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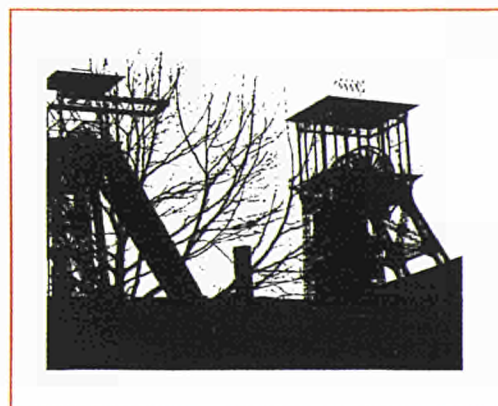
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It seems as though no one knows what to do with coal. If we look round, we realize that it has practically disappeared from everyday life and with it have gone many things and features which only thirty years ago were familiar to all from childhood days onward: the locomotive with its plume of smoke, the coal cellar, kitchen grates, chimney-sweeps,

Moreover, for some time nothing but complaints have been heard concerning it. Coal, say the housewives, takes up too much room and makes the house dirty. Fetching coal up from the cellar, complain their husbands, is a thankless task. Burning coal, warn the hygiene experts, pollutes the atmosphere. Coalmining, threaten the doctors, causes serious damage to the respiratory system and grave occupational diseases. Coal winning, grumble the industrialists increasingly, costs too much and is unprofitable.

Although the coalfields are not exhausted, so much has been heard of the growing difficulties of the coalmining industry and the retraining of miners that it might even be thought that the mines of Europe are very near to closing down.

All this is familiar.

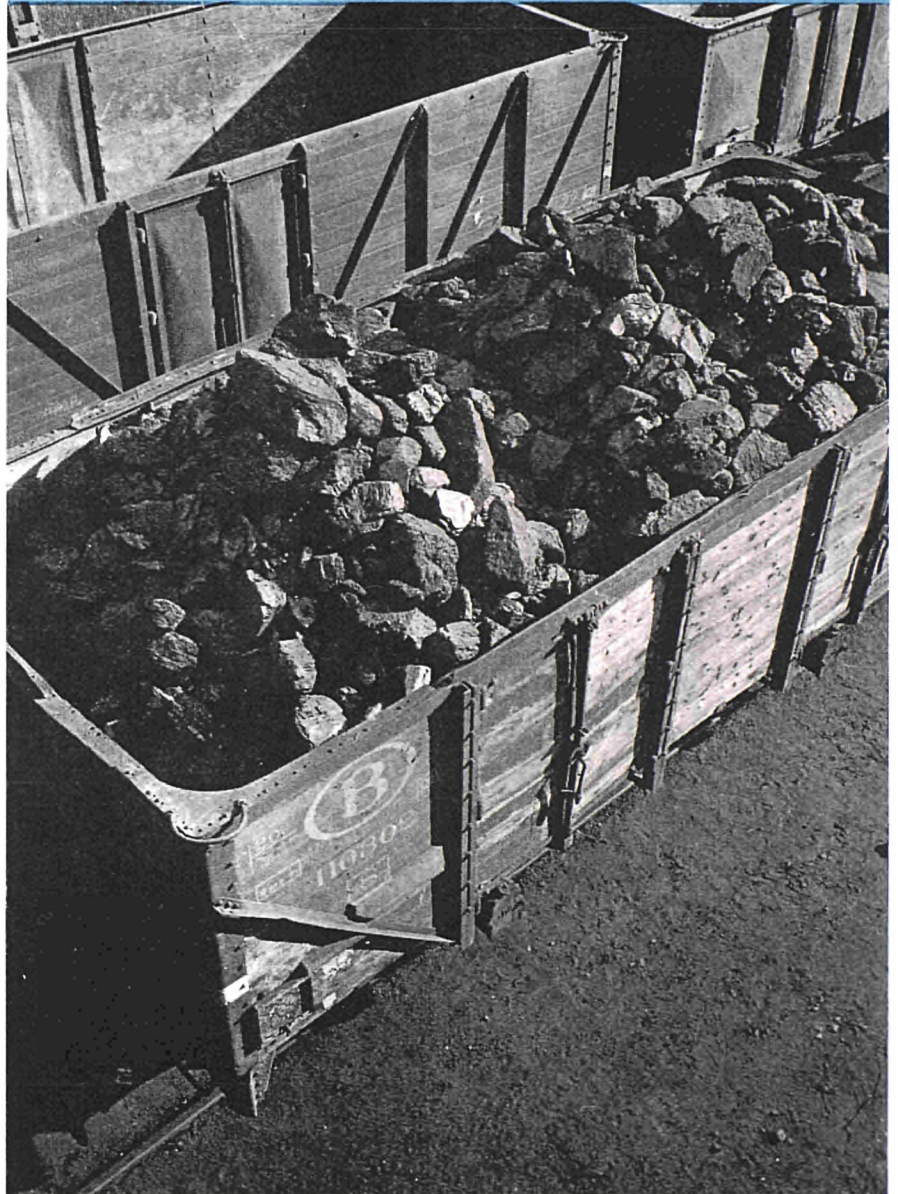
What is less well known is that, for a little over ten years, groups of coal chemistry research scientists have been working hard and enthusiastically to enlarge and deepen knowledge of this much-used material which, however, has for centuries remained virtually unknown from a strictly scientific point of view. Their studies are now beginning to show what new applications and varieties of use already exist for coal, and what others are emerging.

After all, it can perhaps be said that the future of coal is not as black as it has appeared in the last fifteen years.



The seminar on "Research on coal—its application to mining engineering, a starting point for new products", held in Luxembourg on 8 and 9 December 1970 was fruitful in reports presenting the main results of basic coal research in Europe.

Since the findings discussed at this seminar are now being applied in practice, or are likely to be in the future, it is interesting to see along what main lines research has developed, and to give some of the results obtained, fitting them into a kind of forward study of future coal research.



Fundamental research for the coal trade

What future is there for coal chemistry in view of the pre-eminence of petrochemistry?

MAURICE LETORT

Onset of a crisis

It was becoming clear in 1960 that the future of the West European coal industry faced serious threats, after having been for two centuries the very basis of what the history books have termed the "Industrial Revolution". The energy shortage in Europe in the immediately post-war period was quickly followed by a glut of fuels. A flood of oil products, including natural gas, coincided with a considerable and lasting reduction in transatlantic freight which served to stimulate imports from the United States of coal, the cost of which, for geological reasons, was much lower than in Western Europe.

The coal industry was in a state of crisis; it need only be recalled that in France an output of 63 million tonnes for 1965 had been set as a target in 1957 and that less than three years later this was reduced to 53 million tonnes for 1966.

Coal chemistry

It was therefore necessary to ascertain how far chemistry (in French "*carbochimie*") could come to the aid of the coal mining industry and minimise its economic recession.

The word "*carbochimie*" is a coinage. It found its way into the French lan-

guage round about 1950 and expresses, elliptically in the extreme, the essentials of the matter. The word is derived by analogy from a comparison, or, one might say, a confrontation with a new industry based on oil. This term had no *raison d'être* as long as coal and the coking industry reigned supreme at the head of the vast industry of mineral chemicals (ammonia, nitric acid and fertilisers) and organic chemicals (aromatic compounds: benzene, toluene, naphthalene, anthracene, phenol). However, at the end of the Second World War, "petrochemistry" burst upon Western Europe and was accompanied by a novel conception of the design and operation of machinery in the chemical

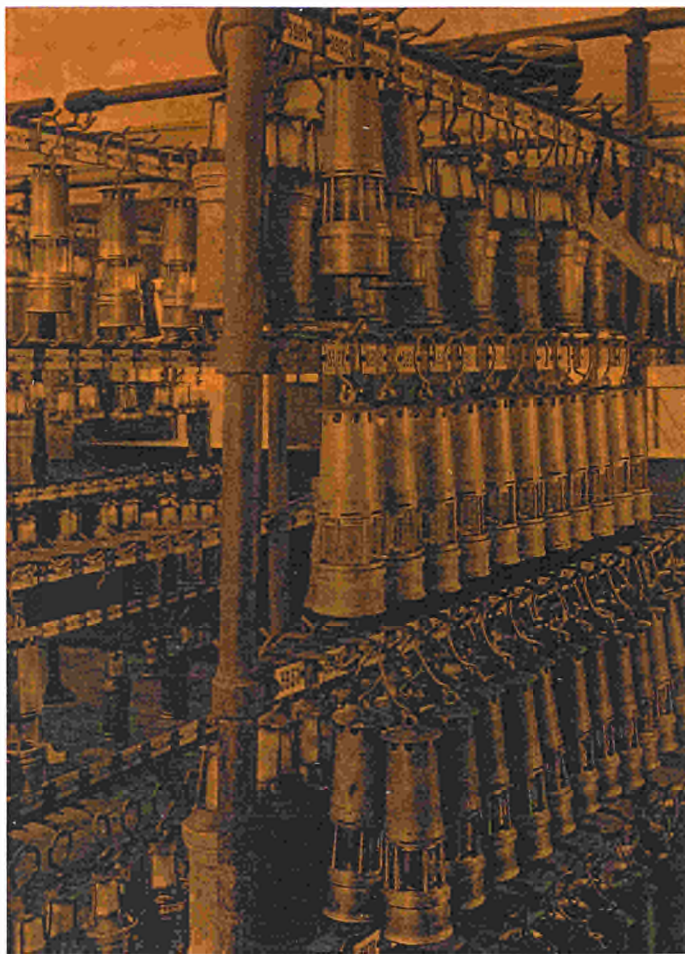
industry; this was chemical engineering. The term "petrochemistry", also known as petroleum chemistry, denotes any and all chemicals manufactured from oil and natural gas. Petrochemistry emerged in the United States between 1930 and 1935 and naturally developed there; equally naturally, industry developed in that country from the other resources besides coal with which nature had so richly endowed it.

The chemical experts whose help was enlisted pertinently assessed the weaknesses of coal chemistry compared with petrochemistry. In view of the cost of coal, it was no use hoping to reintroduce into Western Europe "direct" coal chemistry (the Bergius and Fischer-Tropsch processes, water-gas chemistry) which was a feature of the heavy chemical industry in Germany. Nor, in view of the electrical energy expended, was it any use relying too heavily on acetylene obtained from calcium carbide. It was easy to discern that petrochemistry had three basic advantages:

- (a) It had in its raw materials, whether direct or indirect (cracked and reformed products from petroleum fractions), almost all the molecules which brought success to gas and liquid by-products of carbonisation and it produced an abundance of



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others which were greatly valued by the chemical industry¹;

- (b) The petrochemical molecules were very cheap to produce;
- (c) They could be manufactured in virtually unlimited quantities, whereas the output of coking by-products was governed by the needs of the steel industry, which remained more or less stagnant.

¹ Oil, however, contains no pyridine (though this can be synthesised industrially), pyridine bases, quinoline or carbazole which are present in coal tar in low quantities. Moreover, large-scale processing of oil fractions does not readily produce the "heavy" aromatic molecules which are relatively plentiful in coal tar: naphthalene, anthracene, phenanthrene, acenaphthene, pyrene, etc.

It should be remembered in this connection that the first manifestation of petrochemistry was a sudden increase in benzene and toluene requirements for making explosives when the United States entered the First World War. In 1950, the industrial development of nylon caused a shortage of phenol in Western Europe and it became necessary to synthesise it. This involved the use of propylene, which is not to be found in coal chemistry products, but which is produced in plentiful quantities by the cracking of oil fractions. As from 1958, the scarcity of coke-oven gas ethylene deprived the polyethylene market of sufficient supplies and the benzene produced by coal chemistry, of which there had been a surplus in 1957, no longer met the needs of the chemical industry in 1959;

even so, it had to align itself on the recommended prices set by the American petrochemical industry, which currently supplies 90 % of the benzene consumed in the United States.

Despite this, it was necessary to take full advantage of the privileged by-products of carbonisation in order to protect the price of coke as much as possible in the short term and to mobilise fundamental research efforts with the aim of deriving the full chemical benefit from coal in the long term.

Even though coal has been used on a large scale much longer than oil, its nature is not nearly so well understood. Obviously, man's control of a substance improves with his understanding of it. The main difficulties in the scientific investigation of coal are that it is solid, protean and of a radically heterogeneous composition. Whatever the complexity of the chemical composition of oil, the mere fact that it is liquid represents a considerable factor of simplification both for its study and for its exploitation.

It is to the credit of the High Authority of the European Coal and Steel Community, and subsequently of the Commission of the European Communities, that they had this project implemented by means of a subsidy, covering a large part of the cost, for the research involved.

Advent of "coordinated research"

Despite all efforts, and in particular recent work by the Dutch school at Heerlen, the problem of a better knowledge of coal is so difficult that it has remained largely unsolved.

The general trend of science is continually to place at the disposal of chemists, physical chemists and physicists new instruments with increasing powers of investigation. Advances beyond the use of X-rays for analysing disordered structures, of electron microscopy, the resolving power of which is currently of the order of the molecule, and of infrared, visual and ultraviolet spectroscopy are represented by chromatography in its various forms, high-resolution mass spectrometry, electron

spin resonance, nuclear magnetic resonance, and the use of computers. To this impressive array has now been added induced electron emission.

Thus we have a problem of extreme complexity but, on the other hand, a host of new and powerful techniques. It has accordingly been worth pursuing the battle with redoubled efforts, by bringing together the competent research scientists concerned from the coal-producing countries of the Six and coordinating their work.

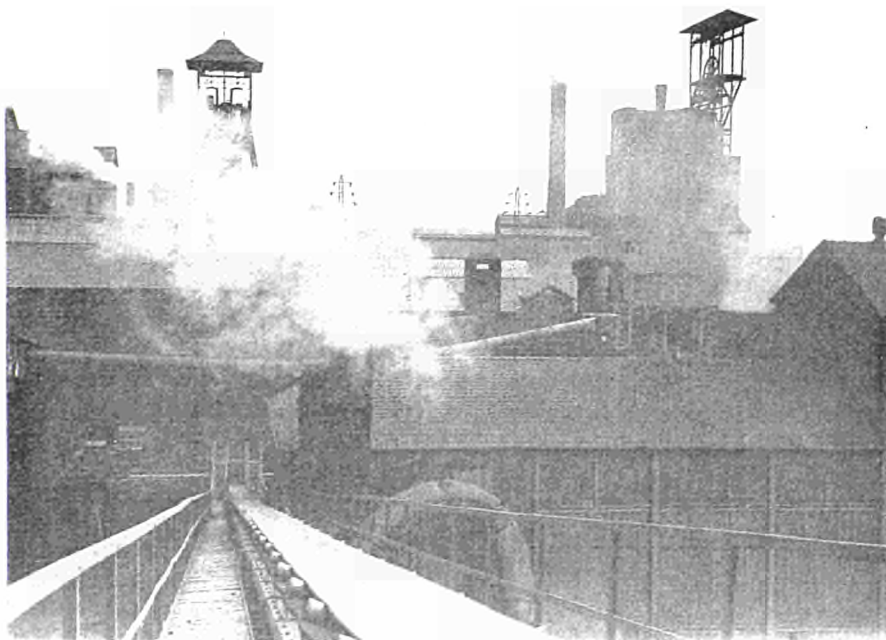
In this connection it must be pointed out that the concept of "coordinated action" in research, i.e. an agreement among scientists with a common end in view, is a relatively recent one. It represents the simplest, quickest and most effective way of making the best use of all the laboratories, in the light of their respective skills and complementarity, while keeping dispersion, futile duplication and discontinuity of effort to a minimum. Every competent laboratory engaged in one or more subjects covered by a comprehensive plan has the right to offer its collaboration. If this is accepted, all it has to do is orientate its work towards the given

aim and report its results periodically. On the other hand, it retains complete freedom, so valuable in research, as regards carrying out its work.

A further argument in favour of action in fundamental research is perhaps banal, but important. This is that there are few cases where a suitably conducted research effort finds no useful application; its utility may be considerable, significant or minor, depending on circumstances. To put it briefly, research is a gamble, but one which rarely involves a complete loss.

The first task of the architects of coordinated action was to draw up a research programme and to share out the many subjects in it, making the most of abilities and available resources, among the national research centres responsible for the work done in each of four countries, either in the centre in question itself or through outside collaboration. The centres in question were:

- (a) For Germany, the *Bergbauforschung* Laboratory, Essen-Kray;
- (b) For Belgium, the *Institut national de l'industrie charbonnière (INI-*



CHAR), Liège, now the *Institut national des industries extractives (INIEX)*, and the research centre of the *Société centrale de carbonisation* de Tertre;

- (c) For France, the *Centre d'études et recherches des charbonnages de France (CERCHAR)*, Verneuil-en-Halatte;
- (d) For the Netherlands, *Staatsmijnen*, Heerlen.

The budget necessary for carrying out the work planned were also prepared. At the same time, a "nine-point charter" (Table I) was drawn up, being followed by technical negotiations and the necessary administrative steps, first by the Western European Coal Producers' Association and then by the High Authority of the European Coal and Steel Community. During the international conference on coal science held at Cheltenham at the end of May 1963, it was announced that the joint application to the High Authority had been accepted, with 80 % financing of the proposed budgets. Officially, coordinated research activity began on 1 July 1963. It proceeded by three administrative stages from 1 July 1962 to 30 June 1965, and then for two successive two-year periods.

A total of 220 articles on the work were published in scientific and technical periodicals from 1963 to 1967; in two recent booklets^{2, 3} issued by the Commission of the European Communities on the first two stages of the research, these articles were brought together and summarised; the Commission's third report⁴, on the third stage, summarises 183 new publications.

This research scheme has thus produced a wealth of results: more than 400 publications in six years.

Secondly, this enterprise must be credited with the moral benefit (rare in the Europe which is being built up)

² EEC-ECSC, *Recueils de recherches Charbon*, Recueil No. 20, Brussels 1968.

³ EEC-ECSC, *Recueils de recherches Charbon*, Recueil No. 29, Brussels 1970.

⁴ EEC-ECSC, *Recueils de recherches Charbon*, Recueil No. 36, Brussels 1970.

of joint working, in an atmosphere of mutual confidence which has always been remarkable. From the first the authors of the "nine-point charter" had certainly hoped that this might happen. That the emphasis in this programme has been heavily laid on the scientific nature of the research is naturally because it was felt that such a measure was essential for the success of the enterprise, but it was also to ensure that preoccupations regarding industrial property should not stand in the way of all the benefit likely to be gained from an unreserved exchange of information and experience.

Eleven round-table meetings were held among the research scientists concerned. Table II gives a list of these meetings, which took place about twice a year and were organised by each of the responsible national centres in turn. At the first meeting, it became apparent that the discussions on the nine points in the programme were falling naturally under three broad headings, one being "pyrolysis", which includes all the problems of carbonisation, and the other two "chemical properties" (cols. 3-6 in Table I) and "physical properties and reactivity" (cols. 1, 7, 8 and 9 in Table I). Thus Table II shows the order in which and the frequency with which each of the three broad headings came under discussion (approximately every 18 months). A twelfth meeting of a special type was held in Paris at the beginning of May 1968; in addition to the research scientists concerned, coking production engineers were invited to attend.

These periodic meetings proved to be very productive and profitable. Besides the many bilateral contacts made spontaneously between research scientists engaged on similar problems, there is a far more rapid exchange of information among all the research scientists involved than is possible by the traditional method of swapping publications.

Results

Industry is today so much in the grip of scientific methodology that



in many cases it now represents a means for the direct and very rapid exploitation of discoveries made in the laboratory.

It was in the thirteenth century, we are told, that pig-iron was cast for the first time from a furnace operated hydraulically from a stream; but it was not until the nineteenth century that the blast furnace took on its classic, if not definitive form. On the other hand, barely three-quarters of a century separate the introduction of the Volta battery in 1800 and the ring invented by the Liège workman Zénobe Gramme in 1872, a basic component of the industrial dynamo. Scarcely six years elapsed between the discovery on the microscopic scale of the phenomenon of fission in the nucleus of the uranium atom (December 1939) and the bombing of Hiroshima (6 August 1945).

Examples of such celerity abound in other fields, such as synthesis macromolecules, antibiotics and electronics. Let us take the transistor: in 1948, from fundamental research aimed at understanding the special phenomena inherent in the physics of solids known as semiconductors, it was discovered that, without any temperature rise and with an instantaneous response, minute crystals of certain elements of very

high purity doped with a few thousand-millionths of other elements could be used to replace the cumbrous cathode/grid/anode unit in radio valves. The Nobel Prize for Physics was awarded in 1956 for this discovery. At the practical level, in that same year the first transistors appeared on the market; in three years they were replacing half the valves and six years later they had ousted them almost entirely. What followed is history and we all know the immense services rendered by transistors in many fields.

Among all the results which I have listed above regarding coal research, there is no spectacular breakthrough—in fact a very rare event indeed—like the discovery of the transistor; those who are unfamiliar with scientific and technical research may therefore regret that no discovery of a “miracle product” has rewarded so much effort. The benefit is not so readily perceptible, but it is none the less real and important. The research scientists engaged in this joint project showed remarkable determination and often a no less remarkable ingenuity in overcoming a number of highly intractable difficulties and thus arriving at a body of new knowledge which is itself of great value for scientific industrial objectives of

immediate interest, as Professor Reerink will show in his article. Here attention will be focussed on the strictly scientific knowledge gained, i.e. knowledge of the material and its evolution, or the devising of original methods and techniques of general interest. I shall have to confine myself to the most important items.

The petrography of coal, i.e. the description of this special rock, has made great progress. So far sixteen petrographic constituents of the maceral type have been identified, not counting varieties of these and the cryptomaceral constituents revealed by chemical etching. The experts are trying to discover how these originated from the initial plant debris; the importance of this problem as regards knowledge of the evolution of the biosphere in which we live need hardly be stressed.

Significant progress was also made in developing knowledge of the chemical composition of coal, an extremely complex mixture consisting mainly of highly diverse macromolecules relating to linear or cyclical carbonated frameworks, the chemical functions (notably hydroxyl or carbonyl oxygenated functions) of which have long been the subject of contention.

For thirty years there has been just as much and as confused controversy concerning the porous texture of coals and cokes. The specific external and internal surface of a single specimen was evaluated by some authors at about $1 \text{ m}^2/\text{g}$ and by others at a few hundred m^2/g . The problem was solved by using six different methods (narrow-angled X-ray diffusion and methods based on the adsorption of gases or vapours) and more especially by a reasoned comparison of the results yielded by these methods⁵.

These results have a considerable practical importance for a number of problems, ranging from *in situ* seam degassing and *in situ* oxidation, which may cause underground combustion, to

⁵ The specific surface is always important; in some cokes, for instance, it may be up to $1200 \text{ m}^2/\text{g}$.

Table I: *The nine-point charter.*

	1 Macerals palynology carboni- zation petrography	2 Functional	Chemical studies				Physical and reactivity studies		
			3 groups and chemical methods	4 Hydro- genation	5 Oxidation	6 Physical methods for studying chemical structures	7 Physical and mechanical properties	8 Reactivity	9 Porosity
Germany	×	×	×	×	×	×	×	×	×
Belgium Inichar Terre	×	×			×		×	×	×
France	×	×		×	×	×	×	×	×
Netherlands	×	×			×	×	×	×	×

the industrial manufacture of activated carbon from coal for use in the fight against pollution. However, they also constitute a general method applicable to the study of all porous media: aggregates, gels, ceramics, catalytic contact masses, etc.

In the field of chemical analysis, scientific progress has been equally marked. The identification and quanti-

tative determination of the hundreds of chemical compounds constituting coal tars and pitches and of the mixtures obtained by processing them with chemical reagents, hydrogen being the most important, have been possible by the development of various chromatographic methods which enable chemical compounds to be traced whose (theoretical) boiling points range up to 600° C, and by the association of these methods

with high-resolution mass spectrometry, absorption spectrography and, now, nuclear magnetic resonance. Here, too, the possibility of an exact definition of analogous but nevertheless not identical media is obviously of great utility (in selecting pitches, for instance), but these original methods and their association further represent an approach of general interest applicable to any complex mixture of organic products.

Table II: *Calendar of round tables and colloquia of the Working Party on Fundamental Research.*

No.	Date	Place	Theme
1	5 May 1964	Verneuil	Report on results of respective activities
2	8 December 1964	Essen	Joint research on pyrolysis
3	8 November 1965	Liège	Physical properties and reactivity
4	21-22 April 1966	Heerlen	Chemical properties in relation to the composition of coal
5	27-28 October 1966	Paris	Pyrolysis and applications of petrography to carbonisation
6	13-14 April 1967	Essen	Physical properties and reactivity
7	23-24 November 1967	Liège	Chemical properties
8	28-29 November 1968	Essen	Physical properties and reactivity
9	7- 8 May 1969	Liège	Chemical properties
10	20-21 November 1969	Paris	Pyrolysis
11	5- 6 May 1970	Berlin	Physical properties and reactivity
Colloquium			
	2- 3 May 1968	Paris	Forecasting of the mechanical grade of coke

Mention may also be made of the discovery, in certain pitches taken as patterns, of spontaneous separation between 400° C and 550° C as a function of time and temperature, of two phases, one being anisotropic, in the form of spherules consisting, as X-rays show, of a piling-up of layers of carbon atoms which are fed from the initial, or isotropic, phase. This phenomenon marks the first stage in the very common and very special process of transforming any organic material into carbon. Apart from its practical consequences, e.g. in making special cokes or other carbon products, this phenomenon represents, from the scientific aspect, the quite exceptional and consequently very interesting fact that, at low temperature, an arrangement of atoms is formed which conditions the entire evolution of a system up to the highest temperatures (2 500° C). It governs all the changes in the system; depending on what happened at about 500° C, the system will become graphite crystal or will remain a disordered structure.

The last-quoted example prompts the observation that the large body of fresh knowledge resulting from joint research on pyrolysis, i.e. the transformation by the sole means of heat from coals and pitches, is particularly valuable because, in the face of the challenge of liquid and gaseous fossil fuels, coal retains a privileged position which should not be overlooked. It is the "ore" of the element carbon. This is the best reducing element known to man, and is better than any other, hydrogen included; it is a universal reducer which no oxide can resist, whether iron ore or the ore of any other element. By thermodynamics this cardinal fact can readily be demonstrated. Consequently, apart from the use of various grades of raw coal for the pre-reduction of iron ore, these three final points should always be borne in mind:

(a) The manufacture of coke, from home-produced or imported coal, will continue to be essential for blast furnaces, which will remain in widespread use for a long time

yet—from 20 to 50 years, according to the experts;

(b) Coke will be increasingly made from coal other than coking coal, which, of course, is becoming rare and consequently costlier;

(c) Industry will increasingly demand "tailor-made" cokes, i.e. various grades better suited to the various uses made of them.

Steel-making processes are currently the subject of major research which has modified and continues to modify the traditional processes. Economic, general or local considerations will in the final analysis decide the future of the new processes. However, the substantial investments now being made in the steel industry in the United States and other countries, both for blast furnace and for coke-oven battery construction, are in themselves an infallible sign of the industrial importance retained by coke.

This de facto situation represents what might be termed the hard core of coal's answer to the challenge of oil, natural gas and uranium.

Conclusions

There would appear at the present time to be a certain disaffection in some countries where research is concerned.

Research is accused of having developed terrifying weapons and unleashed a financially ruinous escalation, both to increase their destructive power and to combat them. Ever since Archimedes's burning mirrors in the port of Syracuse, it has been impossible to deny that war has always stimulated research in an extraordinary effective way.

Scientific research is also accused of developing a technology which showers us with material goods, but, at the same time, inflicts harm on us by a whole range of discomforts known as "pollution": air pollution, marine pollution, water pollution, eutrophication of lakes, deterioration of natural amenities, noise, congestion of towns, roads and minds. These things too are undeniable and, in some cases, are assuming disquietening proportions.

All this is true, but it would be a serious mistake to confuse scientific and technical research with the use made of it. Scientific and technical research is not only a prodigious source of prodigious powers, but is also capable of solving problems for which it is not responsible. And in the specific case with which we are concerned, researchers feel that they have done a useful job.

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Coal research - results, problems and future outlook

Basic research projects on coal—greatly encouraged first by the High Authority of the European Coal and Steel Community and subsequently by the Commission of the European Communities—have added to our knowledge of this substance and can be put to practical use both now and in the future.

WILHELM REERINK

IN HIS PAPER, Professor Letort described how a system of collaboration was started among West European research workers as a result of the initiative of the European Coal and Steel Community; he went on to outline the programme taken as the basis and to give an account of the great store of new knowledge that we owe to these joint research projects.

The value and significance of this work is shown by the fact that, because of it, European research institutes have managed to catch up with the rest of the world in the field of coal research.

American scientists have often said how impressed they were both by the broad outlook and clarity of the coal research programme and by the methodical and trusting spirit of collaboration reigning in Europe, without regard to frontiers. This acknowledgement took on a more tangible shape in the form of proposals for closer collaboration between American and European scientists working on coal research.

It might be a good thing to extend international scientific collaboration even further, as the fundamental problems are the same in the East and the West, for, as Professor Letort said, coal is having to contend with competition in the form of oil, natural gas and uranium.

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tion, but also to determine means of preventing fires in mines.

This knowledge is invaluable for the prevention of accidents and damage.

Other studies have shown how the original character of coal can be altered by the controlled oxidation of very small grains to such an extent that properties which could not have been achieved in any other way are obtained during the subsequent coking operation.

Coal pyrolysis

In the last few years, basic research in the field of coal pyrolysis has produced new data, with both scientific and practical implications. As with the kinetics of oxidation, the processes involved in coal pyrolysis have been subjected to widely differing test conditions. The complete range of conditions has been covered, from low temperatures and heating rates all the way to heating by thermal shocks in plasmas.

Coke, as the main product of pyrolysis, has been the subject of a great deal of attention, in particular from researchers trying to add to our knowledge of its porous structure and its reactivity. This research has led to substantial findings of interest to the technical sector. By new methods, replacing conventional coking pyrolysis, greatly modified products can now be obtained. As a result, the range of properties obtained for solid carbonated pyrolysis products is so wide that one shrinks from using the simple term "coke". The shape, size, porosity, porous structure, strength, electrical conductivity and reactivity can be varied within such wide limits that a large number of special cokes can be produced. *Such special cokes can be employed in electrochemistry, electro-metallurgy and as a reducing agent in non-ferrous metallurgy.*

The new findings in the field of oxidation and pyrolysis have helped to improve the quality of *molecular sieves* and *activated cokes*. A particular example is a discovery which was made quite by chance during research into

the kinetics of oxidation and spontaneous combustion. After further research, it was found that it was possible to prepare a coke capable of being reproduced in large quantities, by the pyrolysis of oxidised coal. The special coke acts as a molecular sieve and has the property of enriching the air with oxygen concentrations of up to 50 or 60%. It is thanks to this special coke that we can now produce the oxygen-enriched air necessary for high-temperature combustion in the MHD process, and at a lower price than the process used hitherto.

One of the main advantages of this technique is the start-up time, which is only a few minutes. This molecular sieve property possessed by certain preoxidised coked coals can in all probability also be employed for separating other gaseous mixtures.

A vast new field for the use of activated coke could be *the purification of air and water*, one of the most important and pressing problems of environmental management which is attracting more and more attention. With present-day techniques it is now possible to produce types of "activated coke" which can be used for this purpose. Thus it is nowadays as easy to prepare a coke which is hard to burn for *absorbing SO₂ from hot flue gas* as to produce another type of coke for *decontaminating radioactive rare gases* produced by nuclear reactors. Activated cokes with widely differing qualities, easily regenerated and made from coal, can be used for *the processing of drinking water*, chiefly to separate organic impurities, and also in *the purification of liquid effluents*.

The by-products of coking plants can also benefit from the results of joint basic research. In comparison with coke, high-temperature tar, by reason of its volume and value, is of secondary importance. In the past, however, tar played an eminent role as a base material in the chemical industry, and this is still the case. The European chemical industry, which recently celebrated its hundredth anniversary, used tar exclusively from the

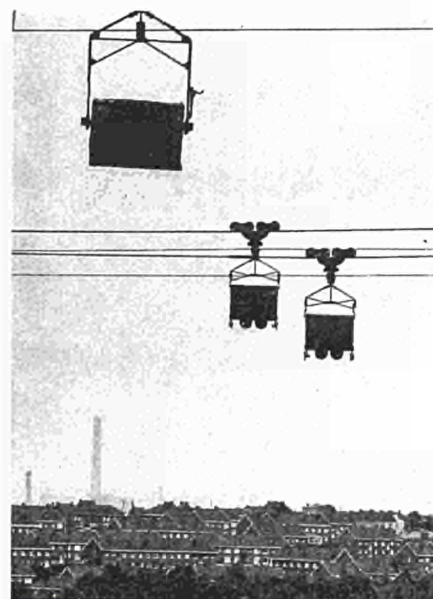
very beginning as a base material in the manufacture of dyes, pharmaceuticals, etc.

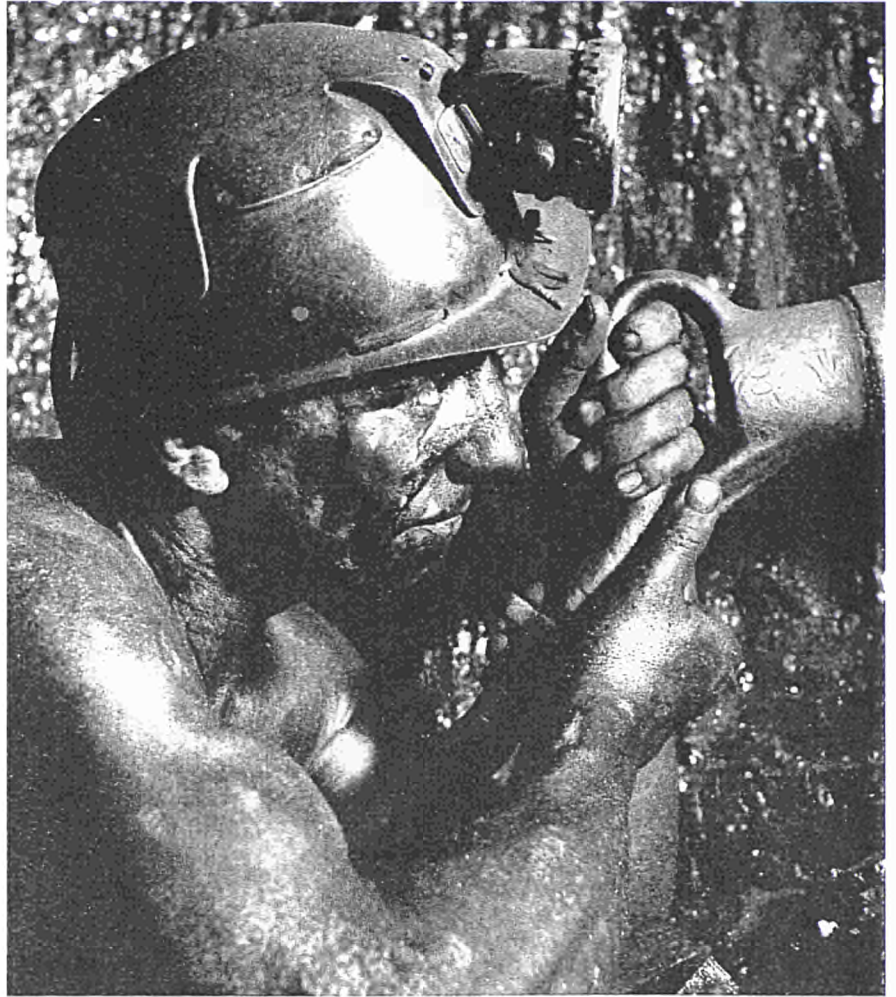
It is now possible to produce some of these aromatic raw materials from petroleum, sometimes at lower cost than those made from coal, which is why the value of tar has dropped. The question often arises as to whether tar could not be used as a fuel in power stations. However, it must not be forgotten that even now a number of aromatic substances—mainly naphthalene and anthracene, as well as the heterocyclics such as pyridine and carbazole—when prepared by other processes cost more than those produced from coal-tar.

We can expect the growing need for aromatics for fuels to lead to a greater use of these tar products. However, research work is likely to reawaken the chemical industry's interest in tar products and at the same time to make it clear that in the long run *it is a better proposition to use tar as a base material for the chemical industry than as a fuel*.

Another important factor for the future seems to be *the use of high-temperature pitch for electrode binders* and for high-grade electrode cokes and graphites, which will be used more and more in the future as the electro-metallurgical industry expands.

Research also gives hope for the *low-temperature tars*, which could assume great importance as by-products in the manufacture of smokeless fuels and briquettes. Low-temperature tar contains more compounds rich in hydrogen, hydro-aromatics, phenolics and aliphatics than conventional coking tars. These compounds can immediately be isolated as base materials for the chemical industry, or else these useful base materials can be obtained by other chemical processes from the compounds present in low-temperature tar. Another possibility would be to submit them to a treatment which, if the operation were inexpensive enough, would enable them to be used *in refineries in the same way as crude oils*.





Coal structure

Basic research has also yielded a large body of new data on important properties of coal and its structure. This knowledge has already been put to practical use or has opened up possibilities for the future.

The calculation of the properties of coal may be cited as the best example of this. There are two possible ways of defining and measuring the properties of coal which determine coke formation and quality, namely, physico-chemical and petrographic analysis. Thanks to the statistical and mathematical evaluation of a large number of analyses and on the basis of appropriate coking tests and laboratory determination of coking capacity, it is now possible to predict the impact and

abrasion strength of coke and to make the best use of the results of coking coal research both in the running of coking plants and in the planning of mining operations.

The new data on the *molecular structure* of coal can be employed for making comparisons with plastics. In fact, after previous mixing or processing coal can be worked in a similar way to other thermoplastics with a high molecular weight.

It is to be hoped that a use will be found for these products as construction or industrial materials.

Research has shown that coal molecules should not be regarded as vague aromatic formations with a large surface area, but that coal is rather a kind of "polymerised tar". When the

molecules are "depolymerised" by appropriate methods, a mixture of aromatic products can be obtained which are suitable not only as base materials for the chemical industry but also as a *fuel component* to fill the growing need for *anti-knock fuels*. This is especially valuable in the context of serious legislative measures aiming at stopping the use of other anti-knock products. It might also be mentioned that this practical application—undoubtedly complex but likely to be economically viable—could already have been carried out (or at least have reached a more advanced stage) by using all the modern scientific methods available if considerably more funds had been allotted for this purpose.

Conclusions

The joint basic research financed during the last six years, originally by the High Authority of the European Coal and Steel Community, and then by the Commission of European Communities, has added to our theoretical knowledge of the chemistry and physics of coal and coke: moreover, its discoveries are already yielding a good return, since many of them are now being profitably applied in practice.

All who took part in this interesting and successful project, to which international frontiers were no obstacle, regret the decision to bring it to an end. This decision also concerns a number of institutes whose scientific staff were very interested in the work. The sad fact is that, in view of the economic situation of the European coal industry, one is entitled to enquire about the successfulness of unapplied scientific research, which should be really concerned solely with pushing back the frontiers of knowledge.

On the other hand, it must not be forgotten that the situation on the market, particularly with regard to coal, can change rapidly. In forty years the pendulum has swung three times from boom to stagnation. It is difficult for a researcher to adapt his work to a radically altered situation. The conclusion may be drawn that basic research must form the subject of long-

term forecasts and should be independent of the economic situation.

This is why, after many years of experience, we strongly support the idea that fundamental scientific research based on international collaboration should be backed by supranational funds, as was done from Luxembourg or Brussels over the past few years. Since it is clear that basic research, unlike technical development work, does not require an enormous budget, mining research institutes and universities could conduct large-scale projects with relatively modest funds. This type of research cannot be planned in every single detail; the researcher must have a certain freedom in his choice of subjects, and it is this freedom which is the yardstick of future success.

Coal is one of the natural resources of our countries. In West Germany,

for example, it accounts for over 70 % of the subsoil in terms of value. We should not content ourselves with knowing only that this product is burnable and cokable, and abandon basic research in this field without knowing the true character of coal, how it is formed and what its chemical and physical characteristics are.

During the last few years public opinion has turned against coal, to the great detriment of not only the immediate victims but also the entire Community. This interest should be revived in our institutes of technology in order to ensure that highly qualified personnel are available for our mines later on. Unquestionably, we are doing the best thing for the future of coal when we extend our knowledge of coal by means of basic research.

EUSPA 10-5



MIMIC

The prediction of mineral resources and long-term price trends in the non-ferrous metal mining industry is no longer Utopian.

JOHAN BRINCK

Manuscript received 15-3-1971.

This paper is dedicated to the memory of the late Mr. Jacques MABILE, Director of the French Atomic Energy Commission (CEA).

A LONG-TERM TARGET price of \$ 6.00/lb U_3O_8 has been determined by interpolation of uranium vital statistics in an econometric model of the non-ferrous metal mining industry. This model results from a sustained co-operative effort between the Directorate-General for Energy, the Euratom Supply Agency and the *Joint Research Centre* of the Commission of the European Communities, implementing the Euratom Treaty of 1957 and the "First guidelines for a Community energy policy" of 1968.

From the quality and size of the uranium ore deposits which made up the reasonably assured reserves as at 1-1-1971, the model indicates that up

From 1950 to 1955, Dr. BRINCK studied the geology of gold deposits in Surinam in the framework of a development project of the *Welvaartsfonds Suriname*. From 1955 to 1960 he was with the *Kenecott Copper Corporation* as exploration geologist and project manager on different mineral prospects in Surinam, Haiti and Puerto Rico.

In 1961 he joined the staff of the Commission of the European Communities and has been engaged in the study and development of geochemical prospecting methods and the commercial, technical and economic aspects of nuclear supply problems. At present, Dr. BRINCK is a member of the Directorate-General for Energy, Nuclear Supply Division.

to 80 million tonnes of possible uranium resources could be found and developed into ore reserves exploitable at prices up to \$ 6.00/lb U_3O_8 (the estimated requirements 1970-2000 are between 2.5 and 4 million tonnes of uranium).

It also indicates that, with current technology and constant dollar value, this target price will be valid for annual requirements of 30 000 to 300 000 tonnes of uranium (current annual requirements are estimated at 12 000 tonnes).

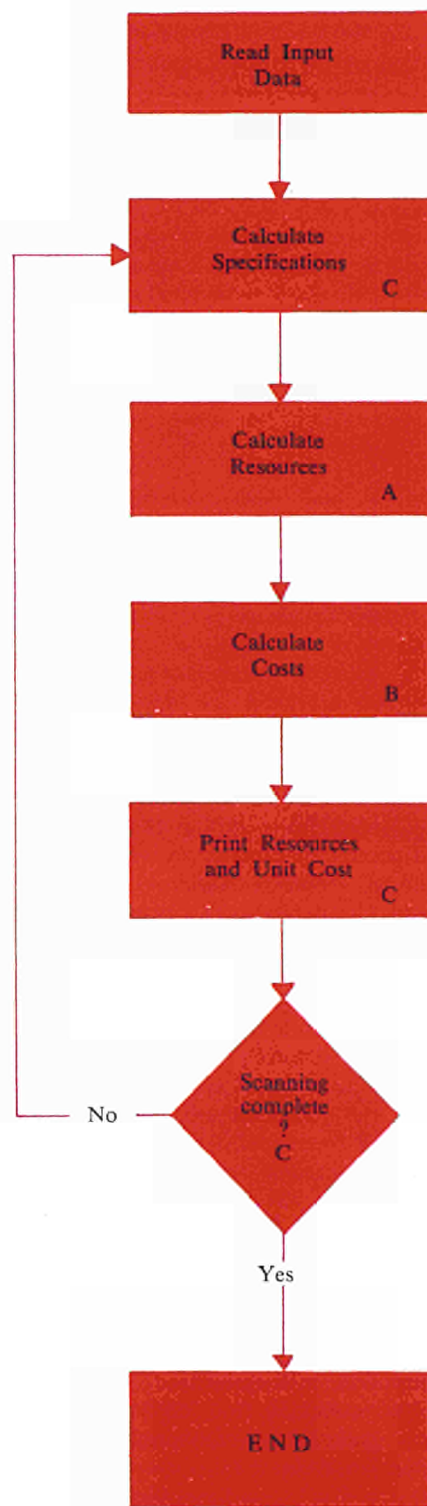
Nothing resembles an ore deposit as much as another ore deposit

The results of this reevaluation of the uranium resources and long-term supply, which has become necessary in view of recent developments in industry, will hardly come as a surprise to insiders.

The really surprising fact is that the economic data for the uranium mining industry, when applied to the geochemical constants of other non-ferrous metals, confirm the data recorded in mining history and the long-term price development of these metals with unexpectedly high precision ($\pm 25\%$).

Applied to the results of a multi-element geochemical stream sediment

Figure 1: MIMIC simplified flow-sheet showing the place of sub-models A and B in the scanning and printing routine C.



survey in the Oslo Region (Norway), the mineral potential of this region for zinc, lead and copper could be estimated. This survey was made in August 1962 by the "Applied Geochemistry Group" of the Joint Research Centre at Ispra, Italy.

The results of our tests confirm that for any given geological environment the quality and size of the mineral resources of the elements making up this environment are defined by two physico-chemical parameters:

X = average concentration of the element in the environment;

Q = specific mineralisability of the element for such an environment.

Furthermore, our results confirm that in a free market economy these same parameters define the long-term price differences between the non-ferrous metals. This is demonstrated for copper, zinc, lead and gold. Within a given economic context, therefore, the model needs only X and Q as external variables to evaluate and compare mineral resources, and to predict long-term price trends in the non-ferrous metal mining industry.

For both theoretical and practical purposes, in estimating mineral resources the use of a log-binomial model of element distribution in the sense of De Wijs is preferable to the more common but rather platonic log-normal model.

Specifications of "MIMIC"

"MIMIC" (Mining Industry Model for Inventorisation and Cost evaluation of mineral resources) has been prepared by making use of previously developed and tested computer programs such as IRIS (resources estimations), EXILE (EXploration Investment LEvelling), EXIST (EXploration Investment by Size of Target), NUCGB (a descriptive model of the intra-industry market within the nuclear mining industry). The results were published in different papers and were discussed at the Colloquium of the European uranium producers (Ispra, 18-19 June 1970). For practical reasons, the prototype pro-

Figure 2: Possible resources of uranium. Plotted on the horizontal scale are the possible resources of uranium occurring in mineral deposits containing between 10 and $3 \cdot 10^{12}$ tonnes of uranium (the earth's upper crust to a depth of 2.5 km).

On the vertical scale uranium concentrations are given in parts per million (grammes per tonne).

The diagonal line indicates uranium deposits of the highest possible grade for a given uranium content (tonnes of metal). From this line, lines of equal metal content for lower grade deposits of possible economic interest are plotted and form the Iris or rainbow diagram.

Superimposed on this diagram are the average unit production costs (\$/lb U_3O_8) for uranium deposits of the given grade (ppm U) and metal content (tonnes U), according to the following subdivision:

dark red possible reserves, i.e. resources which could be exploited at a profit with current technology and at the current market price;

striped red marginal resources, i.e. resources which would become exploitable at slightly higher prices or reasonably predictable technological improvements;

dotted red sub-marginal resources, i.e. resources which, in order to become exploitable, would require significant increases in price and improvements in technology;

white latent resources, i.e. resources from which the metal probably never could be extracted profitably, except as a by-product of other mineral products.

Their ultimate size is projected on the horizontal scale. The arrow indicates the point corresponding to the grade and size of the average ore deposit at the given date. This point, projected on the horizontal scale, divides the possible reserves into "reasonably assured" reserves plus previous production and "possible" reserves, which could be found and developed by mineral exploration.

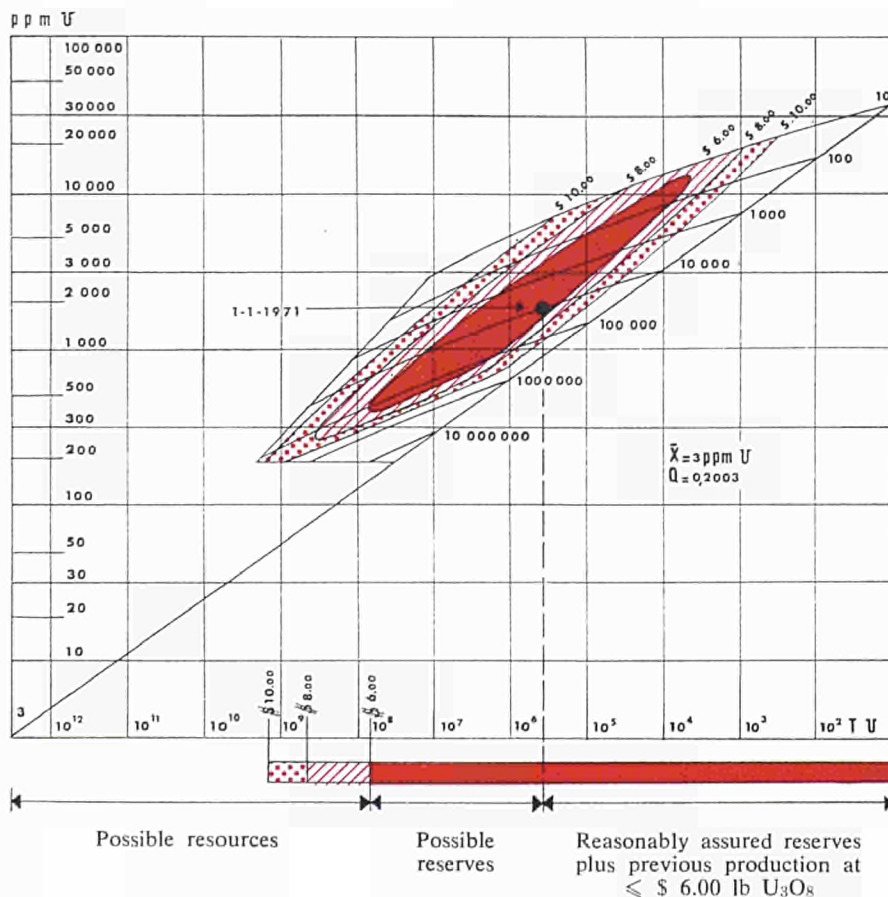


Table I: Estimated exploitation cost of uranium based on the "reasonably assured" reserves in 1967, 1969 and 1971.

Year	Total reserves	Average metal content tonnes U	Average grade % U	Spec. min. Q	Average lb U ₃ O ₈ cost
1967 ⁽¹⁾	500 000	4 000	0.15	0.1915	\$ 7.32
1969 ⁽²⁾	717 000	4 000	0.165	0.1955	\$ 6.78
1971 ⁽³⁾	430 000	10 000	0.185	0.2003	\$ 5.19

(1) J.W. BRINCK: Note on the distribution and predictability of mineral resources. EUR 3461 e.

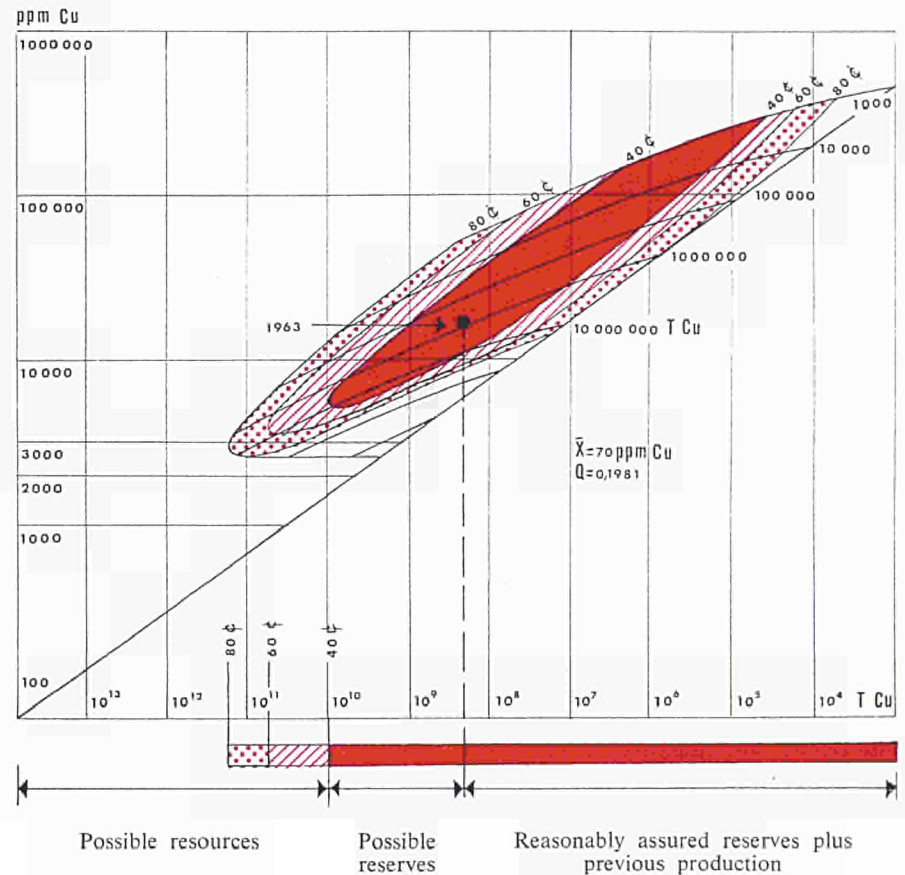
(2) Colloquium Ispra, 18-19 June, 1970.

(3) Estimate as at 1-1-1971.

Figure 3: Possible resources of copper (explanation as fig. 2).

This is a typical picture for a mature and healthy mining industry. The arrow indicates that the cost is determined mostly by capital investment and operating cost. As copper represents already the largest non-ferrous metal mining industry, increases in scale of operations depend directly on technological developments in the industry itself.

It can be seen that the historical long-term average price of \$ 0.35-0.45/lb Cu (at constant dollar value) can be maintained only by the continuous improvement of exploration, mining, milling and marketing techniques and the development of new methods.



gram has been written in "BASIC" ¹ for "time sharing" use. The limitations on program size and the relatively low speed computer made it necessary to simplify the program as much as possible by omitting some of the refinements which will be found in later versions. Besides, a number of auxiliary programs had to be developed for the calculation and testing of several internal and external parameters.

Basically the model consists of two sub-models, A and B, sequentially used by a scanning and printing routine C which generates predetermined specifications (size and grade) for mineral deposits of possible economic interest according to the flow sheet shown at Fig. 1.

Calculation of resources

Resources are calculated according to a log-binomial model of element distribution in the geological environment as proposed by the author and for which the calculating methods have been developed by De Wolde of CETIS, according to the general formula:

$$M = R \cdot X = \sum_{k=0}^{\alpha} \frac{\binom{\alpha}{k}}{2^{\alpha}} \cdot R \cdot X \cdot (1+Q)^{\alpha-k} \cdot (1-Q)^k \quad [1]$$

(Euratom Bulletin, Vol. VI (1967) No. 4)

where:

M = total resources of an element in R;

R = size of the environment in tonnes of rock. It should be remembered that the distribution is volumetric and that this procedure is valid only if the specific gravity of the calculated resources is similar to that of the environment;

X = average concentration of the element in the environment;

Q = specific mineralisability of the element for the environment

$$[0 < Q < 1]$$

¹ BASIC (Beginners All-purpose Symbolic Instruction Code).

α = rational number indicating the order of subdivision of the environment;

k = an integer 0, 1, 2, - - - N

$$[(\alpha - 1) < N \leq \alpha]$$

From this general formula a modified version of the BDW-Function (EUR 4607e, 1971) has been derived which makes this function:

1) a monotonic decreasing continuous function;

2) defined over the interval

$$[Z_0 = R/2^{\alpha}, Z_1, Z_{\alpha} = R];$$

3) integrated over the interval

$$i = 0 \rightarrow i [k \leq i < k + 1];$$

4) reversible: the inverse function

$$[BDWF]^{-1}$$

exists on the same interval.

From the BDW-Function metal resources are found by

$$M_i = z_i \cdot x_i \quad [2]$$

Plotting the log $[M_i]$ values for deposits with equal metal content against the log $[x_i]$ grades of the mineral deposits in which they occur, an equal probability distribution (IRIS-

diagram) is obtained which indicates all "possible resources" of the geological environment.

"Possible resources" are, by definition, the mineral resources which can be estimated on the basis of geological evidence or by extrapolation from known resources, without exact knowledge of their location, grade or size.

Calculation of cost

Costs are calculated by discounting cash flow for the moment when a fully equipped mineral deposit of given size and grade enters into production, according to a model whose prototype was developed by Grijpink during his traineeship with the Commission in 1970.

Exploration cost

Exploration cost is determined as a function of the chance to discover mineral deposits of given size-grade specifications in the geological environment.

This chance is directly proportional to the size and number of mineral deposits with the given specifications present in the geological environment.

Considering exploration as an essentially one-dimensional activity ² (grid sampling, section drilling) in a two-dimensional environment (the earth's surface), the exploration cost for a deposit of given specifications is derived from the exploration cost calculated for a reference deposit.

Normally the reference deposit corresponds to the average ore deposit for which the specific mineralisability Q of the metal has been determined.

Optionally, predetermined specifications of a reference deposit can be introduced.

Capital investment cost

The investments required to develop a "proved" ore reserve into a mine with the required facilities for producing a marketable product depend both on the size of the deposit and the planned rate of its depletion. Furthermore, a scale effect causes an exponential decrease in unit investment cost with increasing size of the ore handling capacity.

Operating cost

Operating cost here include mining, milling and marketing costs in the widest sense, excluding interest charges.

Here also a scale effect causes an exponential decrease in unit operating

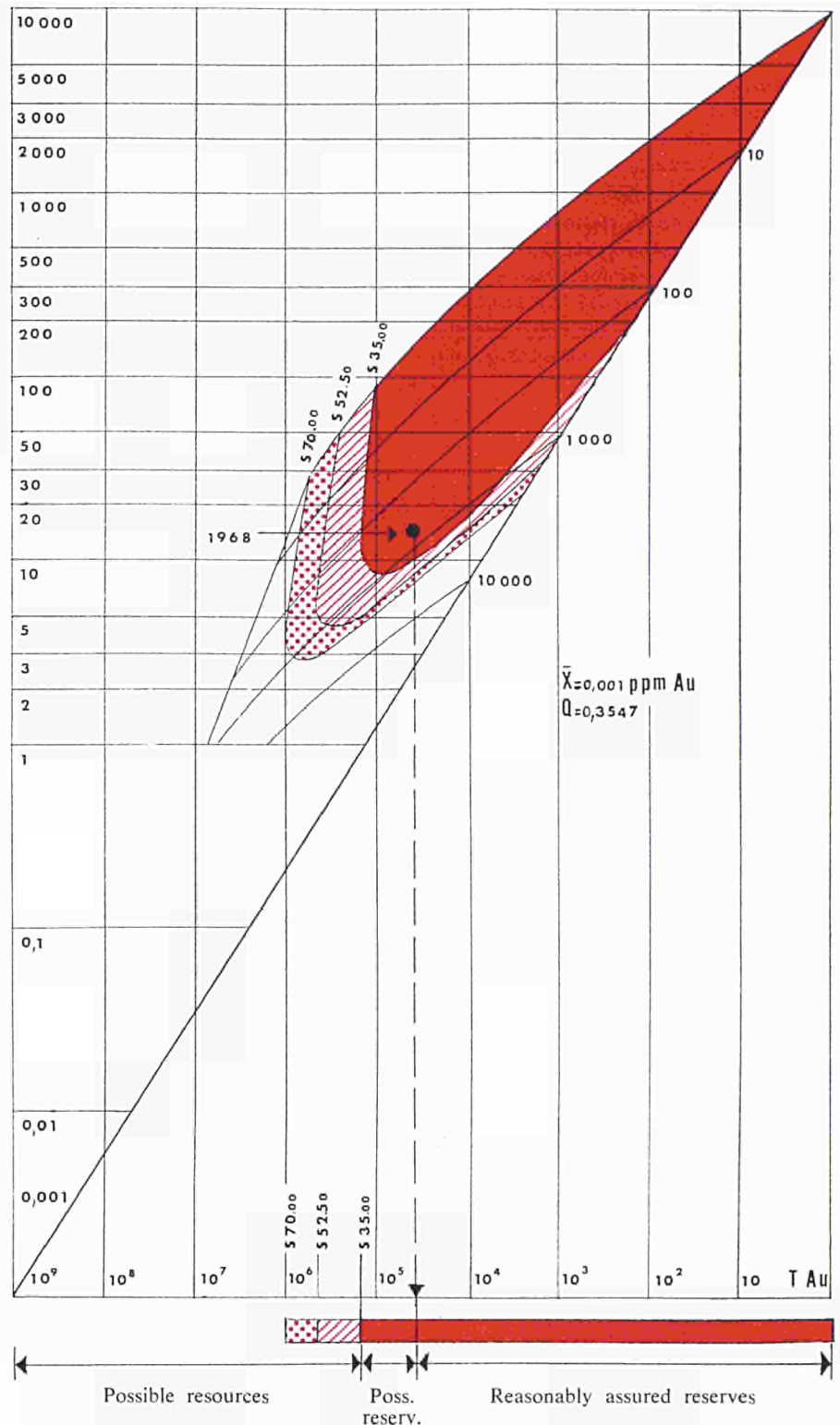
² Actually, it is the contribution of the exploration geologist which brings the probability of finding a uranium ore deposit from a random chance of 1: 10⁹ to the directed chance of 1: 10³ which Cooper and Grant calculated in 1969 on the basis of USAEC statistics on uranium exploration in the United States.

Figure 4: Possible resources of gold (explanation as for fig. 2).

This picture is typical of a mature and efficient industry, with the first signs of approaching senility.

The high Q value indicates that an increase of the average size of the ore deposits results in a decrease of ore grades which is more pronounced than for elements with a lower value of Q .

Here economies of scale would hardly be sufficient to counteract the higher costs involved in working lower grade ores. Consequently, technological improvements and optimisation of exploitation costs are the only tools to fight inflation. The point indicated by the arrow, projected on the horizontal scale, indicates that 1968 reserves were of a better quality than the previously exploited gold ores, thus indicating also that owing to inflation the depletion of reserves takes place at a faster rate than the actual production.



Element	Total reserves + production tonnes metal	Ave. content tonnes metal	Ave. grade % metal	X ppm	Q	Long-term price \$ lb
Copper	2.19×10^8	1.1×10^6	1.7	70	0.1981	0.35 — 0.45
Zinc	1.74×10^8	0.43×10^6	4.3	80	0.2126	0.10 — 0.20
Lead	1.55×10^8	0.50×10^6	5.0	16	0.2793	0.10 — 0.20

Table II: Estimation of copper, zinc and lead possible resources (cfr. EUR 3461 e, 1967).

cost with increasing ore handling capacity.

Scanning routine and printed output

Production costs first are calculated for a reference deposit, according to the specified discount rate and depletion time.

The scanning routine then generates grade-size specifications for mineral deposits of possible economic interest.

Size is specified by average metal content of the individual deposits.

For each series of deposits with equal metal content the program sequentially calculates production cost from possible highest grade deposits to the lowest grade deposits of possible economic interest.

Unit production costs are divided by unit production costs for the reference deposit and printed as a proportion of the reference cost. Exploration, investment and operating cost are specified as a percentage of the total cost.

The program tests for the following anomalous conditions or technological restrictions:

- 1) element concentration higher than in the most important ore mineral. The program prints: "OVERFLOW FOR N = α ", and continues calculation for the next deposit;
- 2) reference deposits which are anomalous for the given X and Q values and size of the environment.

In this case the model prints: "THE REFERENCE DEPOSIT WOULD BE ANOMALOUS FOR THE

GIVEN ENVIRONMENT AND PARAMETERS (X AND Q). AN IMAGINARY PROBABILITY "P" IS EXTRAPOLATED".

- a) If $P > 0.01$, the program calculates a reference price and continues execution;
- b) if $P \leq 0.01$, the program gradually increases the size of the environment to 10^4 times its original size. If the reference deposit will fit for the given values of X and Q the program prints: "DEPOSIT WOULD FIT IN AN ENVIRONMENT OF "R" TONNES", and stops execution.

If the deposit does not fit the increased environment, it prints: "NO RESOURCES OF POSSIBLE ECONOMIC INTEREST ARE INDICATED FOR THE GIVEN DATA", and stops execution;

- 3) if daily ore handling capacity exceeds 32 000 tonnes, unit investment costs first are calculated according to the exponential decrease in cost with increasing size and next by assuming unit investment cost for 32 000 tonnes capacity;
- 4) operating costs are calculated for daily ore handling capacities up to 250 000 tonnes; for deposits larger than $I \cdot 91.25 \cdot 10^6$ tonnes of ore, they are considered to be of this size ($I =$ depletion time in years).

All calculations have been made for a discount rate of 10.4 % to allow for 8 % after tax return on risk capital representing 30 % of total capital.

Both depletion and amortisation time have been set at 16 years.

Within this economic context, the only essential external parameters of the model are X (average concentration), R (size of geological environment) and Q (specific mineralisability).

Average concentration

The average concentrations of the elements are relatively well known and for the calculation of world resources are taken from Green's "Geochemical Table of the Elements for 1959".

The data given in Green's Table show a systematic underestimation of the average concentration of the elements in the earth's crust, which is due to the sampling method and the particular distribution of elements in the earth's crust. This underestimation has not been taken into account although a correction according to the formula given in EUR 4403e, 1969 is feasible. Correcting these data would result in an increase of possible resources at equal target price.

For the interpretation of the stream-sediment survey in the Oslo Region, Norway, the average concentrations of copper, zinc and lead have been determined from the median content and logarithmic standard deviation of the analytical data (EUR 3461e, 1967).

Size of the environment

For the calculation of world resources, the dry land surface of the earth to a depth of 2.5 km has been taken

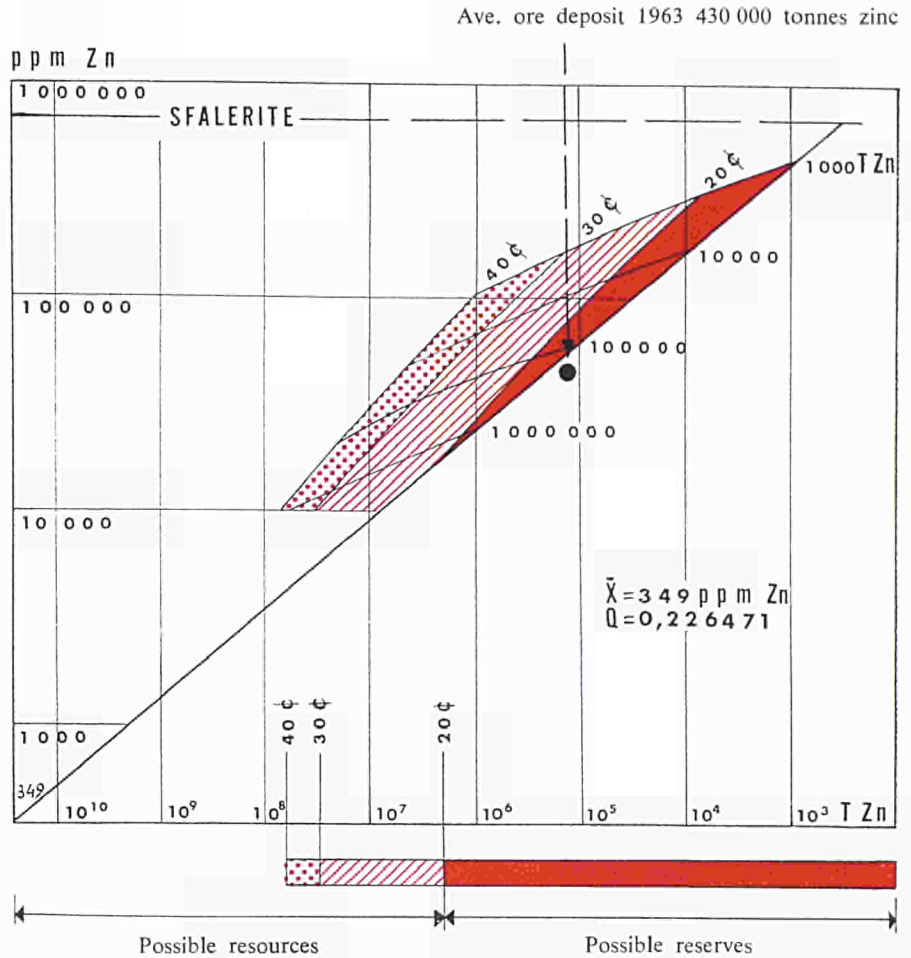


Figure 5: Possible zinc resources of the Oslo Region, Norway. Possible resources were calculated from geochemical survey data (146 samples from recent stream sediments, representing average drainage basins of 15 km² in a total area of 10 000 km²). As indicated, an average ore deposit of the 1963 type (430 000 tonnes of zinc and an ore grade of 4.3 % Zn) has a probability of occurrence in this area which is less than 1. However, the results of this survey point at possible zinc reserves up to two million tonnes of zinc, in ore deposits containing from 1 000 to 2 000 000 tonnes of zinc and having ore grades between 40-1.4 % zinc.

as the size of the environment, representing $1.0 \cdot 10^{18}$ tonnes of rock with a specific gravity of 2.7.

For the Oslo Region the environment is taken as 10 000 km² to a depth of 2.5 km, representing

$$6.75 \times 10^{13} \text{ tonnes of rock}$$

which have been sampled at the surface by 146 samples representing an average of 15 km² each, thus covering approximately 20 % of the total area.

Estimation of the specific mineralisability

The value of the specific mineralisability of an element depends on its physico-chemical characteristics as contrasted to those of all other elements present in the geological environment. It represents the element's tendency to occur in concentrated form. Eventually, this value should be theoretically predictable from the principles already indicated by Niggli, Goldschmidt, Rankama, Sahama and many other theoretical geochemists.

Our own estimations, however, are based on a probabilistic approach

drawn from the measured frequency of occurrence of concentrations of given size and grade.

For world resources, Q is determined from the element's vital statistics (total size of reserves + previous production; average grade; average metal content of the individual deposits making up the reserves), and its average concentration in, and size of, the geological environment.

For the stream sediment survey Q has been determined from the median content, the logarithmic standard deviation and the order of subdivision of the environment as indicated by the average sample size.

Examples of resources and price estimates

URANIUM

Estimation of resources and target price

Exploitation cost for uranium have been estimated on the basis of the "reasonably assured" reserves in 1967, 1969 and 1971 as shown in Table I.

It can be seen that for 1967 and 1969 the estimates had to be made for a target price of \$ 8 to 10/lb U_3O_8 , whereas this year's estimate is based on the actual price of \pm \$ 6.00/lb U_3O_8 , according to the following definition of reserves: "*Reserves*" are the mineral deposits from which one or more components can be profitably extracted.

Only a fraction of this new reserve figure is made up from previous production since the average specifications of ore deposits in the past were essentially less favourable than at present.

This estimate does not take into account the unknown size and quality of uranium reserves in the USSR, People's Republic of China or the East European countries, nor the possible additional reserves mentioned in literature.

The yet unconfirmed ore grades of 23 % U for the Nabarlek deposit, of 0.5 % U for the Ranger I deposit in

Australia, and that of the Rabbit Lake deposit in Canada have been discounted as ≥ 0.185 % U. Neither the important South African by-product reserves nor the large low-grade deposit of Rossing near Swakopmund in S.W. Africa, for which no grade or size figures have yet been published, figure in this reserve estimate for 1-1-1971.

Taking each one of the recently discovered high-grade deposits separately or combined, their reported grade and size would indicate a much higher value for the specific mineralisability of uranium. For these higher values the model would indicate much lower target prices for equally large resources. However, these high-grade deposits do not yet represent sufficient reasonably assured reserves to cover the predicted short- and medium-term requirements. Therefore production from higher-cost resources would be required, for which the marginal producer then would determine the uranium price. In this respect the 430 000 tonnes of reasonably assured reserves, representing 35 years' current annual requirements, together with the current intensive exploration effort, should be considered adequate for the moment, even in view of the predicted rapid increase in annual requirements.

As illustrated in Fig. 2, "possible" uranium reserves from which "reasonably assured" reserves exploitable at prices up to \$ 6.00/lb U_3O_8 could be developed by mineral exploration, can be estimated to be of the order of 80 million tonnes of uranium. With the existing technology, it is indicated that this target price would be valid for gradually increasing annual requirements between 30 000 and 300 000 tonnes of uranium.

It is well known that once a mineral deposit has been discovered and its reserves delineated, exploration costs do not influence the decision whether or not to bring the deposit into production.

Exploration costs, however, do figure in the long-term target price and must be fully recovered. If not, the exploration activity will come to a standstill:

the depletion of reserves would result in decreasing production and, with stable or growing demand, the consequent shortages would increase the price of the product. This in turn would reactivate prospecting, recreating the exploration cycles so well known in the non-ferrous metal industry. A price fluctuation of 25 % is likely to result from such or other influences bringing the price to a range of \$ 4.50 to 7.50/lb U_3O_8 .

The high exploration costs on the right side of figure 6 are largely hypothetical. They indicate that by looking only for the very best of possible deposits, incurred costs could easily exceed the possible benefits from an exploration programme (over-prospecting).

As it can be seen from Figs. 2 and 6, we are only at the beginning of optimum conditions for the given values of X and Q.

Long-term credibility of the target price

The long-term price and resources estimate given here represent the "surprise free projection" in the sense of Kahn ("The year 2000").

The forecast is perfectly valid even for the very long-term as long as the economic context in which it is made and the physico-chemical parameters remain unchanged.

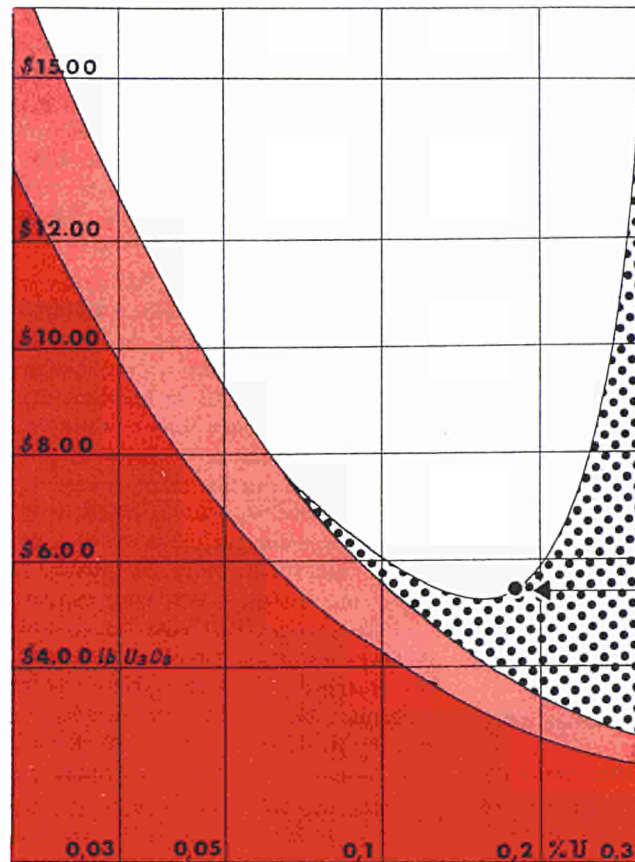
Speculations on the probability of a change in the economic context in which these estimates have been made fall outside the scope of this paper.

A change in quality of the reserves, however, which would be reflected in the value of the specific mineralisability should be considered probable in view of the fact that great surprises in mineral exploration are not yet excluded.

Possible alternative price developments

The recent discovery of several large, high-grade uranium deposits in Australia and Canada could hardly have been predicted from the data pub-

Figure 6: Unit production cost for uranium deposits containing 10 000 tonnes of uranium as a function of grade (\$/lb U_3O_8). The figure represents the 10 000 tonnes uranium deposits of fig. 2. Costs are divided into
dotted = exploration cost
light colour = capital investment cost
dark colour = operating cost
The high exploration cost on the right side indicates that, by exploring only for the very rare highest possible grade, this value could easily exceed the market value of the product and that a compromise has to be found between exploration and exploitation cost. This optimum has not yet been reached for the young uranium mining industry.



1-1-1971

lished as late as June 1970. Until that time most uranium geologists considered a deposit of the Nabarlek type (42 000 tonnes uranium and an ore grade of 23 % U) highly unlikely if not impossible.

However, if we look at the development of the quality and size of the reasonably assured reserves over the past four years, a constant amelioration can be seen which is reflected in the value of the specific mineralisability.

If this trend should be extrapolated in the future, by 1976 a target price of \$ 4.00/lb U_3O_8 for a similar size of possible resources would be indicated. A forecast of this kind would be the "naïve projection" of the economist in the sense of Kahn; it would have a highly speculative character as nobody thus far should be considered able to predict the "if" and "when" of new discoveries with better than average specifications. On the other hand, the

development of new reserves from the indicated possible resources can be predicted with a rather high degree of accuracy as a function of the money spent in mineral exploration (programs *EXILE* and *EXIST*).

Nevertheless, a continuing amelioration of the quality and/or size of the individual ore deposits making up the reasonably assured reserves should be considered the most likely alternative development. Most probably this development will decrease the target price by some 3 % or more annually and for a long time to come.

From the point of view of the mineral economics there is no reason to expect an increase in the target price, although national policies in respect of natural resources easily could and do create short- and medium-term discriminatory conditions on the uranium market, with higher than average prices for certain consumers (USA).

On the other hand, a significant decrease in the target price below \$ 6.00/lb U_3O_8 would require an equally significant increase in the value of the specific mineralisability.

Metals with a high specific mineralisability, however, are much less equally distributed than those with a lower one.

A significant increase in the Q value of uranium therefore would tend to decrease the number of countries that could produce at the lower target price. This would make it easier for these countries to dictate an artificial price which would optimise in one form or another the difference in quality of the uranium reserves of the few happy and the many unhappy producer countries.

The possibility of such a development is indicated by the discovery of the Nabarlek deposit in Australia, the existence of the Shinkolobwé mine in the Congo, and to a somewhat lesser extent of the Great Bear Lake and Joachimstal deposits.

It is clear that Australia at present stands the best chances of being one of the happy few.

COPPER, ZINC AND LEAD

Resources for copper, zinc and lead have been inferred from production until 1963 plus 20 years' forward reserves of the current average grade and size as shown in Table II.

Figure 3 illustrates the possible resources and production costs for copper determined by the model as a function of X and Q.

The long-term price stability for this metal is easily explained by the figure itself.

Figure 5 represents an estimate of the "possible" reserves and resources of zinc in the Oslo Region (Norway), which have been determined also for copper and lead (Table III).

GOLD

A first estimate of gold resources was made on the basis of the known world production until 1962 plus 20 years' forward reserves at the historical average grade and size of the Witwatersrand gold mines (*Transvaal and Orange Free State Chamber of Mines, Annual Report 1962*).

For the average concentration a value of 0.001 ppm has been accepted.

The specific mineralisability Q was determined as 0.339.

Calculated for these values, the cost price for deposits of historical average grade and size would have been higher than the official gold price of \$ 35.00/oz Au.

Our revised estimate of world gold reserves was made on the basis of that published in 1968 by *Anderson, Wilson & Co.* in "Gold Galore".

Table III: "Possible" reserves and resources of copper, zinc and lead as determined for the Oslo Region (Norway).

Element	X ppm	Q	R tonnes	Possible reserves
Copper	107	0.1970	6.75×10^{13}	No resources of possible economic interest indicated.
Zinc	349	0.2265	6.75×10^{13}	Possible reserves up to two million tonnes of Zn in deposits containing 1 000 to 1 000 000 tonnes of Zn and ore grades ranging from 40 to 1.4 % Zn.
Lead	35.2	0.3189	6.75×10^{13}	Possible reserves up to 10 000 tonnes in deposits containing 1 000 to 10 000 tonnes and ore grades higher than 10 % Pb.

From this estimate a Q value of 0.3547 could be determined and a cost price well below \$ 35.00/oz Au. (see Fig. 4) was found.

The estimates confirm that the presently known gold reserves, through inflation, will be depleted at a rate faster than that of production.

Without field checks on the distribution of gold an evaluation of the accuracy of this gold estimate may be obtained by extrapolating "possible resources" to the largest gold nugget that one could expect (~ 100 % Au).

Taking into account the different specific gravity of gold and that of the geological environment, such a nugget could be expected to weigh about 22.5 kg.

By comparing this predicted weight with some of the most famous nuggets found, such as

- *Welcome Stranger* -
Ballarat, Australia 70.9 kg
- *Blanche Barkley* - Victoria 54.5 kg
- *Carson Hill* - California 40.3 kg

we observe that, although our estimates are very prudential, they do show the right order of magnitude.

Element distribution in ore deposits

The log-binomial distribution of the useful metals in their ore deposits has been studied by De Wijs who, as early as 1953, made the following subdivisions for Q values:

- < 0.15 conspicuously regular;
- 0.15 - 0.25 no comment;
- 0.25 - 0.35 fairly irregular;
- > 0.35 extremely irregular.

The specific mineralisability for copper, zinc, lead, tin as found by De Wijs in hydrothermal fissure veins is of the order of 0.2, and for gold ranging from 0.35 to 0.45.

Acknowledgements

I would like here to thank the members of the *AMICA* project who, after the dissolution of the Section for

mineralogy and geochemistry of the *Joint Research Centre* at Ispra in 1962, mainly out of scientific enthusiasm spent many week-ends and nights working at thousands of chemical analyses on stream sediment samples of the Oslo Region, as well as on the maps and the computer programs required for their interpretation.

Of paramount importance to the development of the model has been a study of the late Mr. Jacques Mabile, to whom this paper is dedicated. In his study on the "long-range trend for uranium" (Oklahoma, 1968) he compared the long-term development of prices and resources in the copper, lead and zinc mining industry with the expected trend for the much younger uranium mining industry.

It is a very sad coincidence indeed that confirmation of his thought-provoking theories became available only a few days after the tragic accident which caused his death in January 1971.

EUSPA 10-6

Literature: (1) Exploration to power reactors. *Conference on nuclear fuel*, Oklahoma City, Oklahoma, 23-24 May, 1968. (2) Uranium exploration geology. *International Atomic Energy Agency, Proceedings of a panel*, Vienna, 13-17 April, 1970. (3) Uranium—resources, production and demand, estimates of 1965, 1967, 1969, 1970. *European Nuclear Energy Agency and International Atomic Energy Agency*. (4) Uran ur svensk skiffer. *Aktiebolaget Atomenergi*, Stockholm, 1968. (5) The problem of uranium resources and the long-term supply position. *Report EUR 414 d,f,i,n,e*. (6) J.W. BRINCK, A. HOFMANN: The distribution of beryllium in the Oslo Region (Norway), geochemical, stream sediment study. *Report EUR 919 e*. (7) Les ressources en uranium dans la Communauté européenne. *Report EUR 2961 d,f,i,n*. (8) J.W. BRINCK: Note on the distribution and predictability of mineral resources. *Report EUR 3461 e*. (9) H.I. DE WOLDE, J.W. BRINCK: The optimisation of mineral exploration investments by the computer program EXILE. *Report EUR 4403 e*. (10) H.I. DE WOLDE, J.W. BRINCK: The estimation of mineral resource by the computer program IRIS. *Report EUR 4607 e*. (11) J.W. BRINCK: Calculating the world's uranium fuel resources. *Euratom Bulletin* Vol. VI No. 4, p. 109.

Under this title *euro-spectra* regularly reports some of the new processes or equipment recently developed at the *Joint Research Centre's* establishments or at the works of firms or institutes performing research under contract to the Commission.

It will be recalled that, under the Euratom Treaty, knowledge thus acquired by the Commission can be communicated to interested firms in the European Community under favourable conditions.

Any firms interested in acquiring a deeper insight into these possibilities should write to: Commission of the European Communities, D.G. XIII-A, 29, rue Aldringer, Luxembourg.

New developments in scientific cinematography

An automatic exposure control system conferring a wider range of uses on cine-cameras.

LAURA CAVARA

LAURA CAVARA is Editor of *euro-spectra*.

SCIENTIFIC CINEMATOGRAPHY has become an essential accompaniment, rather than a mere aid, to research, teaching and certain professional activities. It is already being used in many fields and the number of its applications is certain to grow. Whichever form is in question, be it cine-micrography, cine-macrography or cine-endoscopy, it is clear even to the layman that dynamic phenomena can be better understood if recorded and studied in their various stages of development. A moving picture can be viewed repeatedly, so that the phenomena concerned can be studied at leisure.

Until recently, despite the advances in this field over the past few years and the undoubted benefits resulting from the general switch to colour film, the pictures still suffered from technical shortcomings the elimination of which gave rise to some fairly complex problems.

A recent innovation in this field is the work of a researcher¹ at the Petten (Netherlands) Establishment of the *Joint Research Centre*. It relates to a cine-camera with an automatic exposure controller². The improvement to scientific cinematography due to this innovation has aroused interest in many different quarters; the new device is already in use in cine-microscopy (with optical and electron microscopes), cine-endoscopy and cine-radiography. By the time this article appears it will have been used for underwater filming.

The range of applications is very wide and it is certainly no exaggeration to say that there will be valuable further developments in the near future.

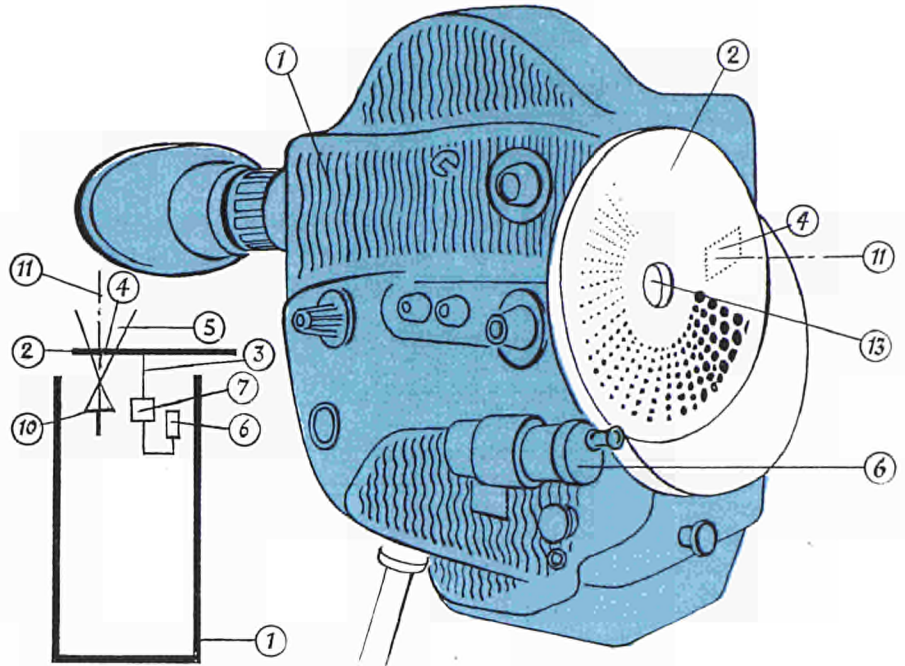
Particulars of the device

The new apparatus is intended to replace the diaphragm as the element controlling the luminous intensity. Its main component is a disc made of a

¹ Mr. Robert De Cat.

² The system was briefly described in Technical Note 54/C (*euro-spectra* Vol. IX (1970) No. 3, p. 92).

Figure 1: Drawing and schematic diagram of the Beaulieu cine-camera fitted with the automatic exposure control system. (1) Magazine from which the unexposed film (10) is fed, intersecting the camera's optical axis (11) at the point where the image is registered. In front of the film is placed a disc (2) which rotates about an axis (3), parallel with but offset from the optical axis of the camera, so as to intercept the luminous flux (5) on a surface (4). Rotation of the disc is controlled by a photo-electric cell (6) the pulses from which are amplified and transmitted to a miniaturised electric motor (7) driving the disc.



material the opacity of which varies linearly with angular position. The principle of operation is illustrated in Figure 1. According to the luminous intensity as measured by the photo-electric cell (6), the disc (2) is rotated until it occupies the correct angular position for the film to be exposed to a luminous flux of constant intensity. When the light level varies continually during the taking of a shot the disc (2) revolves constantly in either direction so as to maintain a constant flow of light on to the film. This new automatic exposure control system therefore serves two purposes:

- (a) automatic and precise control of the amount of light admitted to the camera to match the shutter speed and aperture;
- (b) full automation of the exposure so as to relieve the cameraman of any need to measure or adjust the brightness of the subject image.

The device was originally conceived as a means of reducing a troublesome phenomenon known as the vignetting effect.

When a cine-camera is coupled to the eyepiece of an optical microscope, its lens has to be removed and replaced by another which does not constitute

a complete optical system in itself. Firstly, the diaphragm now has very little influence on the luminous flux reaching the film (this remains virtually constant, whether the aperture is set to maximum or minimum) and, secondly, a circle appears on the film. This circle is a sort of ghost image of the diaphragm, and its size therefore varies with the aperture. Thus any change in brightness causes the image on the film to be enclosed in a circle of a different diameter, and this change in the size of the circle is termed vignetting.

The device developed at Petten replaces the diaphragm as a means of controlling the luminous intensity. It also has a number of other marked advantages over the diaphragm, notably the absence of wear and complete freedom from jamming. Since the new device takes over the job of controlling the luminous intensity, the diaphragm is no longer required to perform this task and can revert to its primary function of controlling the depth of focus (which also means far fewer movements and longer life). The depth

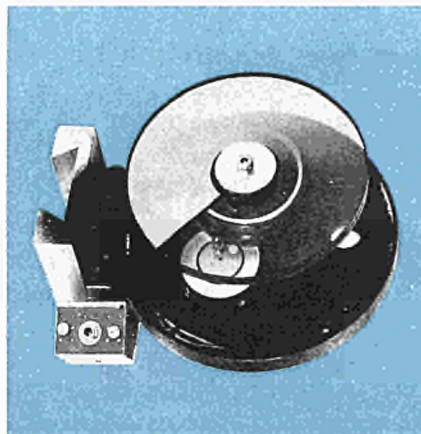


Figure 2: The disc (item 2 in Fig. 1), with its graduated light transmission, is clearly visible in this view of the exposure control device.

of focus can therefore be controlled without the need to consider other requirements.

In this way the new automatic exposure control system adds to the capabilities of the cine-camera to which it is fitted. It can be used in all spheres—even in amateur cinematography—but more particularly in those reviewed below.

Cine-micrography with optical microscope

This new automatic exposure control was first developed as an answer to the above-mentioned problem of vignetting in cine-micrography. Various dynamic phenomena, such as liquid diffusion in a crystalline solid, melting and solidification of crystals, and many others, can now be readily filmed under the microscope. It should again be stressed that the image recorded on the film is of constant size.

Cine-micrography with electron microscope

Here some rather delicate problems arise in the avoidance of image distortion. In short, it was necessary to fit light amplifiers in front of the cine-camera with automatic exposure control, and in view of the length of the complete assembly this meant that the camera had to be sited almost at floor level, so that the operator had to lie prone to look through the eyepiece. A TV camera was then attached to the eyepiece, enabling the image to be relayed to a TV screen set up in a more convenient position for the operator, who can thus sit watching the screen and can operate the cine-camera by remote control when any phenomenon of interest appears on the screen.

Medicine

Cine-cameras equipped with the Petten automatic exposure control system are already being widely used in medical circles, particularly in France. They supply objective data which are of unquestioned value for diagnostic, research and educational purposes.

Cine-radiography. — This entails working under very special conditions. Precautions have to be taken by the operator owing to the danger from primary radiation emitted by the X-ray source and secondary radiation emitted by the patient. There can be no question of the operator's remaining close to the patient; nevertheless, the image has to be monitored during filming, and the dynamic process must be visualised in between the various sequences. Also, the patient has to be easily movable relative to the axis of the amplifier system so that the organs in motion can be observed. It was therefore necessary to build remote-controlled tables. As in the case of electron microscopy, these special requirements entail coupling a TV camera to the cine-camera, a procedure first advocated 15 years ago by Dr Noix of Paris, whose experience tallies with that acquired more recently by the Petten Establishment in the field of electron microscopy. This set-up, which derives from the results of joint experiments with a cine-camera fitted with the automatic exposure control system, is a brilliant solution to the medical problem in question.

Cine-endoscopy—or the filming of the internal cavities of the human body—has certainly advanced enormously since 1919, when Giulio Pancinelli Calzia, then aged 42 and working in this Hamburg phonetics laboratory, was the first man to film the movements of the vocal cords in action. Calzia was a true pioneer in the field, being director, cameraman and actor rolled into one. Faced with this complex problem, he solved it by standing in front of the camera and directing on to the lens the image of his larynx reflected by the small mirror on the laryngoscope. By means of this arrangement he was able to view the image reflected in the camera lens, keep a constant check on the position of the laryngoscope and release the shutter at the right moment.

The great advantage of cine-endoscopy over photographic endoscopy is, of course, that the phenomenon under investigation is recorded while it is actually taking place, and that it pro-

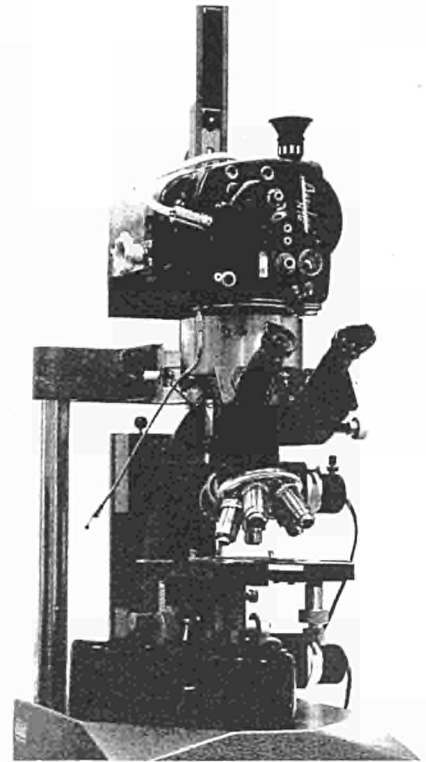


Figure 3: Cine-camera, with automatic exposure control system, mounted on an optical microscope.

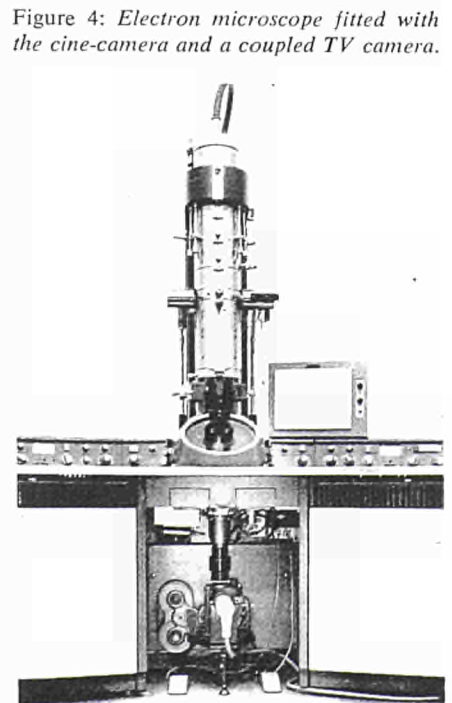


Figure 4: Electron microscope fitted with the cine-camera and a coupled TV camera.

vides data which are unquestionably objective and can be viewed and studied repeatedly.

Cameras fitted with the type of automatic exposure control developed at Petten, and coupled to an endoscope, have already become an important tool in urological endoscopy (cystoscopy), for if an ordinary cine-camera is used with an endoscope the problem of vignetting arises for the same reasons as in optical microscopy.

Dr M. Jaupitre, an eminent French specialist and Chairman of the *International Medical Society for Endoscopy and Cine-radiography*, who is well known for his work on the application of cine-endoscopy to urology, has strongly urged its adoption and widespread use. In his opinion the best results are produced by a cine-camera fitted with automatic exposure control as developed at Petten. He now uses one as standard practice and has reported on its value at scientific congresses. The equipment is much less expensive than that used in scientific cinematography hitherto, works more efficiently and gives much better results. A further point is that films made in the past, even years before, are always

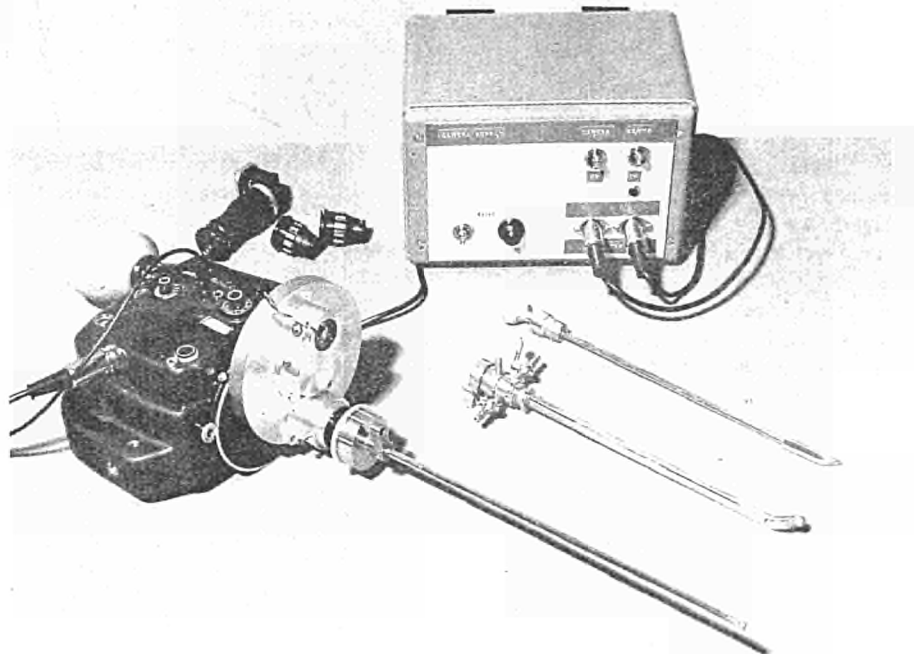
shot with the same exposure and are therefore fully comparable; this makes possible—indeed, enormously simplifies—the task of those responsible for monitoring the progression of a pathological process. Dr Jaupitre was enabled first to observe, then to analyse thoroughly, some typical symptoms of bilharziasis (brown patches, dilatation of the vesical veins, narrowing of the ureteral orifices due to sclerosis of the trigone) the importance of which had originally been underestimated.

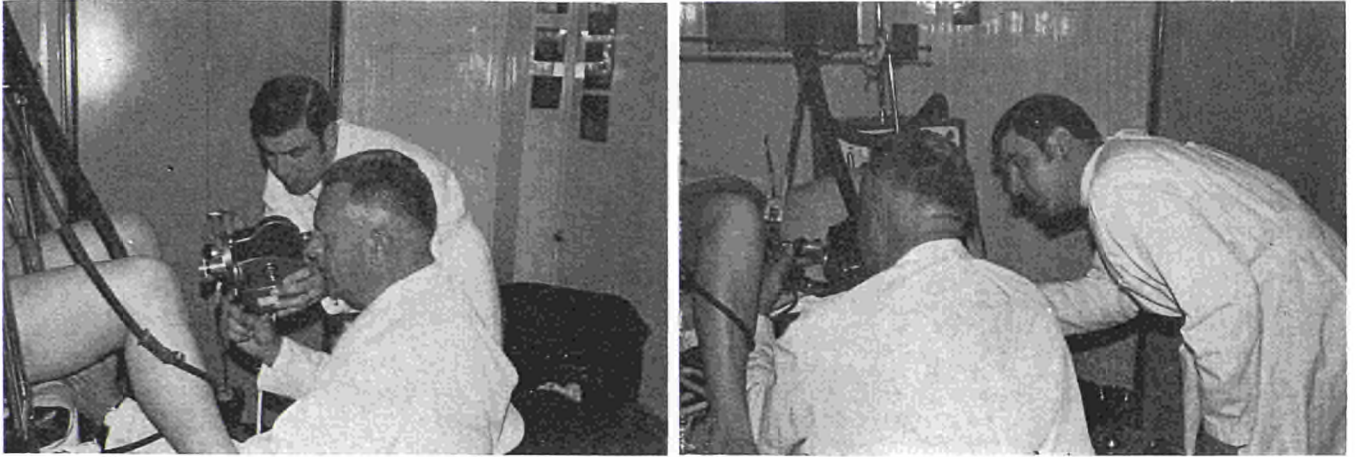
It should be added that complete “first-time” success is achieved in a single session, which rarely lasts more than 10 minutes and which the patient willingly undergoes since it involves no inconvenience.

Also worth mentioning is the fact that the equipment is automatic: all the operator has to do is to align the field and start the camera. The field is controlled by following the image appearing in the reflex viewfinder (or on the TV monitor screen) and making any corrections required, without having to interrupt the sequence.

Physiopathological research, too, is bound to benefit immensely in a variety

Figure 5: A cine-camera with the automatic exposure control and accessories for cine-cystoscopy.





Figures 6 and 6a: *Placing a camera with automatic exposure control on an endoscope preparatory to a cine-urolological examination.*

of fields from the use of such an accurate instrument and from the fact that either speeded-up or slow-motion sequences can be taken. Examples include the investigation of the mechanism of various bladder disorders, the

early diagnosis of cancer and the remote examination of the results of destructive, reparative and plastic surgery. The combined study of cine-endoscopic and cine-radiographic films shedding light on one and the same pathological phenomenon likewise opens up new prospects in medical research.

The great value of films obtained in this way for teaching need hardly be stressed.

Underwater cinematography

There are two major problems in underwater filming: adequate lighting of the field and accurate alignment of the image. The diver is prevented from putting his eye to the eyepiece by his

Table I: *Block diagram of modifications made to the Beaulieu cine-camera.*

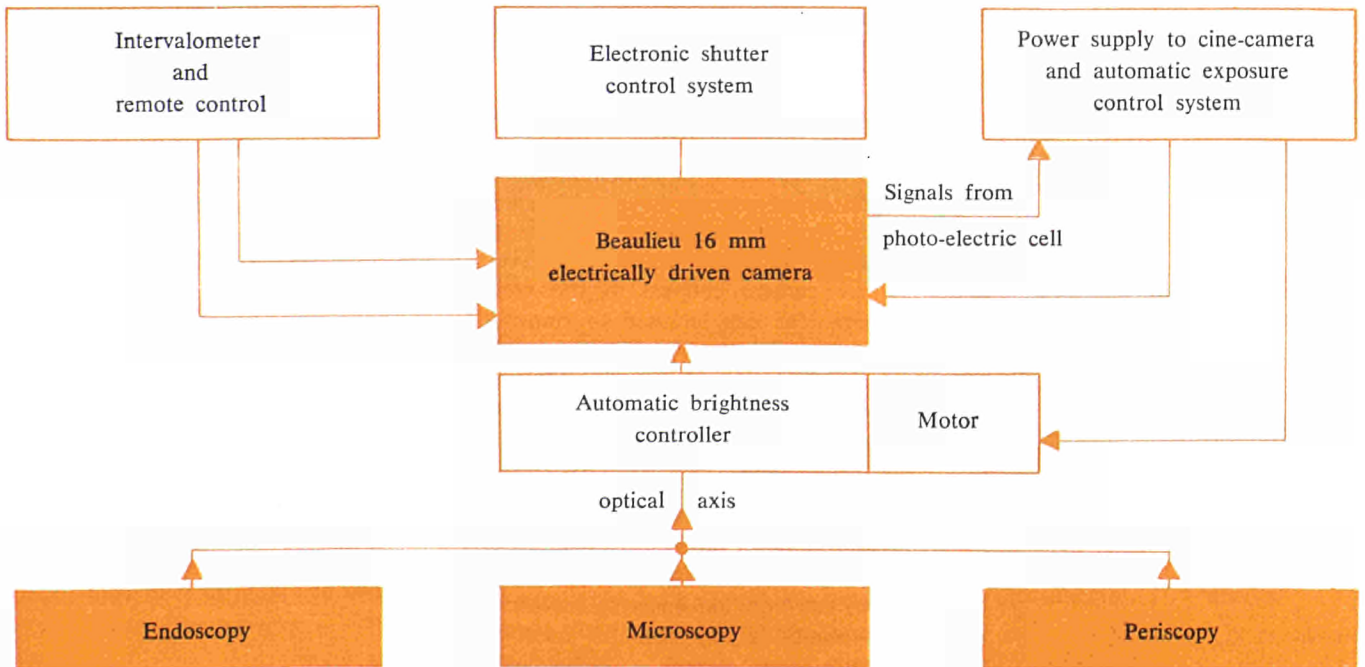


Figure 7: Cine-camera with automatic exposure control. A TV camera is mounted at 90° to the camera in place of the eyepiece. The TV screen shows the image from the transparency placed on top of the camera lens.



mask and by the watertight container housing the camera.

The first of the two difficulties is usually surmounted by using powerful flood-lights, which, however, are bulky, necessitate a mass of complex equipment and disturb the aquatic environment. The only solution hitherto found to the problem of camera/subject alignment was the very rough-and-ready one of attaching a frame, or sometimes two frames, which the cameraman can use as a viewfinder, to the watertight camera container. Obviously, this is hardly a satisfactory solution, especially when a zoom lens is used.

Both these problems can now be solved by placing one or more light amplifiers in front of the cine-camera, which is, of course, fitted with automatic exposure control, in order to amplify the low ambient light level. A TV camera coupled to the cine-camera lens can be used to transmit the image picked up by that lens to a small TV screen located inside the watertight case and opposite a window, through which it can be observed by the cameraman.

The image can also be transmitted simultaneously to the support ship, thus offering a useful means of supervising the diver's work and ensuring his safety. The same facility can be used to monitor and control a cine-camera

housed in a submerged robot operating without human agency.

Versatility of the camera

All the set-ups described above were assembled by Mr De Cat at Petten, using a commercial 16 mm camera. The versatility of this camera enables the range of its applications to be extended. The basic camera had an impressive specification to begin with, which made possible its adaptation for use in the above-mentioned fields. Its features included an electric drive motor with a very wide speed range, very high light efficiency, a very bright reflex viewfinder, and a photo-electric cell mounted behind the lens and scanning the whole of the framed image. A camera based on the original model is to be marketed by the firm Beaulieu. It will feature the automatic exposure control system and provision for the easy fitting, in accordance with the specifications laid down by the Petten Establishment, of the following instruments: optical microscope, endoscope, light and brightness amplifier (for cine-radiography), electron microscope, TV camera, periscope, telescope.

The Commission of the European Communities also intends to lend copies of films produced with the cine-camera developed at Petten to interested firms or users.

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Technical Notes

— 23/C: Single-channel discriminator

This equipment, known as the Model DC2 Single-channel Discriminator, was developed at the Ispra Establishment of the *Joint Research Centre*.

It is housed in an ESONE plug-in module and consists of the single-channel discriminator with means of manual or externally threshold setting.

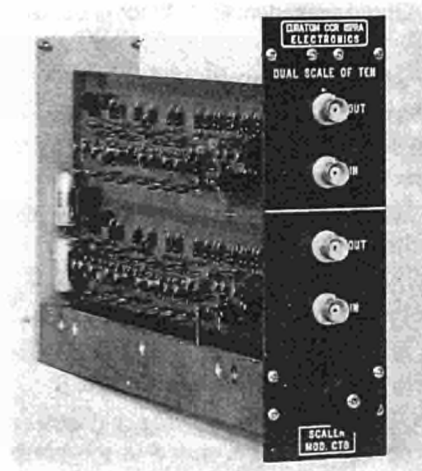
Specification:

Input pulses: negative polarity, 0.1-10.1 V.

Input differentiating time constant: 1 ms, obtained with 1 μ F and 1 kOhm.

Channel width:

- 1) 0.1-2 V, in five fixed steps when using external threshold setting;
- 2) variable within two ranges, 0-1 V, and 0-5 V, when using manual threshold setting.

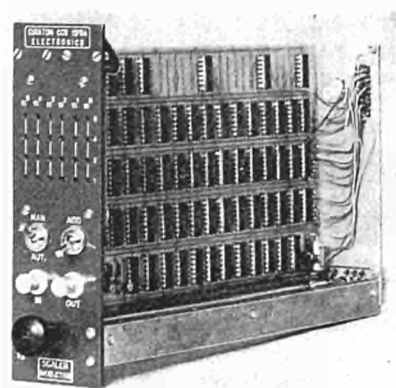


Minimum acceptable time spacing (statistical input: 50 ns). Both decades are used as a divider with no read-out and no output to a printer.

— 25/C: Scaler

This unit, known as the Model CT6B Scaler, was developed at the Ispra Establishment of the *Joint Research Centre*.

It is housed in an ESONE plug-in module, and is an integrated version of the Model CT6A Scaler (see Technical Note 20/C) with which it is interchangeable from the operational angle, though having different power requirements.



Storage capacity: 10^6 counts.

The unit can be manually or automatically controlled.

The Commission's *technical notes* give descriptions of original results obtained under the Euratom research programmes. Their purpose is to enable firms to decide whether they should consider industrialising these results.

On the basis of article 12 of the Euratom Treaty, a non-exclusive licence may be granted on the results covered by patents, in so far as the licensee is in a position to make effective use of these results. The conditions of the licence, as well as the royalties for technical assistance, will, for each individual case, be fixed after joint consultation.

Requests for additional information should be sent to: Commission of the European Communities, D.G. XIII-A, 29, rue Aldringer, Luxembourg.



Threshold drift in the 0-55° C range: less than 1.5 mV/° C.

Channel width drift in the 0-55° C range: less than 20 μ V/° C.

— 24/C: Scaler unit

This equipment, known as the Model CT8 Scaler Unit, was developed at the Ispra Establishment of the *Joint Research Centre*.

The scaler is housed in an ESONE plug-in module, and consists of two self-contained decades which can be used separately. Both are provided with an input discriminator for short pulses (5 ns FWHM).

Input impedance: 1 kOhm, dc coupled.

Dead time, measured with a double pulse, is less than 100 ns.

Maximum pulse recurrence frequency: over 10 MHz.

Sine-wave input signal up to 10 MHz.

Minimum pulse width: 20 ns (at half amplitude and with 6 V pulses).

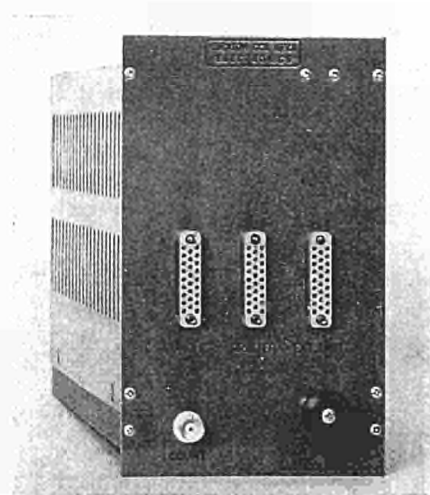
The display is binary coded decimal and obtained with filament lamps.

A switch on the front panel enables the contents to be erased at the beginning of a cycle if desired.

A built-in memory enables existing data to be read and printed out even while another cycle is in progress.

— 26/C: Printer drive-unit

This equipment, known as the Model ST2 Printer Drive-Unit, was developed at the Ispra Establishment of the *Joint Research Centre*.



It is housed in a double ESONE plug-in module. Five CT6-series scalars (see Technical Notes 19/C, 20/C and 25/C) can be connected to the rear panel, one of which can be a base scalar, connected via a timer.

The unit scans all the connected scalars decade by decade and feeds the

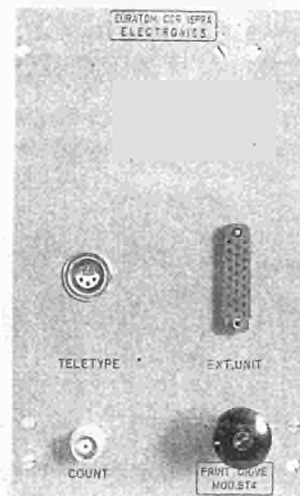
data, in IBM code, to a printer and/or tape punch.

A larger number of scalars can be connected to the ST2 via a corresponding number of UE1 adapter units (see Technical Note 32/C) in an open loop configuration.

The unit is designed to drive an adding machine or electric page printer.

— 27/C: Printer drive-unit

This equipment, known as the Model ST4 Printer Drive-Unit, was developed at the Ispra Establishment of the *Joint Research Centre*.



It is housed in a double ESONE plug-in module. Five CT6-series scalars (see Technical Notes 19/C, 20/C and 25/C) can be connected to the rear panel, one of which can be a base scalar, connected via a timer.

The unit scans all the connected scalars decade by decade and feeds the data to a page teleprinter in ASII code. The standard output current is 20 mA. The parity bit is generated inside the ST4 unit and the character space, carriage return and line feed are added in the required position. A larger number of scalars can be connected by using a corresponding number of model UE1 Adaptor Units (see Technical Note 32/C) in an open loop configuration.

The unit is chiefly designed for use with a model 33TAC Teletype with tape punch and printer.

— 28/C: Decimal scanner

This unit, known as the Model SC2 Decimal Scanner, was developed at the Ispra Establishment of the *Joint Research Centre*.

It is housed in a double ESONE plug-in module, and is used for the step-by-step variation of a voltage.



There is a number of resistors connected up in such a way that when a current is fed to them a voltage can be scanned step-by-step in 101 channels. Five modes of operation are provided:

- 1) upward scanning and stop;
- 2) downward scanning and stop;
- 3) upwards and downwards and stop;
- 4) upwards and downwards indefinitely;
- 5) upwards with fast flyback indefinitely.

The total number of steps can be concentrated into half or a quarter of the total range, thereby increasing the actual number of steps to 200 and 400 respectively.

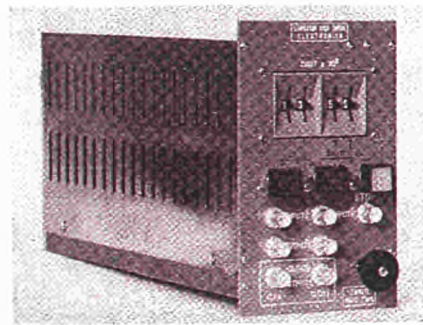
— 29/C: Timer

This unit, known as the Model TM4 Timer, was developed at the Ispra

Establishment of the *Joint Research Centre*.

It is housed in a double ESONE plug-in module.

It consists of a preselection unit operating in conjunction with an external scaler, which acts as a base scaler, and a tuning fork clock providing 10 and 100 Hz output pulses. Two cycles for counting and interval times can be



preselected by means of the switch mounted on the front panel. Both have a significant bit and a multiplier: number from 1 to $9 \cdot 10^{-6}$ can be preselected. An interval of zero can also be selected. The TM4 timer can operate with a preset time or a preset count, depending on the fed into the base scaler (generally one of the CT6 series (see Technical Notes 19/C, 20/C and 25/C). The unit can be started automatically by a built-in switch if the unit is connected to the mains.

Clock accuracy: $\pm 5 \cdot 10^{-5}$ at 25°C.

Stability: better than $3 \cdot 10^{-4}$ in the range 0-45°C.

With a special tuning fork these figures can be improved to $\pm 10^{-6}$ and $\pm 4 \cdot 10^{-5}$.

— 30/C: Logic unit

This equipment, known as the Model CL2A Logic Unit, was developed at the Ispra Establishment of the *Joint Research Centre*.

It is housed in an ESONE plug-in module and is made of two self-contained sections.

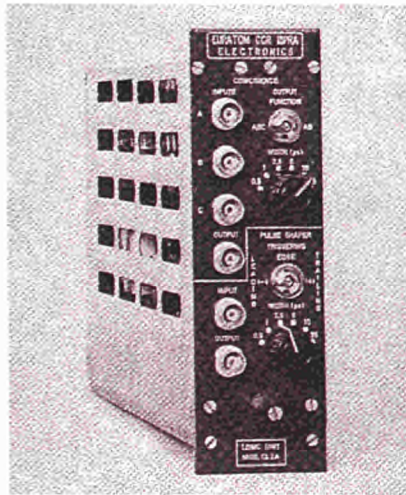
a) Triple-coincidence circuit

Input differentiating time constant: 1 ms, obtained with 1 μ F and 1 kOhm. Output pulse width: adjustable in six steps from 0.5 to 25 μ s.

Fan-out (ESONE): 4.

b) Pulse shaper

Capable of processing negative rectangular pulses. Input differentiating time constant: 1 ms, obtained with 1 μ F and 1 kOhm.



Triggering: on the leading or trailing edge.

Output pulse width: adjustable in six steps from 0.5 to 25 μ s.

Fan-out (ESONE): 4.

— 31/C: Ratemeter

This unit, known as the Model INT6 Ratemeter, was developed at the Ispra Establishment of the *Joint Research Centre*.

It is housed in a double ESONE plug-in module. A total of fifteen measuring ranges is provided, with the time constant decreasing as the counting rate rises. The normal time constant is between 10 and 1 s.

The six upper ranges can operate with a time constant 0.01 s for recording variable phenomena.

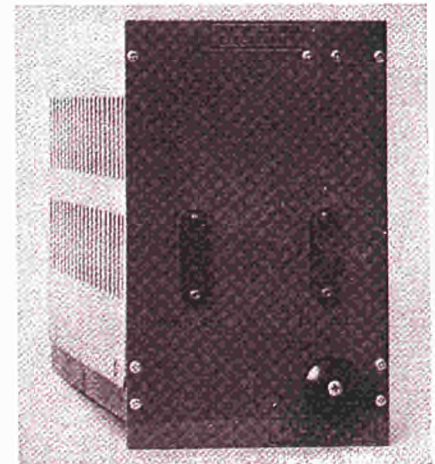
Dead time losses are negligible in the lower range and less than 0.4, 0.8 and 1.6 % respectively in the 10^5 , $2 \cdot 10^5$ and $4 \cdot 10^5$ ranges.

Accuracy is 1 % in the 10-45°C temperature band. Data display in the front panel, or the data can be stored in an external memory, the output for which is 10 mV on a 10 Ohm resistance.

— 32/C: Adapter unit

This equipment, known as the Model UE1 Adapter Unit, was developed at the Ispra Establishment of the *Joint Research Centre*.

It is housed in a double ESONE plug-in module and can be connected to five CT6-series scalers (see Technical Notes 19/C, 20/C and 25/C) and an ST2 or ST4 printer drive-unit (see Technical Notes 26/C and 27/C), or to another UE1 unit.



It raises to five the number of scalers that can be scanned by an ST2 or ST4 unit.

It regenerates all the signals transmitted by the printer drive-unit for scaler and decade selection purposes, as well as the data signals returned from the scalers to that unit, permitting an unlimited number of them to be used in an open loop configuration.

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