Excluding 67 MWe conventional superheat.

[2] Possibly a joint German/Swiss plant of 600 MWe.

2. Percentage breakdown of the reactors in operation and under construction, according to type

Gas graphite	2,568 MWe, i.e.	59%
Boiling-water	627 MWe, i.e.	15%
Pressurised-water	823 MWe, i.e.	19%
Heavy-water	233 MWe, i.e.	5%
Other advanced converters . .	60 MWe, i.e.	1%
	4,311	100

3. Breakdown according to state of completion and by country

	Germany	France	Italy	Netherlands	Belgium	Community
Reactors in operation . . .	317	833	607	—	—	1.757
Reactors under construction.	618	1.741	—	52	143	2.554
	935	2.574	607	52	143	4.311
Reactors planned	1.520	700	600	—	1.200	4.020
TOTAL	2.455	3.274	1.207	52	1.343	8.331

Development of thermal insulation concrete

The development of concrete with thermal insulation properties for the lining of graphite-gas reactor prestressed concrete pressure vessels is covered by a research contract concluded on 22 September, 1966 between Euratom and the French *Atomic Energy Commission (CEA)*. The types of concrete involved will consist of readily available and cheap constituents, both binders and aggregates, as well as being easy to prepare with the standard techniques.

This project should lead to substantial savings, which will be assessed in relation to the cost of the current processes. At present, a layer of pumice concrete (see *Euratom Bulletin* 1966, No. 2, pages 59 and 60) is employed as insulator between the hot CO_2 and the prestressed concrete vessel, which must remain fairly cold to maintain its mechanical properties, but this type of concrete is difficult to make and therefore quite costly.

The *CEA* studies will bear on concretes based on expanded clay or alumina aggregates, and on binders having the particular property of not losing water between 250 and 500°C. A test programme is planned involving various temperatures and pressures as well as irradiation.

These studies will find a natural place beside other researches set on foot by Euratom under contract and designed to cut the capital investment cost normally bound up with thermal insulation in graphite-gas reactors. Among the research contracts concluded in this sphere reference may be made to those with the Italian group *SNAM* and the Dutch firm *Bredero*, under which methods are being investigated of improving the properties of the type of concrete employed in pressure vessel construction. Other contracts, awarded to *Indatom, Deutsche Babcock & Wilcox, Bertin et Cie, Sud-Aviation* relate to the study of allied techniques, such as the use of water-tube and metal screens.

Course in molecular biology and radiobiology

A course in molecular biology and radiobiology, sponsored by Euratom, was held at the *Free University of Brussels* from 19 September to 14 October 1966.

In charge of the course was Prof. J. Brachet. Professors from the *Free University of Brussels* and twenty guest lecturers dealt with subjects relating to RNA and protein synthesis, the expression of genetic information, the radiobiology of the cell and of morphogenesis, the structure and synthesis of antibodies.

The course was attended by forty young research scientists from the Community, twenty of whom also had the opportunity to attend a series of demonstrations of modern biological research techniques.

EURATOM NEWS

The SENA reactor goes critical

The reactor of the Franco-Belgian Ardennes nuclear power plant, located at Chooz in France, went critical on October 18, 1966. This plant, which will attain a capacity of 266 MW, belongs to the *Société d'énergie nucléaire franco-belge des Ardennes (SENA)*, a company incorporated under French law, whose capital is held in equal shares by *Electricité de France* and the Belgian group *Centre et Sud*, which represents practically all the electricity producers and distributors in Belgium.

The power plant, which was built under the Euratom/United States Agreement for Co-operation, is equipped with a pressurised-water reactor of the type developed by the American firm of *Westinghouse*. Nearly all the equipment was supplied, however, by Belgian and French firms, in particular *Ateliers et constructions électriques de Charleroi, Métallurgie et mécaniques nucléaires Cockerill-Ougrée ateliers de la Meuse* and the French consortium *Framatome*.

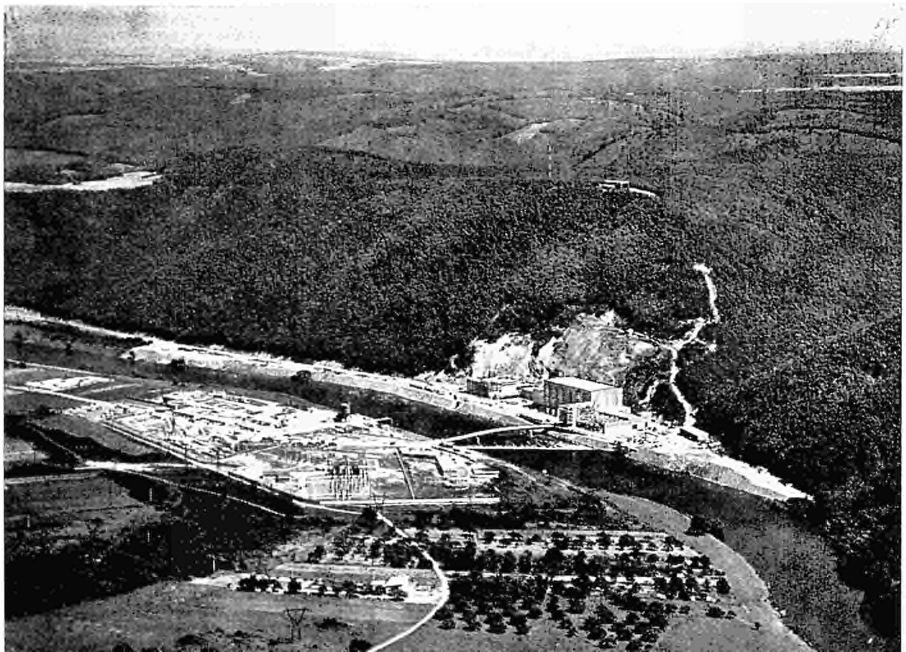
The *SENA* nuclear power plant will be the first in the world to be operated jointly by two countries. The French and Belgian grids will each take half the power generated. For France, whose power-reactor construction programme has centred chiefly on the graphite-gas series, the Chooz plant will provide the opportunity for thorough study of a totally different system.

Belgium, on the other hand, is already acquainted with this system, as a pressurised-water reactor, the BR 3, went into operation at Mol in 1962. But the BR 3 is only a low-powered pilot installation, whereas the Ardennes power plant, with its 266 MW, affords Belgium the benefit of a full-scale experiment.

Under the Euratom/United States agreement the *SENA* enjoys several advantages, including a right to purchase fuel on deferred-payment terms, the irradiated fuel elements being reprocessed in the United States until the requisite plant is brought into service within Community territory.

The *SENA* has "joint enterprise" status within the meaning of the Euratom Treaty, a privilege which entitles it to certain fiscal, customs and other advantages.

In addition, the Ardennes plant has been incorporated into the Community's programme of participation in power reactors. This means, first, that Euratom will assume responsibility for part of the start-up costs, which are inevitably fairly high with a nuclear power plant whose novel characteristics are still relatively unfamiliar. Euratom will also contribute to the manufacturing costs for fuel elements for the reactor's second core, provided that they are manufactured in the Community, the intention being to promote the growth of a European nuclear fuel industry. In exchange, the *SENA* passes on to Euratom, for circulation among the Member States, all the information it acquires on the design, construction and operation of the power station, and allows engineers from other Community enterprises to work with its staff. These arrangements will enable the Community's entire industry to profit from the experience acquired at Chooz.



Irradiation techniques in the wood-processing industry

On 18 and 19 October 1966 the Bureau *Eurisotop* held a working meeting on the use of irradiation techniques for the preparation of wood/plastic bondings. These new materials, which are obtained by irradiating wood which has previously been impregnated with monomers, possess improved physical and mechanical properties (hardness, dimensional stability, bending strength, etc.) while maintaining the aspect of natural wood. The wood-processing industries and research centres are particularly interested in this new material, which must be considered not only as a substitute but also as a new product capable of creating a market of its own. There would, indeed, appear to be scope for several applications in the following fields:

- building and construction (doors, frames, flooring, planks for boats, etc.);
- special-purpose articles (knife and tool handles, work-benches, etc.);
- sports goods (skis, tennis racquets, etc.);
- industrial articles (containers, hat-blocks, etc.);
- toys and school equipment.

The meeting afforded an opportunity for discussion of the properties of the new materials, the research carried out on them and the results achieved, and their various potential applications. Experts in the fields of wood-processing and irradiation techniques were able to consult together on the necessary conditions for using these materials on an industrial scale.

Index

volume V (1966)
Issue and page are indicated.

GENERAL & MISCELLANEOUS

BIOLOGY, MEDICINE & AGRICULTURE

CHEMISTRY

ENGINEERING & EQUIPMENT

HEALTH & SAFETY

INDUSTRIAL APPLICATIONS OF ISOTOPES AND RADIATIONS

MATHEMATICS & COMPUTERS

PHYSICS

REACTORS

LAW, ECONOMICS & INDUSTRY

DOCUMENTATION

EDUCATION & TRAINING

SHOULD YOU WISH TO RECEIVE EURATOM BULLETIN REGULARLY, PLEASE SEND YOUR ORDER FORM TO:

Agence et Messageries de la Presse
34, rue du Marais
Brussels 1, Belgium
(Postal account C.C.P. 416.69)

or:

H.M. Stationery Office
P.O. Box 569
London S.E. 1, Great Britain

or:

European Communities Information Service
Suite 808
Farragut Building
Washington 6, D.C.
U.S.A.

Please see overleaf

SHOULD YOU WISH TO RECEIVE EURATOM BULLETIN REGULARLY, PLEASE SEND YOUR ORDER FORM TO:

Agence et Messageries de la Presse
34, rue du Marais
Brussels 1, Belgium
(Postal account C.C.P. 416.69)

or:

H.M. Stationery Office
P.O. Box 569
London S.E. 1, Great Britain

or:

European Communities Information Service
Suite 808
Farragut Building
Washington 6, D.C.
U.S.A.

ORDER FORM

I wish to subscribe to the **English**/................ edition* of EURATOM Bulletin for one year at the price of 18/–; US $ 3.50

as from...

Name ....

Full address...

....

....

....
(Signature)

☐ Please invoice me.

☐ I am sending my remittance forthwith by money order/transfer/cheque (enclosed)/ ....

* Besides the English edition, EURATOM Bulletin is published in German, French, Italian and Dutch.

Second international conference on methods of preparing and storing labelled compounds

Between 28th November and 3rd December 1966 in Brussels Euratom held its *Second International Conference on Methods of Preparing and Storing Labelled Compounds*. This was almost exactly three years after the first conference, which was held, also in Brussels, in November 1963.

The object of the meeting was to exchange information on the progress achieved in the intervening period and to discuss new results.
The programme covered eight main topics, namely chemical synthesis methods, biochemical synthesis methods, radiochemical synthesis methods, autoradiolysis mechanisms and storage methods, synthesis of compounds labelled with stable isotopes, special problems involved in tritium-labelling, analysis and purification methods and, finally, technological problems raised by the use of labelled compounds as tracers.
A special feature of the conference was the exhibition held concurrently under the sponsorship of *Foratom* and *Belgicatom*. European and American companies displayed their latest counting, analysis and manipulation equipment. Producers of labelled compounds from both continents also had their stands at the exhibition.

Measurement of the fissile-material content in irradiated fuel elements

The Euratom Commission has recently assigned to the firm of *Interatom GmbH*, Bensberg (near Cologne) the task of developing a process for the simultaneous and non-destructive determination of the U 235 and Pu 239 content of irradiated fuel elements.
This technique is of practical and economic significance for the operation of reactor plants. Its salient feature is that the number of fissions during neutron bombardment is used to gauge the fissile-material concentration. Separate analysis of U 235 and Pu 239 is effected by measuring the total chain fission yield at two neutron energies, since owing to the very different effective cross-section curves of these two isotopes the ratios of the U 235 and Pu 239 fissions to the total chain fission yield vary independently of each other and to a degree which differs with the neutron energy.

On the basis of the theoretical estimates, an error of ± 5% may be expected in the determination of the U 235 and Pu 239 isotopes. Efforts are being made, however, to bring this margin down to ± 1%.

A neutron source based on fission products

Euratom has recently developed a neutron source based on cerium 144 and its daughter product praseodymium 144. This development has a two fold importance: in the first place this new type of source is likely to be considerably cheaper than conventional neutron sources such as antimony 124, which it is therefore destined to oust completely; secondly, the discovery of a use for dangerous radioactive waste products simplifies the problem of storing them. (It is estimated that by 1970 the French reactors alone will have produced about 70 million curies of cerium 144.)

Cerium 144, which has a half-life of 284 days, is a beta and gamma emitter. On disintegration the cerium atom is transformed into an atom of praseodymium 144, which has a very short half-life of only 17.5 minutes and likewise emits beta and gamma radiation. It is primarily the gamma rays from this element formed by the disintegration of cerium which are useful for the production of neutrons. They possess sufficient energy to react, for example, with beryllium target atoms, thus causing a neutron to be ejected from the nucleus.

The advantages of cerium 144 over antimony 124 as a neutron source can be summarised as follows: whereas antimony has to be activated in a reactor, cerium is simply a by-product. Furthermore, when a sample of antimony is exposed to a reactor flux, only a small proportion of its atoms are effectively activated; with cerium 144, on the other hand, it is possible to obtain a radiochemical purity of almost 100%, i.e. a grade in which nearly all the atoms are radioactive. Consequently, a cerium source of a given volume has a far higher activity than an antimony source of the same volume.
Preliminary tests carried out at the Ispra Establishment of the Joint Nuclear Research Centre indicate that the emission rate will be 20,000 neutrons/second per curie of cerium 144/praseodymium 144. The corresponding value for antimony 124 is in the region of one million neutrons/second per curie, that is to say the yield per curie is very much higher. Nevertheless, owing to the high specific activity obtained with cerium 144, a cerium source can emit a neutron flux which is approximately twice that of an antimony 124 source of equal volume.

hip 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 schiffsantrie

EURATOM

CDAA66004ENC