euro spectra

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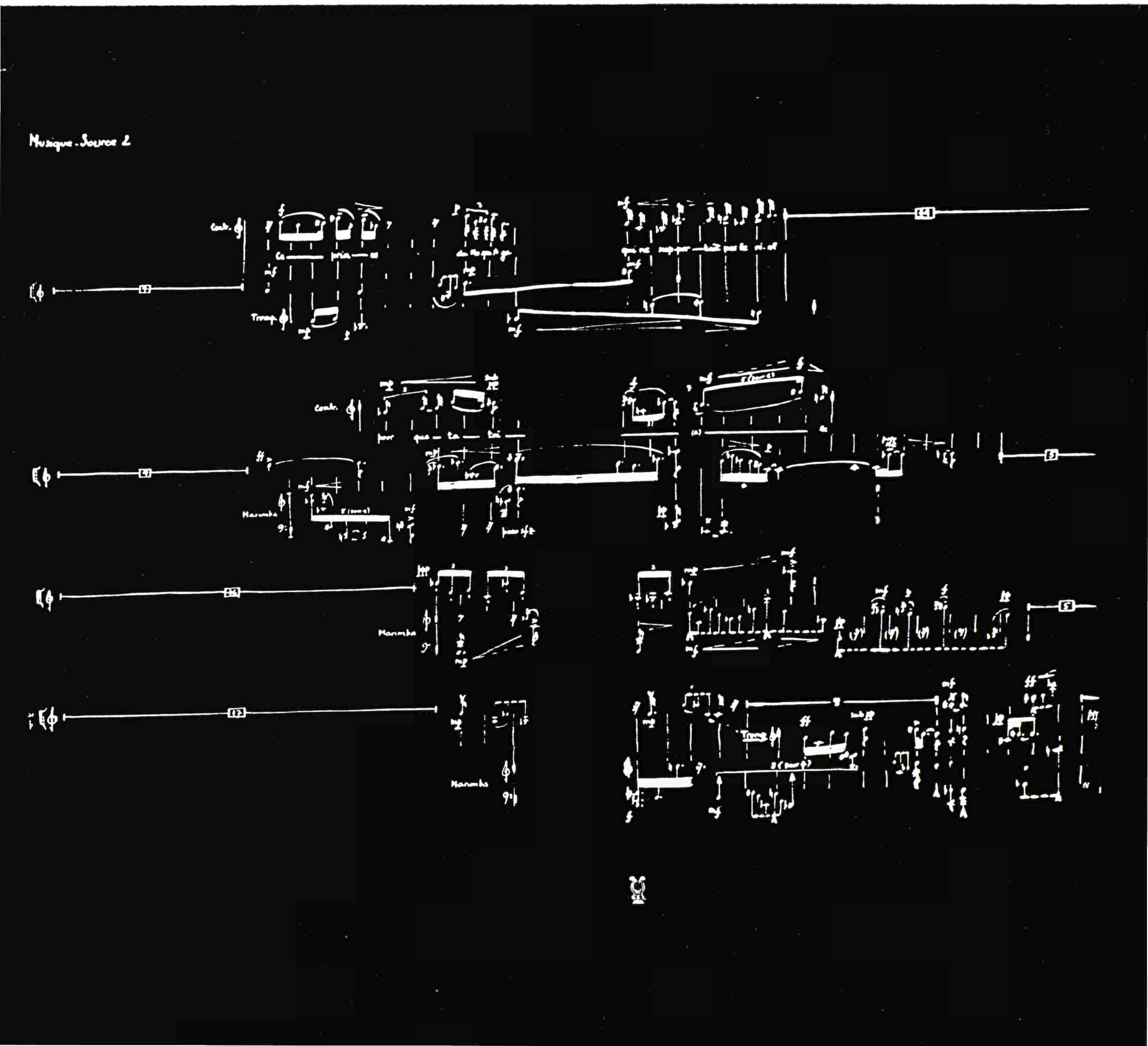

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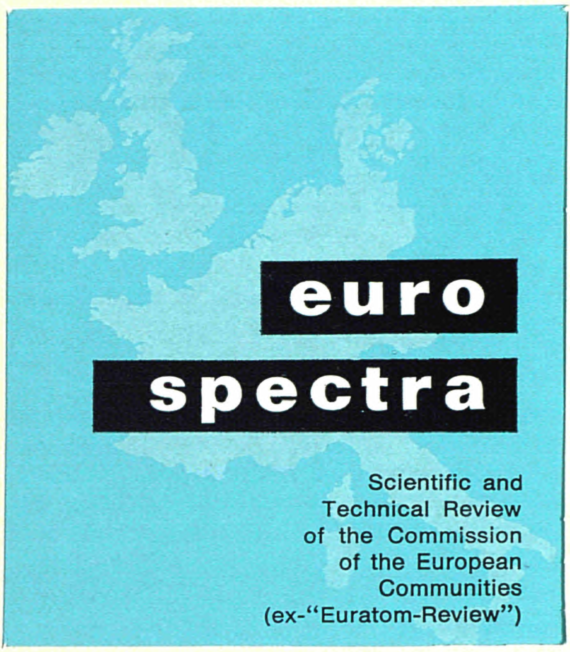

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Picture credits : p. 6 : Ed. Casterman; p. 11 : Xenakis; pp. 24, 25, 27, 29 : CISE.

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This number of "euro-spectra" could have been devoted to the "quality of life". Our readers are in fact presented not only with articles on the cycle of sulphur in the atmosphere and on the still much debated question of the disposal of nuclear waste, but also with one — in our opinion rather original — on computer music, written by one of the composers active in this new field.

Such a variety of topics, however, should, not cause undue surprise, if seen in the light of what is said above. If many, and perhaps too many, of to-day's problems are, owing to their impact on everyday life, a source of countless unhappy meditations, it is comforting to realize that this does not prevent the blossoming of healthful and artistic initiatives which contribute greatly to the very preservation of our "quality of life".

André Riotte who was born in Paris in 1928, studied composition first with Arthur Honegger and then with André Jolivet. Olivier Messiaen's lectures on musical analysis opened up new perspectives which be studied more deeply with Jean Barraqué. It was through Barraqué that he became aware of the importance of the Viennese School. In 1962, after a long search for a material richer than the classical sequence, he defined the concept of the balanced cycle, which was the application of a series of intervals on a series of pitches.

André Riotte is also an electronics engineer trained in data processing. He worked for four years as the assistant to the head of the Data-Processing Centre at the Euratom Joint Research Centre at Ispra, Italy. There he used the computer to calculate every possible balanced cycle, including cycles of derived intervals, and to analyse their formal characteristics.

Several of his works have been performed in the principal European countries (France, Belgium, Germany, Italy, Spain, Portugal and Switzerland) and in the United States.

While perfecting the writing technique derived from balanced cycles, which he developed when composing works like "Perspectives 360 for String Quartet", André Riotte realized that his musical poetics was founded on a new concept of form. Thereafter his ambition was to create "Etres Musicaux", Musical Beings, with the twin characteristics of unity and constant renewal. His twofold training as composer and computer expert enabled him to formalize the language and the structures which he used. But when he used a computer it was as a combinatorial tool and not as a machine for random creation. Speculation on forms allowed him to enlarge his framework wherein he selected the immediate, the priviledged event which embodies these forms, and to multiply their possibilities without losing control over them.

André Riotte's work as a data-processing engineer enables him to stay clear of any naive infatuation with the new computing techniques and facilities.

He is aware of the variety of possibilities offered in this field and took part in the study group on Musical Mathematics organized by Xenakis, but he remains convinced that a new Art can only be synthesized by man as a complete being, that it must go beyond formalism and technique and rest upon a new conception of open forms, as close to life as possible.

ANDRÉ RIOTTE

Works significant for the context:

Music for the film "From one world to another" a documentary film about the Euratom Research Centre at Ispra, for 13 instruments	*(1965)*
"Jubilation Heuristique", for contralto, clarinet, trumpet and marimba	*(1968)*
"Orbitales I and II", for piano	*(1970)*
"Perspectives 360", for String Quartet	*(1971)*
"Edre Musical", for 15 instruments	*(1971)*
"Suite explicite", for clarinet	*(1973)*

Computer Music : a new meeting-point of art and science

AS FAR BACK in time as we can trace, the civilizations which have practised music have always associated it with numerical relationships; the resonance of a bowstring was discovered by a hunter and the birth of metrics (the division of a length into equal parts) made man aware of "natural" harmonic intervals. It took the mind of a physicist to discover that a sound of specific pitch is a periodic phenomenon, but rhythm itself, as the relative disposition of sounds in time, was born of "discerned periodicity" at the very outset.

It was natural that, after a long eclipse, this correspondence between music and numbers return to the fore in an age when the very foundations of four centuries of music, the products of which still form the basis of musical education in the Western world, were being questioned, and when a powerful new instrument based on the ultra-rapid manipulation of numbers, i.e., the computer, was making its appearance.

After being dissociated from their common origin, namely the quest for understanding of the absolute being, which has guided metaphysics throughout the ages, Art and Science are now tending to become once again the two sides of the same spiritual adventure. This reconciliation implies the disappearance of the barrier of incomprehension which has separated them as humanist attitudes since the Renaissance. The digital computer was born in answer to a physicists' need; its use has taken the form of a new branch of science, now known as data processing. But the fusion between Art and Science had yet to take place, and only men trained in the two disciplines, combining a scientific training with musical interests, could attempt to achieve it.

ANDRÉ RIOTTE - Directorate-General for Industry, Technology, Science and Research, Commission of the European Communities.

The use of the computer for musical or musicological purposes began as a series of modest experiments, among which one of the most important examples of the automation of a composition model from existing material was D. A. Caplin's programming (towards 1955) of the game of dice conceived by Mozart in 1780 for composing waltzes from short, compatible sequences. Since then, experimentation has developed gradually as data-processing methods have become established and applications more varied.

The object here is to give an outline of the present state of the nascent discipline of computer music; the abundance of literature on the subject means that we can refer only to a selection of texts and works, notably those in which the reader will be able to find additional book references or more detailed basic information. Very few sound recordings are available as yet, however.

Music and the exact and experimental sciences

Music is related to the sciences at several different levels. Discounting historical evolution and the fact that these levels are mutually influential in many ways, it is possible, for clarity's sake, to begin by differentiating between them even if they must be recognized afterwards as interdependent.

The first and most concrete level[1] (1) is the production of the sound itself; this used to be the work of instrument makers, now it has also become that of electronics engineers (the ancestor being the Martenot instrument, 1928), the enthusiasts of *musique concrète* and electronic music, and finally the computer experts who create music by signal sampling, digital-analogue conversion and transformation into direct or recorded sound waves. This level also includes analytical studies of musical signals from the acoustic or sensory point of view, which fall chiefly under the heading of physics (vibratory phenomena) and digital analysis (differential systems).

The second level (3) concerns the spatial limits of music, i.e., quantification of the pitch of sounds to be given preference in the continuous spectrum of audible frequencies, subdivisions of time in relation to a pre-established metre (durations being countable). Music theorists, from Pythagoras to Xenakis, devoted their greatest attention to the choice of sound scales because their object was to reconcile a rational subdivision with natural harmonies. Since the time of Rameau, composers have primarily endeavoured, using the existing scales, to define what seemed to them the most meaningful combinations of sounds, and have in most cases determined the distances between these chords intuitively.

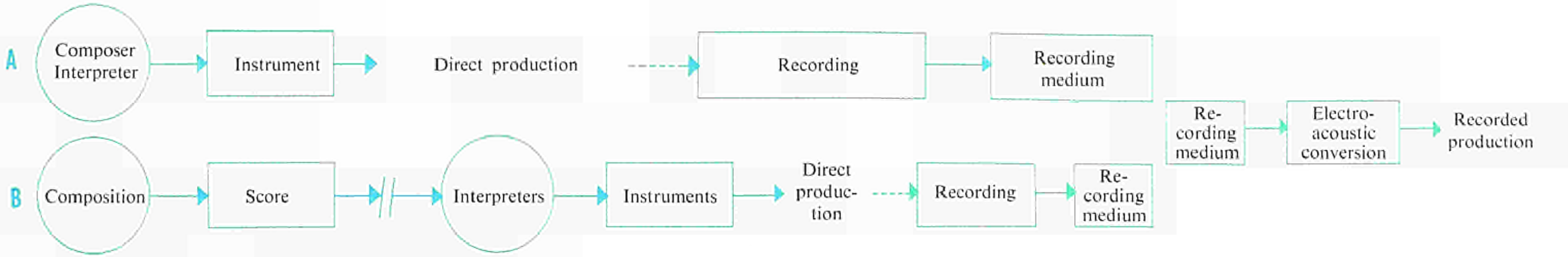
In contrast, the formalism of the length of notes is still relatively unexplored beyond the conventional binary system. It is modern algebra (the theory of sets—groups, congruences and graphs) which will provide the most effective tools for research at this level.

Analytical studies of musical forms (5) have taken various paths: some composers have made detailed studies of the structure of certain key words (Stravinsky's "Rite of Spring" by Boulez, Debussy's "La Mer" by Jean Barraqué) and questioned the characteristics of their own language (Olivier Messiaen). But the development of new theories, such as information theory and the resulting statistical studies, the theory of formal languages and the problems connected with artificial intelligence, has in each case opened the way to analytical studies with varying degrees of success.

Musicology has also begun to make use of the resources of information retrieval (bibliography, listing on particular subjects, etc.).

Finally, there is the level of the conception of actual musical forms, which is the keystone to the whole problem. It should be pointed out that theses dealing with purely musical concepts (harmony, counterpoint, fugue and composition) rarely went beyond strictly didactic considerations: they were collections of *ex cathedra* statements, limited to describing "what should not

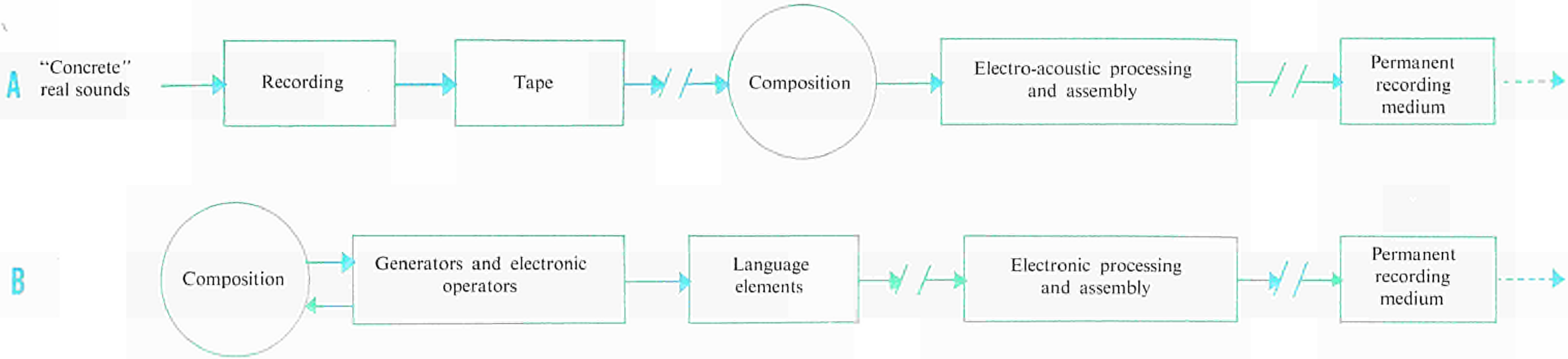
[1] The numbers in superscript correspond to the various subdivisions of the bibliography; the letters refer to the individual publications listed in these subdivisions.



NB : The symbol →//→ indicates an unspecified caesura in time.

Fig. 1 : *Classic composition and interpretation in direct or recorded production.*

Fig. 2 : Musique concrète *and electronic music.*



be done", to asserting that this or that sequence is better than another or to compiling summaries of conventional forms. There are of course some exceptions, but even today a detailed study of musical forms remains to be made.

However, although this level remains closely connected with the previous one, data processing can play a decisive role in the describing of forms. Since the composer must describe the bases of his language and formalize them in order to convert them into computer programs, a new attempt at precise description is now emerging which should open the way for a true structural approach to musical creation.

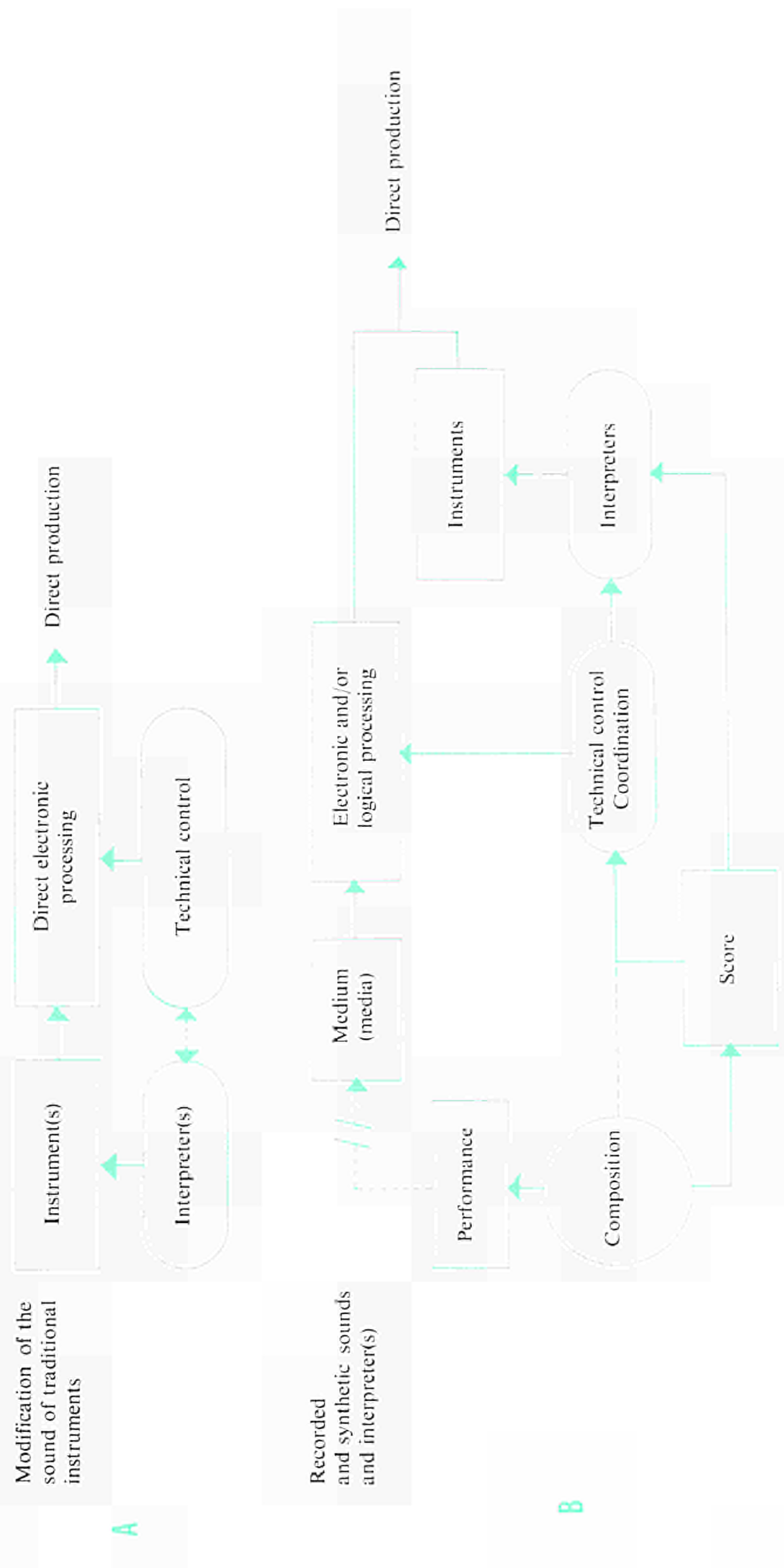
Whether or not they have a "scientific" bent, several composers who play an influential role in present-day music have been led to define their formal concepts without any hint of post-romantic subjectivity (5. a, b, c, d). And this is precisely where the need is felt for a formal language which is unambiguous and concise; since the task is to define transformation operators applied to families of complex objects which can themselves be described in parametric form, it is clear that mathematics and its most modern developments are the correct instrument for the purpose. But the field is admittedly relatively unexplored.

The introduction of technology into music: the role of electronics

The widespread use of electronics in everyday life in the West (radios, record-players, tape-recorders, etc.) and in particular of devices for broadcasting sound, and therefore music, has led the main broadcasting stations to set up sophisticated electroacoustic laboratories (*RTF* in Paris, *RAI* in Milan, Westdeutscher Rundfunk in Cologne, the Liège Centre, etc.). These centres of research on the handling of sound by electronics have played a major role in the evolution of the concept of tone and greatly influenced the essential meaning which composers attach to musical creation, even those trained in the traditional school.

During the classical era, apart from a few anecdotal exceptions such as Haydn's "Toy Symphony" or Berlioz's "Artilleries", music used only sources of sound, i.e., musical instruments, which were designed to retain their qualities through-

Fig. 3 : *Variations : electronics in sound production.*



out time and space. Basically, a violin was regarded as "equivalent" to another violin, for the criteria of sound quality and virtuosity of use were considered apart from the other criteria.

A musical work originated from a model symbolized by the score, performances of which would only differ from the instrumentalists' point of view in terms of subdivisions (playable or not playable) and from the listeners' point of view in terms of a modulation of tempo, referred to as "interpretation", when the other characteristics of the model (timbre, accuracy, dynamic proportions) came within a range regarded as sufficiently close to the original.

Musique concrète, which was developed chiefly by Pierre Schaeffer in the laboratories of the *ORTF* in the fifties, changed this situation in that it tried to restore to each complex sound, captured from the world of sound enveloping us, its own personality and its irreproducible qualities, whilst producing from it, by

Photograph 1: *from A. Moles: "Art and Computer", "Synthèses Contemporaines", Casterman, Tournai (Belgium), p. 189, 1971.*

INSTRUCTION

pour composer des Valses par le moyen de 2 Dèz sans avoir la moindre connaissance de la Musique ou de la Composition

1. Les Lettres A-H qui sont placées au dessus des 8 Colonnes des Tables de nombres, montrent les 8 Mesures de chaque partie du Walzer. Par Exemple : A. la première, B. la seconde, C. le troisième, etc et les nombres dans la Colonnes dessous les lettres démontrent le nombre de la mesure, dans les notes.

2. Les nombres de 2 jusqu'à 12 montrent la somme du nombre qu'on peut jetter.

3. On jette donc par exemple pour la première Mesure de la première partie du Walzer avec deux dèz 6 et cherche près du nombre 6 dans la Colonne A. le nombre de la mesure 148 dans la Musique. L'on met cette mesure sur le papier et voila ce qui fait le commencement du Walzer. Après cela on jette pour la seconde Mesure p. c. 9. on cherche près de 9 sous B. et on trouve N°. 81 de la table de musique. L'on met cette mesure a coté de la première et l'on continue ainsi jusqu'après avoir jetté les dèz huit fois, et alors on a achevé la première partie du Walzer : ensuite on fait le signe de répétition et commence 2d partie. Veut on avoir un Walzer plus long, on recommence de la même manière, et ainsi cela va a l'infini.

Table de Chiffres

Première Partie

	A	B	C	D	E	F	G	H
2	96	22	141	41	105	122	11	30
3	32	6	128	63	146	46	134	81
4	69	95	158	13	153	55	110	24
5	40	17	113	85	161	2	159	100
6	148	74	163	45	80	97	36	107
7	104	157	27	167	154	68	118	91
8	152	60	171	53	99	133	21	127
9	119	84	114	50	140	86	169	94
10	98	142	42	156	75	129	62	123
11	3	87	165	61	135	47	147	33
12	54	130	10	103	28	37	106	5

TABLE de MUSIQUE.

Mozart. Würfelspiel. **(Jeu de dés).**
La méthode imaginée par Mozart pour composer des mélodies en jouant aux dés sur une table spéciale des mesures successives de la partition montre que de très grands compositeurs ont eu une idée claire de l'intervention de l'aléatoire dans la structure d'ensemble du message musical. Il est vraisemblable qu'ils auraient accueilli avec intérêt les essais récents de composition de la musique à la machine.

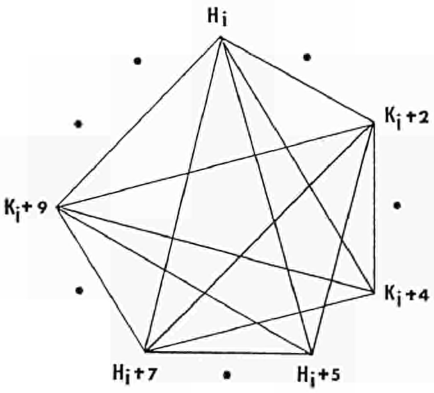
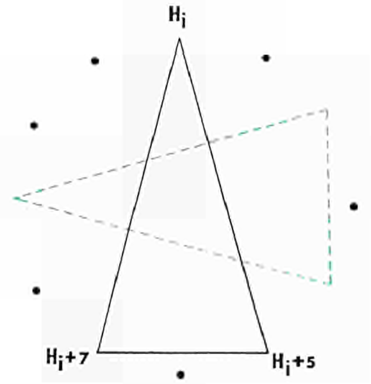


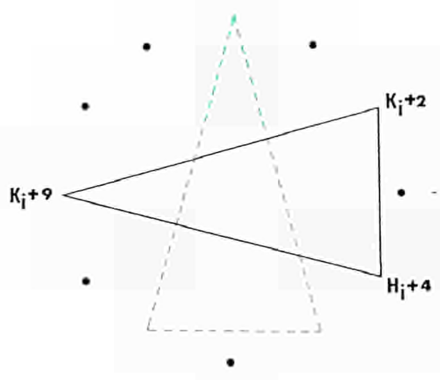
Fig. 4 : *Symmetrical graph of the non-modulating tonal pathways in "i major".*



I

Sub-graphs of the tonic, sub-dominant and dominant relationships:

I) in "i major";



II

II) in the relative minor of "i major".

---

means of various electronic processes (filtering, flattening, loops, mixing, etc.), derivatives peculiar to the work itself to provide the bases of its language.

In the most successful cases this gave a new importance to complex sounds, introducing a continuous frequency spectrum which had hitherto been found only in the percussion family of the traditional orchestra. Incidentally, there has been a revival and considerable extension of the use of percussion instruments in the scores of the last 20 years.

Electronic music, of like origins, was founded on a completely different basic principle: the composer using sinusoidal waves emitted from electronic generators, tended to retain only the most amorphous, reproducible elementary component of the sound, proceeding thence by a succession of syntheses, collages and continuous variations of frequency; this principle thus updated, if only in an elementary fashion, the relationship between sound and continuity. But there was another snag: to synthesize a sound with a specific tone it is necessary to combine a large number of sustained frequencies, its attack is characterized by a difficult and complex transient. To reintroduce the characteristic features of transients it was necessary either to accept incomplete, experimental solutions, already carried out by electronic instruments of limited scope (Martenot waves, electronic organs, etc.) or to use methods, which could only be guaranteed to work when very great technical skill was applied.

Of course, any division between *musique concrète* and electronic music would be arbitrary; the two techniques were very quickly amalgamated and the majority of the present compositions make use of both.

There is another way, exploited more particularly by Karlheinz Stockhausen, which consists in acting *in situ* upon the sound of existing instruments by means of electronic operators which are controlled precisely or approximately (potentiometer, ring modulation by means of periodic generator waves, active or passive filters, time lags, etc.)[2].

Some soloists have even built up a complete set of equipment around their instruments, thereby multiplying the effects which they can obtain (cf. the Dutch oboist, Evert Van Tright, for instance).

The commonest of these effects have been distinctly successful in the field of popular music, and "synthesizers" including generators, filters, modulators, mixer keyboards and panels are now sold everywhere on the American market.

---

2 For example:
Mikrophonie 1 (1965) for tom-tom, 2 microphones, 2 filters, potentiometers - Karlheinz Stockhausen.
Mikrophonie 2 (1965) for choirs, Hammond organ and ring modulators - Karlheinz Stockhausen.

The arrival of the computer

The use of electroacoustics and electronics in music, which has been developing for the last twenty years, has helped to bring art and technology together; but the main object was to obtain new means of sound production. Although a reaction was inevitable regarding the conception of musical forms, the speculation did not concern the works themselves.

As is quite natural in a period of research into acoustics, sound usually received more attention than structure. Each auditive choice was shaped with extreme precision, which is a good thing, but was carried to interminable lengths, which is not so good. The supposedly felicitous shock, relic of a past creed, was with few exceptions (Stockhausen, for example) the principle that shaped hesitant forms and froze them with their weaknesses disguised as qualities.

But with increasing contacts with advanced technology, new questions were asked. Even if information theory did not provide the anticipated ferment, because of its over-simplistic understanding of the message whose significant structures it ignored, it weakened the boundaries between art and the pure and applied formalisms which were developing—i.e., the theory of control mechanisms, analogue computing and problems of artificial intelligence.

Sets, groups, congruences, graphs, probabilities, combination became the musician's tools of trade and this resulted in a new appetite for strictness and economy in describing musical phenomena.

In about 1955 a computer was used by D. A. Caplin for an early composition already referred to, the programming of Mozart's "Musikalisches Würfelspiel".

But it was Lejaren Hiller who, with Isaacson, produced the first computed "work", the Quatuor Illiac, at the University of Illinois in 1957. This set of experiments, based on the filtering of numbers taken at random by elementary rules of tonal and then atonal catenation, was far from convincing in its musical quality. In 1963 Hiller devised, with Baker, a program called Musicomp which laid down a set of processes, based on the same principles, from which the user could choose (6. e).

In 1959 Mathews, Pierce and Guttman began research into the synthesis of sounds at the Bell Telephone Company, using a digital/analog converter as the output device. They then prepared a program ("*Music IV*" for *IBM* 7094, followed by "*Music V*" for *GE* 645) the input language of which consists of blocks simulating wave and logical function generators which virtually provide the musician with an electronic laboratory free from the hazards attached to any kind of equipment (7. b).

In Paris, Pierre Barbaud produced his first computer opus in 1960 and developed a technique based on the use of algorhythms and groups of permutations. He also worked out a detailed formalization of tonal harmony derived from the theory of groups, which has a definite didactic value (5. e).

Iannis Xenakis, a composer, an engineer by training and an architect has, since the time of his early works, resolutely depended on mathematical formalization; Pythagorean by birth (he is Greek), he had a feeling and a taste for evolving sound volumes. In order to control a profusion of events he used the theory of probabilities, which enabled him to direct clouds of sound in which the systematic use of *glissando* opened up the still unexplored field of pitch continuum.

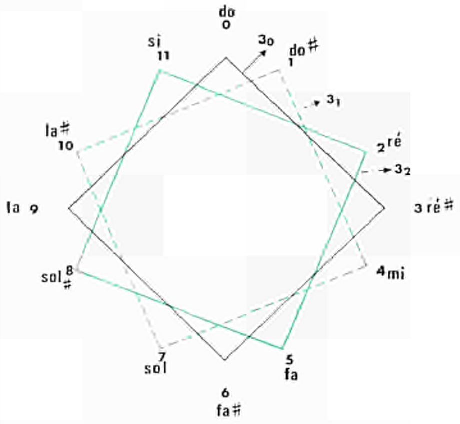
A faculty for abstraction, rare in a composer, enabled him to extend his means of expression by using other areas of modern algebra. It was natural that he should come round to using computers; and 1961 saw the performance of his first work generated by a program, *ST*/10-1, developed from the model of an earlier work, "Achorripsis".

The model, based on the theory that a piece of music requires a minimum of composition rules, consists of a bidimensional matrix each compartment of which specifies, for one unit of time, the family of instruments, the type of event and the average density, distributed stochastically by applying Poisson's law, whence the name stochastic music (5. a, d).

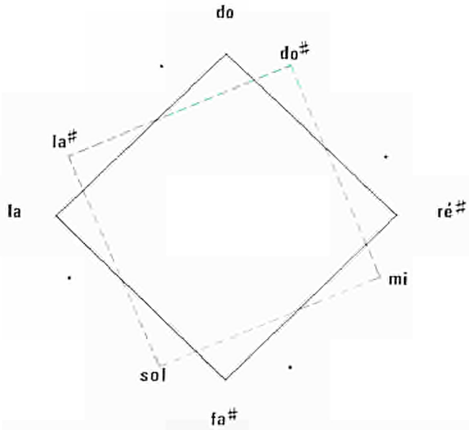
In 1964 Gottfried Koenig, the artistic director of the electronic music studio of the University of Utrecht, began working on a program:Project 1. Written in Algol 60, Project 1 was devised in blocks assigned to the main sound parameters. In each block the passage from the maximum variation of the parameters to a certain level of repetition is pre-programmed. A new version, Project 2, increases the possibilities of this method (7. e).

Alan Sutcliffe, when working as head of a programming department in the British firm *ICL*, also built his own program, *ZASP*. It is based on the fixing of distances between short random

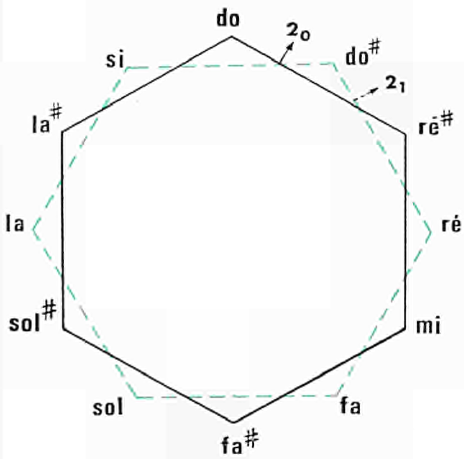
Fig. 5:



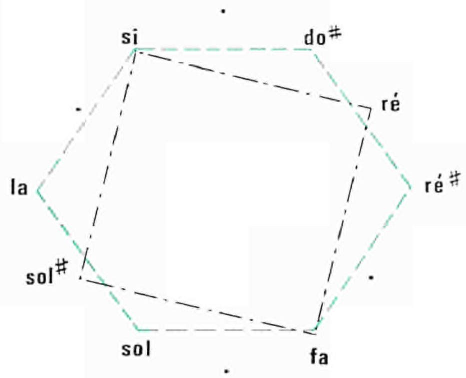
The three classes of base-3 residues.



Example of the formalization of the 2_1 mode used by Olivier Messiaen: $3_0 \cup 3_1$.



The 2 classes of base-2 residues (Debussy's tone scales).



Example of formalization of the mode used in Dualités (A. Riotte, 1964)

$2_1 \cup 3_{i+1}$ $i = 0, 1, 2, 3$

For this figure $i = 1$.

sequences in order to get closer to the notion of structural variation; its chief limitation is that the output cannot be modified during computing.

On the other hand, it allows the fine subdivision of pitches (90 in an octave) and can therefore be translated into electronic sounds; it was one of Sutcliffe's *ZASP* compositions, produced in collaboration with Peter Zinovieff, whose studio is automatically controlled by a small computer, which was awarded a prize at the *IFIP* "Computer-Composed Music Contest" congress in 1968 (6. g).

Other approaches have been used: Pietro Grossi, head of the Studio di Fonologia Musicale at the Conservatorio L. Cherubini in Florence, first studied the occurrence of frequencies of electronic signals and then became involved in the acoustic transformation of existing scores by means of algorhythms chosen from a console. He compiled the program DCMP which synthesizes sounds from a memorized score (7. c).

The author of the present paper has used the computer since 1962 to determine every possible series of sounds meeting criteria of maximum variation of both sounds and intervals, and to classify them into subsets according to harmonic relationships. Using this material, christened "balanced cycles", he has since written his works without any other form of automation simply confining himself to formalizing the principles of concatenation (6. a, c).

Many more specific works have been developed in recent times; examples are the statistical studies of musical styles by Professor W. Fucks at Aix-la-Chapelle, Gabura at Toronto and Mendel at Princeton and studies on analysis and synthesis of folk music styles in Russia (Zaripoff, Gutchin) and in Hungary (Ferentzy).

Finally, mention should be made of the use of a small computer for automating the control of equipment in an electronic music studio, which was achieved by Peter Zinovieff in London, Knut Wiggen at the Electronic Music Studio in Stockholm and Max Mathews and Dick Moore at the Bell Laboratories in New Jersey. A more complete historical account goes beyond the scope of this article; see bibliographical references (in particular 6. b and 6. c).

AN OUTLINE OF FORMALIZATION PROBLEMS

If one accepts the subdivision of frequencies from a unit interval $2^{\frac{a}{n}}$, in which the integer n represents the number of intervals contained in one octave and the integer a each of the degrees used, all sound scales of "equal temperament" may be regarded as the set Z_n of the fractions

$$Z_n = \left\{ \frac{a}{n} \right\}$$

The first term or lower limit will represent the frequency of the deepest sound used, i.e., $X \cdot 2^{\frac{o}{n}}$. By means of a modulo-n congruence, based on the fact that the ear senses an immediate relationship between 2 sounds separated by a whole number of octaves, the terms of Z_n are brought within a single octave and the bijective application of the corresponding frequencies on the integers $a = 0, \ldots, n - 1$ makes it possible to represent the chosen scale

$$Z_n = \{ 0, \ldots, n - 1 \}$$

n = 12 for the traditional tempered chromatic scale;

n = 24 for the scale in quarter-tones;

n = 72 for the Aristoxenian scale, etc.;

Z_n is a commutative group in terms of the law of addition (transposition in musical terms).

For:

1) The application is associative:

$\forall a, b, c \in Z_n \; (a + b) + c = a + (b + c)$;

2) There is a neutral element:

$a + 0 = 0 + a = a$;

3) Each element allows a symmetric expression:

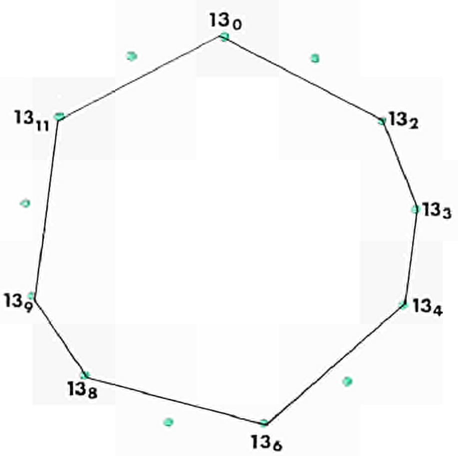
$\forall a \in Z_n \quad a + a^{-1} = a^{-1} + a = 0$.

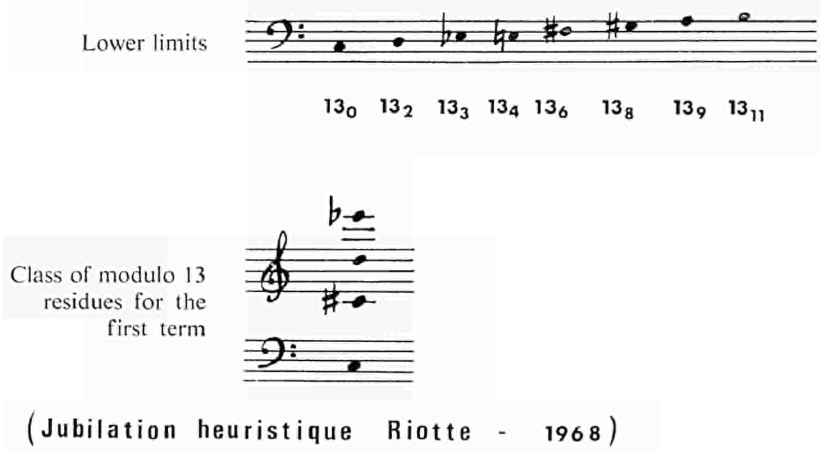
This law is defined everywhere as:

$\forall (x, y); x, y \in Z_n \quad (x + y) \in Z_n$

It is therefore possible to formalize subsets, more especially of Z_{12}, which

Fig. 6:
Non-octaviant scale with modulo 13 congruence.





have a special musical significance, such as:

$P_4 = \{ 0, 3, 6, 9 \}$ scale in minor thirds or diminished seventh chord,

$P_6 = \{ 0, 2, 4, 6, 8, 10 \}$ tone scale adopted by Debussy.

These subsets are subgroups of Z_{12}; for

$$\forall x, y \in P_i : x + y \in P_i$$

The major scale $P_M = \{ 0, 2, 4, 5, 7, 9, 11 \}$ is not a subgroup of Z_{12}.

It may, for instance, be regarded as the combination of three subsets $H_0 = \{0, 4, 7\}$; $H_5 = H_0 + 5$; $H_7 = H_0 + 7$, which are the three perfect major chords constructed on the tonic (0), the subdominant (5) and the dominant (7). Similarly, if $K_i = \{ i, i + 3, i + 7 \}$ represents a perfect minor chord, the three possible forms of the minor scale relative to C major will be obtained by means of the logical expressions:

$P_m = H_2 \cup H_4 \cup K_9$ melodic form

$P_n = K_2 \cup H_4 \cup K_9$ harmonic form

$P_p = K_2 \cup K_4 \cup K_9$ modal form.

If one constructs the subset $T_i = \{ H_i, K_{i+2}, K_{i+4}, H_{i+5}, H_{i+7}, K_{i+9} \}$, it describes all the perfect chords existing in the "tone" i.

For the relative minor the subset will have to be extended $T'_i = \{ H_i, K_{i+2}, H_{i+2}, K_{i+4}, H_{i+4}, H_{i+5}, H_{i+7}, K_{i+9} \}$.

It is then possible to describe:

a) the probabilities of transition from one chord to another in the form of a double input table which corresponds to a particular tonal style; the possible routes are represented by a symmetric graph (Fig. 4);
b) modulations can likewise be represented by the probabilities of transition from common chords, which connect the i and k graphs by arcs.

For example:

$$T_i \cap T_{i+2} = \{ K_{i+3}, H_{i+7} \}$$

This formalization allows us to deal with the traditional tonal styles (5. e, 6. h). However, one may wish to define other scales of modulo-12 congruence (see 3. b); the cribbles theory provides a concise formulation of all modes with internal symmetry. By using the classes of residues with base 2, 3 or 4 (Fig. 5) and their logical combinations, we obtain, for instance for Olivier Messiaen's three modes "with limited transpositions" (type 2 modes), the expressions:

Mode $2_1 = 3_0 \cup 3_1$; Mode $2_2 = 3_1 \cup 3_2$ Mode $2_3 = 3_0 \cup 3_2$ and Modes $6 = 2_i \cup 3_{i+1}$ $i = 0, 1, 2, 3$[3].

More complex scales, which either make use of a fine subdivision of the cyclical or non-cyclical scale of frequencies or correspond to a different congruence of the octave, may be represented by more elaborate logical combinations. We could quote the use of a modulo-13 scale M_{13}, and its complement N_{13} such that $M_{13} \cap N_{13} = \Phi$, applied to all the sounds of the tempered scale without further use of injection in the octave (Fig. 6)[4].

Formalism derived from the theory of sets may also be used for post-serial language.

Let $A_1 = \{ a_1, a_2, ..., a_k, ..., a_{12} \}$ an ordered sequence of 12 elements $a_k \in Z_{13}$ and $D_1 = \{ d_1, d_2, ..., d_i, ..., d_{12} \}$ an ordered sequence of 12 elements such that the d_i can be deduced from the a_k by the expression:

$$d_i = a_{i+1} - a_i \pmod{12} \quad d_i \in Z_{12}$$

The d_i represent the intervals between successive sounds.

If $a_i \neq a_j, \forall i \neq j, \forall a_i, a_j \in Z_{12}$ we say that A_1 is a series of pitches.

If $d_1 \neq d_j, \forall i \neq j$, except for one $i = 6$ (doubling of the augmented fourth interval) we say that A_1 is a cycle of intervals.

If $a_i \neq a_j, \forall i \neq j, a_i, a_j \in Z_{12}$ and $d_i \neq d_j, \forall i \neq j$, except for $i = 6$, we say that A_1 is a balanced cycle.

The set of existing balanced cycles has been calculated by program (6. a).

Let the transformation be Φ defined on the symmetrical group S(E) made up of the 12! permutations of the elements of Z_{12}:

Let $\varphi_1, \varphi_2 \in S(E)$. $\varphi_2 = \Phi(\varphi_1)$ if and only if the image φ_2 is obtained by applying a cyclical permutation to φ_1.

The set of transformations $F = \{ \Phi, \Phi^2, ..., \Phi^{11} \}$ divides S(E) into 11! classes of equivalence.

---

[3] Basic mode of "Dualités pour violon et piano", by André Riotte. Production at the Théâtre des Champs-Elysées 1964.

[4] Modes used in "Jubilation Heuristique", a variable musical milieu, by André Riotte, Galerie Entremonde, Paris 1968.

It can be shown that the application of Φ^k to a balanced cycle also gives a balanced cycle (Fig. 7). This property makes it possible to define a group U, obtained from E by the bijections:

– $E \rightarrow E + g \quad g \in Z_{12}$

– $u: g \rightarrow g^{-1}$, application of E on itself.

U commutes with Φ and may thus be considered as a quotient group of Φ_0 U, which comprises 288 elements.

These properties make it possible to define a concatenation operator on U which provides cyclical chains of particular properties.

Finally, it is possible to analyse the internal symmetries of a balanced cycle. Let us take, for instance, cycle No. 357[5]. The distribution of odd and even intervals shows the transpositions (rotations) and reversals (symmetries in relation to diameters) which retain or reverse the order of the intervals (Fig. 8).

This brief description gives some idea of the new resources open to the composer for structuring his material and establishing the relationships. It is easy to imagine that this type of formalization lends itself to computer processing, and may be extended to the other components of sound (duration, intensity, attack).

[5] Basic cycle of the String quartet "Perspectives", by André Riotte, unpublished.

Present teams and tendencies

Whether it is considered from the physical, psychological or expressive point of view, reality can be partially described on the basis of hypotheses which endeavour to anticipate certain results in given circumstances.

In order to move closer to reality, observation and speculation set up an alternating dialogue; this is the scientist's approach.

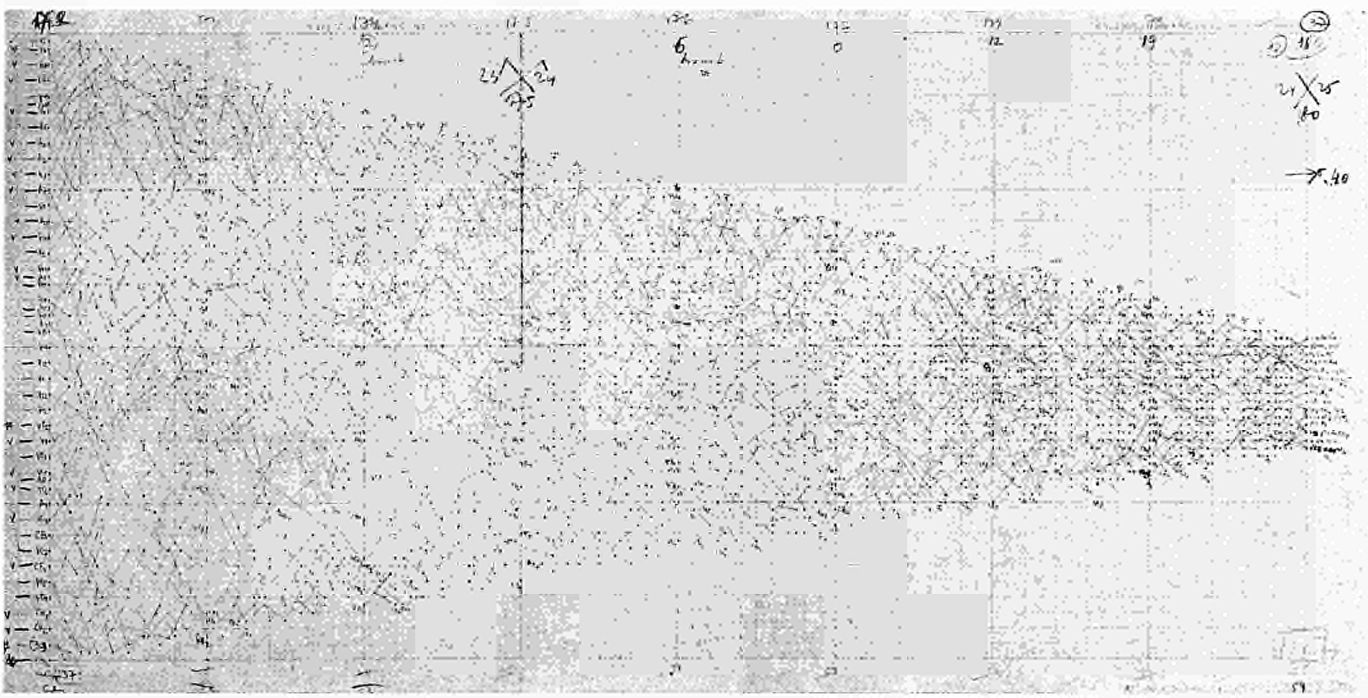
In contrast, the artist seeks to express the subset of reality which is his individuality. His first choices are of a sensitive nature: he begins by verifying with a body of evidence which hints at plenitude, the relationships between certain aspects of the known and potential components of his own development.

He explores or defines, as the case may be, the space in which his work will be situated. Its boundaries do not constitute limits for him, in view of the proliferation of figures issuing from the combinative method. "If all is allowed, nothing is possible" wrote Stravinsky in his "Poétique musicale". Indeed, one of the characteristics of a composer's style lies in the paths which he chooses to follow within a given space.

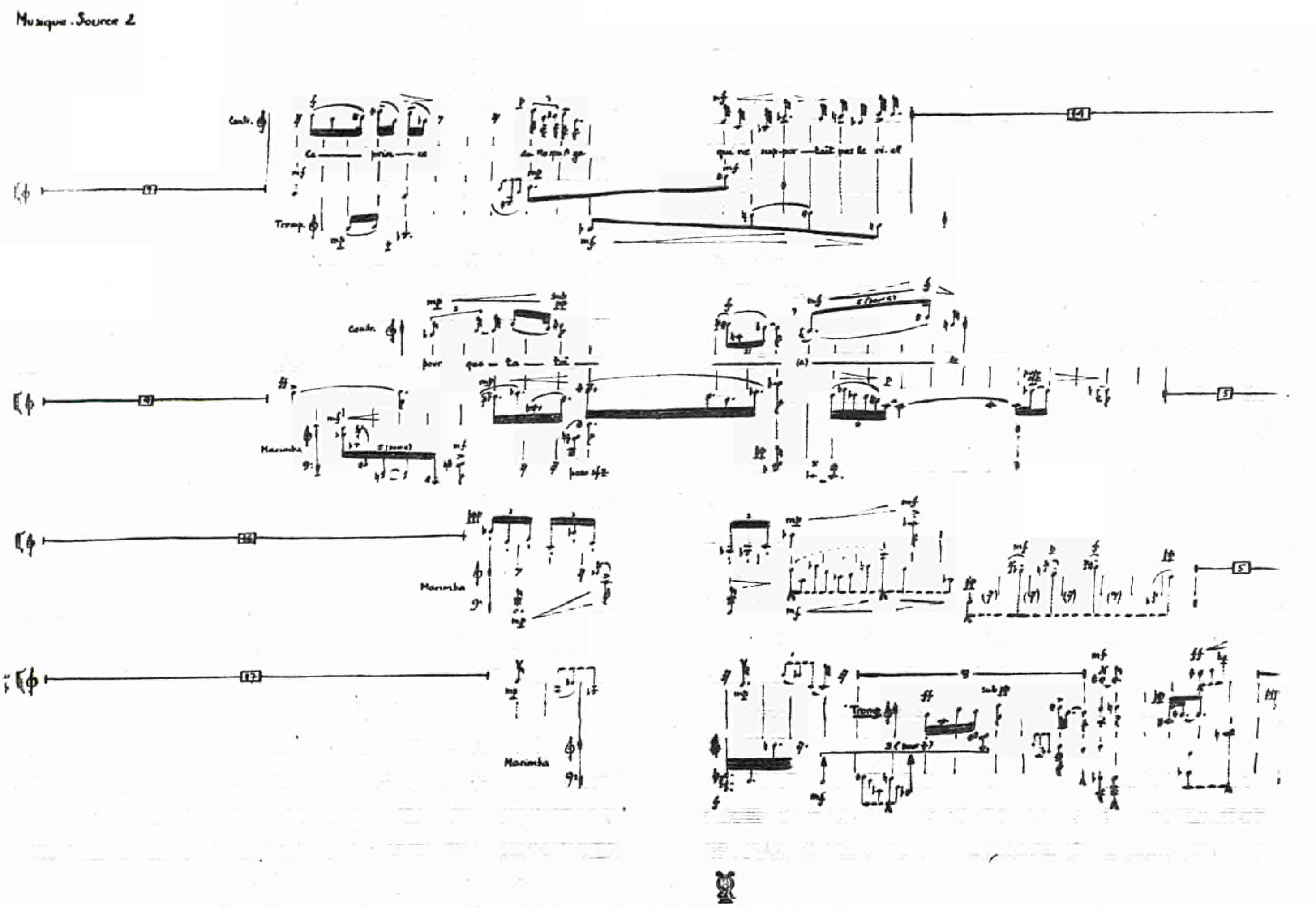
The whole problem, for a computer-programmer composer, consists in making these paths rational and, if possible, describing their mechanisms. The process is full of risks: the chief one is that of formulating an over-simplistic or over-rigid model which would impose its own rules and take the place of its creator.

Several solutions are being tested at the moment:

- overall organization, or macroscopic control of events whose dispersion remains statistical and obeys a Poisson distribution: this is one of the favourite approaches of Xenakis;
- a gradual move from disorder to order, which arranges all sound parameters in an increasingly precise pattern (Koenig);
- finding criteria for moving from one event to the next, digital transformation algorhythms, and allowing production to develop within the established limits (tessituras, dynamics, silences, etc.). Control of the result is a matter of appreciation (Barbaud considers that any performable production is *a priori* satisfactory);



Photograph 2: *Part of the score, in semi-log coordinates, of "Pithoprakta" (Xenakis, 1956), corresponding to a gradual increase of chord density.*



Photograph 3: *Part of the score of one of the three musical sources for "Jubilation Heuristique" (A. Riotte, 1968), musical background for an exhibition of works by the painter Aldine, Entremonde Gallery, Paris. The natural cycle of this background achieved with equipment set up at the exhibition, was about 100 listening hours.*

– endeavours to resolve the problem of the mechanisms of formal creation by using models and languages derived from previous works (Greussay, Riotte).

The type of approach chosen is influenced by other factors: the more or less elaborate nature of the hardware and software to which computer-programmer composers have access may guide their research in one direction or another; for their work has to be slipped in among the paramount profit-making tasks of the computers, which are generally a built-in part of a powerful structure for capitalization of money and knowledge.

Teams have been formed all over the world, on the strength of the works described in an earlier paragraph, around facilities capable of handling their programs or in places that give their research a welcome. An attempt will be made below to describe the activities of the groups formed in Europe, it being understood of course that the US studies mentioned are being pursued in numerous universities and research centres (Mathews - *MIT*, Hiller-Illinois, Strang - California State College, Dodge - Columbia, etc.). Even for Europe this summary does not claim to be exhaustive.

In France, in 1966, Iannis Xenakis founded the *EMAMu* (Musical Mathematics and Automation Team) with the help of Professor Louis Leprince-Ringuet. Seminars were organized under the auspice of the Social Mathematics group at the *Ecole Pratique des Hautes Etudes* and then the Nuclear Physics Centre of the *Collège de France*, where mathematicians like Thomas Guilbaud or F. Génuys could meet musicians, computer programmers and students of various origin such as P. Greussay, P. Barbaud, J. C. Risset, H. Bestougeff and A. Riotte. In 1968, a donation from the Gulbenkian foundation made it possible to start designing a high-performance synthesizer (sampling frequency of up to 94 kHz) at the National Centre For Telecommunications Research; this is now in use. Its very existence should encourage experimentation in the production of hitherto unknown sounds and timbres and influence research on form, which will be the logical framework for such experiments.

One may, for example, expect that a composer like Jean-Claude Risset, who has made intensive studies of sound synthesis by computer [he was the first to synthesize the sound of a trumpet at the Bell Telephone Co. and took an active part in the work of Mathew (1 .a, b, c, 7. b)], will make a significant contribution.

As for Xenakis himself, he is continuing to explore mathematical methods for creating sounds by means of a converter, using three lines of approach:

- clouds of points judiciously distributed over the entire audible area;
- patterns based on probability functions;
- continuous or non-continuous transformations of amplitudes or angles of trigonometric series[6].

At the University of Paris VIII (Vincennes), an "Art and Data-processing" group from the Institute of Artificial Intelligence is working on analysis and musical programming under the direction of Patrick Greussay, a specialist in languages and a musician of note, whose recent doctoral thesis (5. f) opens up new perspectives in the concept of computer composed music. Jacques Arveiller, a psychiatrist, computer programmer and musician, is for his part carrying out original research on macroscopic forms which—starting from chosen criteria and limitations—find their own equilibrium state. The group publishes a journal, *ARTINFO-MUSINFO*, which describes research in progress. Other composers and teams are at work in Paris (Barbaud, Nicole Lachartre) and at Grenoble (*IMAC*, on automatic transcription of scores). The *CNRS* recently organized an initial seminar on computer-composed music at which some of the works referred to in this article were presented, together with various musicological applications (6. h).

[6] Personal communication - August 1973.

The *IRIAM* (Institute for Acoustic/Musical Research and Coordination) is planning substantial hardware for its future activities at the Beaubourg theatre under the direction of Pierre Boulez.

In Germany several teams are working along the same lines as Hiller, but detailed information is not available. Mention should also be made of the *GEASCOPE* program of H. Kupper (Düsseldorf) (7. c).

In the United Kingdom the Computer Arts Society, of which A. Sutcliffe is one of the founder members, organizes regular performances and publishes a bulletin, *PAGE*. An important exhibition organized by the Institute of Contemporary Arts in London in 1968, "Cybernetic Serendipity", combined graphic and musical works composed with the help of various mechanisms and computers.

In the Netherlands G. Koenig is also working on real-time synthesis of sounds by computer. He is developing a program based on the description of sound-waves, amplitude and time, combined in accordance with laws of distribution which he formulated on the basis of experience acquired in his previous research (projects 1 and 2). The program will also make it possible to digitalize specific sounds and transform them according to certain laws of selection and permutation. Lastly, the program will be interactive, hence the faculty for users to make direct experiments. This activity has given rise to other research at the Institute of Sonology at the University of Utrecht (B. Truax, O. Laske, W. Keagi, S. Tempelaars), which publishes a six-monthly review, "Interface", and progress reports[7].

In Italy P. Grossi is now working towards real-time conversational use at the Computer Centre of the University of Pisa (*CNUCE*). An audio-terminal is being set up which will be able to give out up to twelve voices simultaneously[8].

In Belgium, a computer music workshop has been working for a year in Liège as part of an experimental music seminar conducted by Henri Pousseur; the author of this article is working there on the analysis and definition of models of cellular development and interaction (5. g). In answer to the usual criticism regarding the musician who hands over his function to a computing machine, it is worth noting that a composer like Pousseur, who does not make use of data processing, nevertheless for his works constructs harmonic grids (5. d) and formal structures with random access (random drawing from a set of data—see, for example, the "Icare obstiné") which could be a typical product of computer processing.

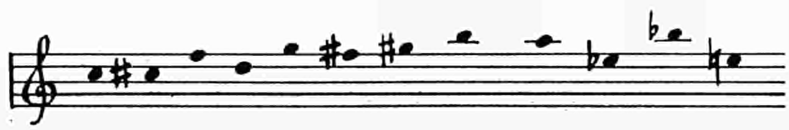
A few considerations on the advisability of adopting a formalized approach to musical composition

Although it is true that there are still objections of principle to the use of data processing in musical composition, these stem more from ignorance of the very real possibilities offered by computers and mathematics than from perception of a dividing line between their use and the work of a musician.

The real problems lie elsewhere.

Two contrasting approaches can be discerned in the main works referred to above: the partial suspension of disorder which displays outlines of order in a stochastic magma, and partial break-up within a highly ordered milieu.

The argument over the validity of deterministic as opposed to probabilistic models may be considered as a variation on the traditional debate concerning hereditary and acquired characteristics. To take a series of decisions in advance seems constrictive; however, a creation which is something more than the instantaneous reflection of impressions received by the creator is and will remain a speculation, a work which is to some



$$A_1 = \{1,2,6,3,8,7,9,12,10,4,11,5\}$$

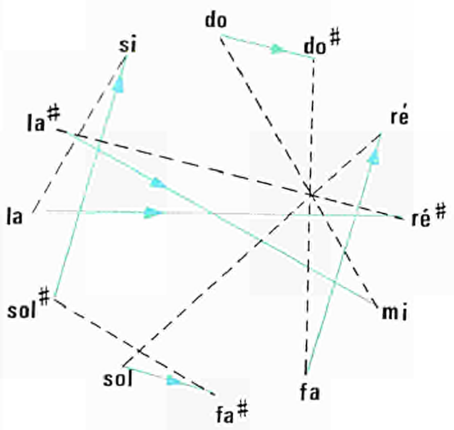
$$D_1 = \{1,4,9,5,11,2,3,10,6,7,6\}$$

Fig. 7: Balanced cycle No 357

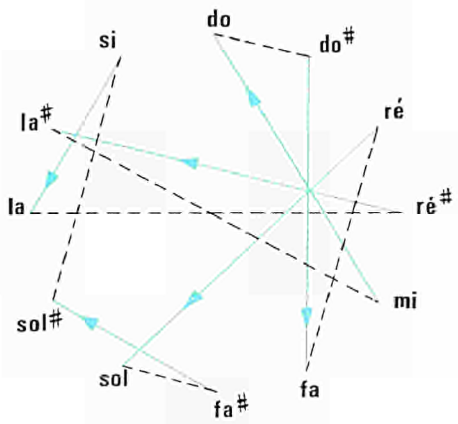
[7] Personal communication - September 1973

[8] Personal communication - September 1973

Fig. 8: *Internal symmetries of the balanced cycle No 357.*



Odd intervals



Even intervals

degree a closed system from the moment of its conception.

Speculation is the artist's manner of participating in the general growth of awareness; going beyond his feeling and their immediate translation, his intuition is projected into another dimension of reality, within which time is not arranged in a straight-line sequence.

There he unfurls his plans in a territory where before and after are no more or less apparent than high and low; so that succession becomes a phenomenon equivalent to gravity and is simply the coordinate of a "data distance", a pressure of proximity which must be retransmitted from the beginning to the end of the message—compare the scope of cyclic phenomena. To deny the need for this projection reduces the artist to the level of the unconscious detector. He wanders about with a movement which is at best elegant, but without expressible aim or inner force.

Training in gesture is of course a prerequisite, loosening the shackles of the psyche; improvisation is the sign that it is liberated. Movement is not a gesture unless it makes an appeal. Since birds have existed, their singing has not changed the world.

Although, from the point of view of formalism, one person feels drawn towards a predetermined message, whereas another will prefer indefinite localization, they both refuse randomness.

"Pure" speculation (not corrected in Barbaud's sense of the word) divorces the musician from his inner ear if the complexity involved runs away from him completely. It is essential that the creator should remain the key element of the system he is organizing; he must therefore exercise sufficient control over the developments supplied by the computer to make them coincide with his intuition, and only accept them on these conditions. This may mean that he only retains their proportions, their formal dynamics, or simply the structuring of the space in which he will let his imagination range.

Boulez's famous statement "the unforeseeable becomes necessity" is still a wonder-worker's formula. On the other hand it acquires rich significance for the computer artist if it is modified to "the improbable becomes necessity".

Indeed, what better tool than the computer for grasping the improbable if the conditions of its manifestations are specified[9]?

Prospects

Of course, the computer is still a costly tool for the composer. With few exceptions, computer music is not yet counted among the interdisciplinary studies in Europe and it suffers from a lack of information and research. It meets with the usual difficulties—confidential research, justifications for access to facilities, non-transferable programs, inadequate attempts at programming. It could benefit from action at various levels:

- the compiling of an exhaustive bibliography and discography;
- the description of existing systems, programs and routines, beginning with the ones which are accessible, and the setting up of an exchange and information centre;
- aid to pure and applied research, on analysis or synthesis[10];
- development and reform of music teaching, putting the stress on the new means of formalization and processing of data.

There is reason to hope, however, that the rapid development of conversational techniques, time-sharing and real-time will make facilities more accessible and encourage the development of specialized languages. Conceivably one of the future roles of data processing would be to provide the means for the true integration of music into life: it would offer the possibility of an infinite variety of compositions, based on models which are veritable "musical beings", influenced by their surroundings fitting in with the architecture and permitting more or less active participation by the listener depending on the extent of his interest.

Finally, a dialogue between instrumentalists and musical beings, via compatible structures, leaves the way open for controlled improvisation.

A considerable effort, is obviously still needed, in order to define the mechanisms of creation more clearly and to discover the real possibilities and limitations of computer-composed music.

Nonetheless it has already given a new lease of life to an art whose chief manifestations at the moment prove that it could no longer, even at the consumer product level to which it is all too often relegated by Western civilization, make do with time-tested recipes whose real meaning still escapes us.

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[9] Let us take, for example, the 61 balanced cycles obtained from a series of calculations and selections by a computer from the 12! = 479 001 600 possible permutations of 12 sounds.

[10] We would mention in passing that considerable service could be rendered to the computer musician by Zadeh's recently innovated fuzzy subsets.

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The cycle of sulphur dioxide in the atmosphere

MAURICE PAYRISSAT

Before making a choice of methods aimed at reducing SO_2 pollution, we must first acquaint ourselves with the natural processes whereby SO_2 is taken up and recycled in the atmosphere.

Some definitions and statistics

IT IS COMMONLY assumed that air pollution is a relatively recent problem which came in with the large-scale chemicals industry and the motor car, but in fact it has dogged us for centuries. As long ago as 61 BC, Seneca had the following to say on the subject of Rome: "As soon as I can get away from the oppressive air of the city and the stench of the smoking chimneys, which, as soon as the fires have been lit, belch forth all their pestilent fumes and soot, I will feel a completely new man".

Twenty centuries later, atmospheric pollution has increased on an enormous scale but, to all intents and purposes, its definition remains as empirical as ever. Before we examine the reasons for this, let us compare the words of Seneca with the Council of Europe definition as set out in its Report of 14 September 1967: "Air pollution exists when the presence of foreign matter or a significant variation in the proportion of its constituents is likely to produce a harmful effect, taking into account the scientific knowledge of the day, or to cause discomfort".

This definition, based in effect on observation of a harmful effect produced by the air, implies the corollary "clean" air - in other words, air which produces no harmful effects. Now, as far as the chemist is concerned, this "clean air", which is colourless, odourless and tasteless, can be defined in scientific terms: samples of it can be taken in the countryside and it can be analysed to determine the nature and the proportions of its constituents. The sample thus obtained may be used as a standard of reference and treated as a quality criterion in a concentration/time bracket, outside which a nuisance may be said to exist. Thus, in the case of SO_2 these quality standards are defined in terms of a mean concentration during a predetermined period of time, i.e., mean concentrations per year, per 24 h and per 3 h. In the United States, for example, the corresponding concentrations are 0.02 ppm, 0.1 ppm and 0.5 ppm[1]; below these figures, the air is deemed to be clean in respect of SO_2. It would be logical to take the standard levels above as a reference.

Given the fact that the composition of air is not immutable, however, it has to be conceded that a sample of "clean air" is not a standard in the same sense as the standards used to define a second or a metre. One has to consider, on the one hand, the gradual and continuous evolution of nature and, on the other, the various human activities that produce changes, general or local, in the composition of air.

The only natural sources of sulphur dioxide are volcanoes, forest fires and oxidation of the hydrogen sulphide (H_2S) produced by the breakdown of living matter. The remaining 95 % of the SO_2 found in the atmosphere is of man-made origin. Most of it is caused by the burning of coal for industrial and domestic purposes (involving a 2-3% sulphur content), the burning and refining of heavy petroleum products containing H_2S and mercaptans and the treatment of pyrites (sulphides) in foundries.

In 1943 Katz estimated that the worldwide emission of SO_2 amounted to $77 \cdot 10^6$ tonnes a year, while in 1960, according to Robinson and Robbins, this figure had risen to $146 \cdot 10^6$ tonnes. Bearing in mind that an oil refinery is capable of producing up to 500 tonnes of SO_2 a day and that a brass-foundry can emit 1 350 tonnes into the atmosphere, it is to be expected that in the vicinity of these sources the SO_2 concentrations will frequently exceed the quality standards limit. On the other hand, it is not unknown in the highly industrialized areas to find a permanent residual concentration of SO_2 which is up to 1 000 times as high as the concentration found in rural areas, and yet it still does not exceed the quality standards (e.g., 600 $\mu g/m^3$ as against 0.6 $\mu g/m^3$).

This ambiguity would cease to exist if quality standards were laid down on the basis of an air sample which showed no trace of SO_2 of man-made origin... in other words, if one were to close down all the factories and plants!

In point of fact, the concentration of SO_2 in the air we breathe is not the only nuisance factor. Account must also be taken of the way in which the SO_2 acts: it is not as harmful in the presence of other pollutants (synergism) or of moisture. Furthermore, one has to consider its evolution and life-span in the atmosphere, factors which are greatly affected by the environment.

SO_2 pollution - a problem transcending national frontiers

Between the moment when the atmosphere begins to exert an influence on the SO_2 particle (emission) and the moment when that influence ends (immission), there is a transmission stage during which the atmospheric influence on the particle reaches its maximum. The life-span of the SO_2 in the atmosphere, i.e., the interval between emission and immission or the duration of the transmission stage, may be several days. During this time the SO_2 is exposed to all kinds of meteorological and physico-chemical factors present in the environment in which it is evolving - the action of atmospheric parameters, other air constituents, solar radiation, etc.

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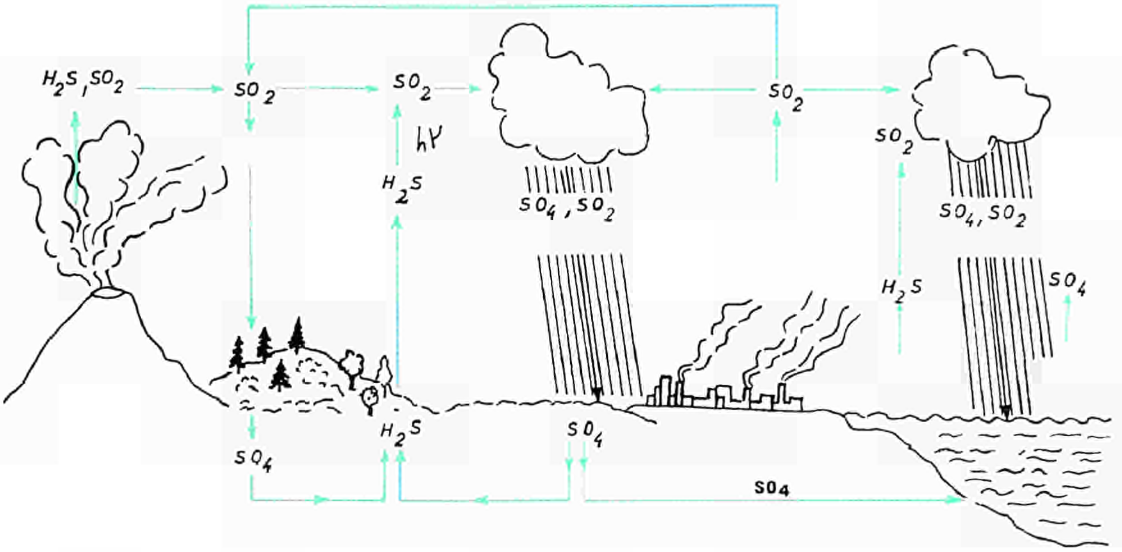
[1] 1 ppm (part per million) = 1 cm³ of air per m³ of air. Under normal conditions 1 ppm SO_2 = 2.850 mg/m³.

Fig. 1: *Circulation of sulphur in the natural environment.*



During the transmission stage the SO_2 may spread into the various atmospheric layers and be borne on the wind across continents and deposited far from the polluting areas. The report presented by Sweden at the United Nations' Conference on the Human Environment (Stockholm, 1972) spelled out the long-distance effects of sulphur pollution. About 50% of the sulphur deposited annually on Swedish territory originates in Central Europe and the United Kingdom.

Since SO_2 is a reducing agent, it tends to oxidize in the atmosphere into SO_3^{--} and, above all, into SO_4^{--}, sulphates which are the ultimate stage of oxidation. This transformation is promoted by a number of parameters: in polluted areas other pollutants may act as a catalyst, while in the upper layers of the atmosphere the transformation would occur by photochemical interaction with ozone in sunlight. In both instances contact with fog droplets or envelopment in cloud results in the formation of smog or acid rain (sulphuric acid: H_2SO_4).

During the last 10 years the increasing acidity of rainwater has lowered the pH by 8-23% in certain lakes in Sweden, with dangerous consequences for the fish there.

Although there are a number of techniques for desulphurizing fossil fuels, no international agreement has ever been drawn up fixing a maximum permissible sulphur content for each fuel. However, faced with the damage occasioned, most of the industrialized countries have had to introduce laws or regulations. At European level, in order to assist governments in setting the requisite desulphurization levels, a number of study groups have been formed to investigate the physico-chemical behaviour of SO_2 in the atmosphere and to study conversion, absorption and diffusion mechanisms.

As a result of man-made pollution, the amount of sulphur processed by Nature has increased by half

If it were possible to achieve a chemical synthesis of the biosphere, i.e., that part of the earth's crust and atmosphere where living creatures evolve, the compound obtained would have the aggregate formula $H_{2900}O_{1480}C_{1480}N_{16}P_{1.8}S$. Each of these elements has its own biogeochemical cycle, which involves the flora and fauna and takes place in the atmosphere, the hydrosphere and the lithosphere.

For a long time man has been discharging into the atmosphere considerable quantities of pollutant substances such as oxides of carbon, nitrogen and sulphur, and one may well ask how these substances fit into the cycles and to what extent the balance of nature is disturbed.

To see how SO_2 circulates in the natural environment we must consider the processes occurring during the gaseous phase of the sulphur cycle,

Fig. 2: *In-tank measurement of SO_2 absorption by decrease of concentration.*

A static measurement is taken in a plexiglass tank containing an absorbent sample of soil (1). A pressurized nitrogen sulphur dioxide mixture is introduced through the orifice (2) by means of a sampling syringe. The fan (3) is used to agitate the atmosphere which is monitored by a thermometer (4) and a hair hygrometer (5). The absorbed air is replaced by ambient SO_2-free air which is filtered through absorbent chromic oxide cartridges (6). The quantity of air required for analysis purposes is fed via the connecting tube (7) to the analyser (8). The concentration vs time is registered on the recorder (9).

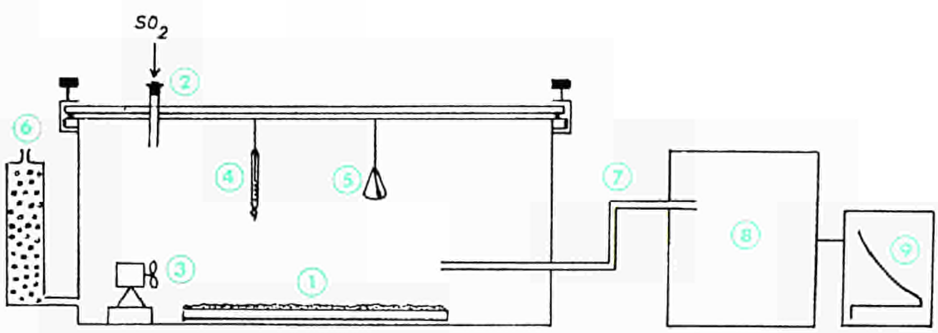
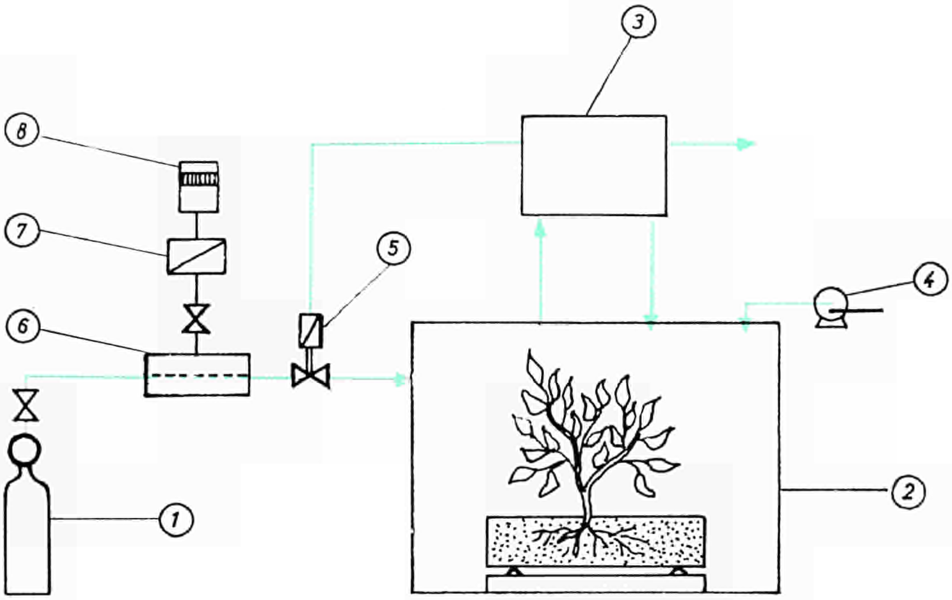


Fig. 3: *In-tank measurement of SO_2 absorption with the concentration maintained.*

The mixture of air and SO_2 is released from the cylinder (1) and circulated through the tank (2) and the electrochemical analyser (3), a small amount being bled off for the continuous SO_2 analysis. An auxiliary diaphragm pump (4) is used to make good the mixture bled off for analysis purposes. The electromagnetic valve (5) admits a quantity equal to the quantity absorbed by the sample. This feed is metered by means of a calibrated diaphragm (6) connected to a transducer (7). The SO_2 feed absorbed by the sample is read off on an integrating flowmeter (8).



whereby the SO_2 becomes present in the atmosphere and subsequently disappears. In the course of the complete cycle a number of compounds are formed: these compounds are more or less volatile, more or less soluble and eventually undergo changes themselves, if conditions in the medium permit. The sulphur may progress from the degree of oxidation S^{2-} to the degree of oxidation S^{4+} (hence the wide variety of chemical reactions observed). It is usual to regard the atmosphere as the seat of the cycle and to use the term "sources" to describe all media and processes by which sulphur is emitted. Similarly, the term "captors" is used to describe those media in which the atmospheric sulphur is absorbed, i.e., media where immission occurs (irrespective of whether chemical conversion takes place or not).

Fig. 1 shows a diagram of SO_2 circulation, which may be summarized as follows.

In addition to the SO_2 produced as a result of human activities, another notable source of sulphur is represented by the oceans (1 g of seawater contains 2.65 mg of salts in the form of sulphates). More sulphur, in the form of H_2S, comes from the transformation of marine biological material. Significant quantities of sulphur are absorbed in soil and vegetation which, together with the oceans, are the chief natural "captors".

Plants and soil bacteria metabolize the SO_2 and sulphates they absorb, converting them into H_2S which is emitted, in turn, into the atmosphere to be reoxidized photochemically into SO_2 in presence of ozone. Another part is dissolved in the soil and finds its way to the oceans, taking with it the other sulphates produced as a result of mineral erosion.

Knowing the size of the chief sources and the kinetics of the various conversion or absorption processes, we can assess the annual quantities involved and estimate the length of the transit time.

It is estimated at present that in the northern hemisphere alone (in effect, the industrialized hemisphere) man's contribution to the sulphur cycle is equivalent today to nearly 40% of nature's contribution and by the year 2000 will exceed it. How can one assess the quantities of sulphur involved within the cycle? How are they moved along?

Measuring SO_2 absorption in the surface of the soil

Confronted with the enormous accumulation of SO_2 in the atmosphere, one could easily conclude that there would be a rapid threat to life if the remaining clean air were to become sufficiently polluted, that is, if the sources emitted more quickly than the "captors" could absorb. Fortunately, the presence of SO_2 in the atmosphere does not depend solely on the quantities emitted, but also on the speed at which the SO_2 disappears or is transformed. Because of its diffusion in the atmosphere, and above all because of its short life-span, the SO_2 scarcely has time to accumulate.

Observations have shown that this life-span is largely determined by the meteorological factors involved in the chemical conversion of the SO_2 into sulphates (temperature, relative humidity, rain) and by absorption in the surface of the soil. The life-span varies from a few hours to several days, depending on conditions. On the other hand, measurements taken on the same sites under identical conditions show that the level of atmospheric SO_2 is between eight and 10 times higher in winter than in summer, and it has been found that the curves representing the concentration of SO_2 are similar to those showing the CO_2 concentration, the gas being particularly abundant during months when there is little photosynthetic activity among the vegetation. This fact proves, and other experiments have also shown, that SO_2 is preferentially or more actively absorbed by chlorophyllian plants, via the stomata of the leaves.

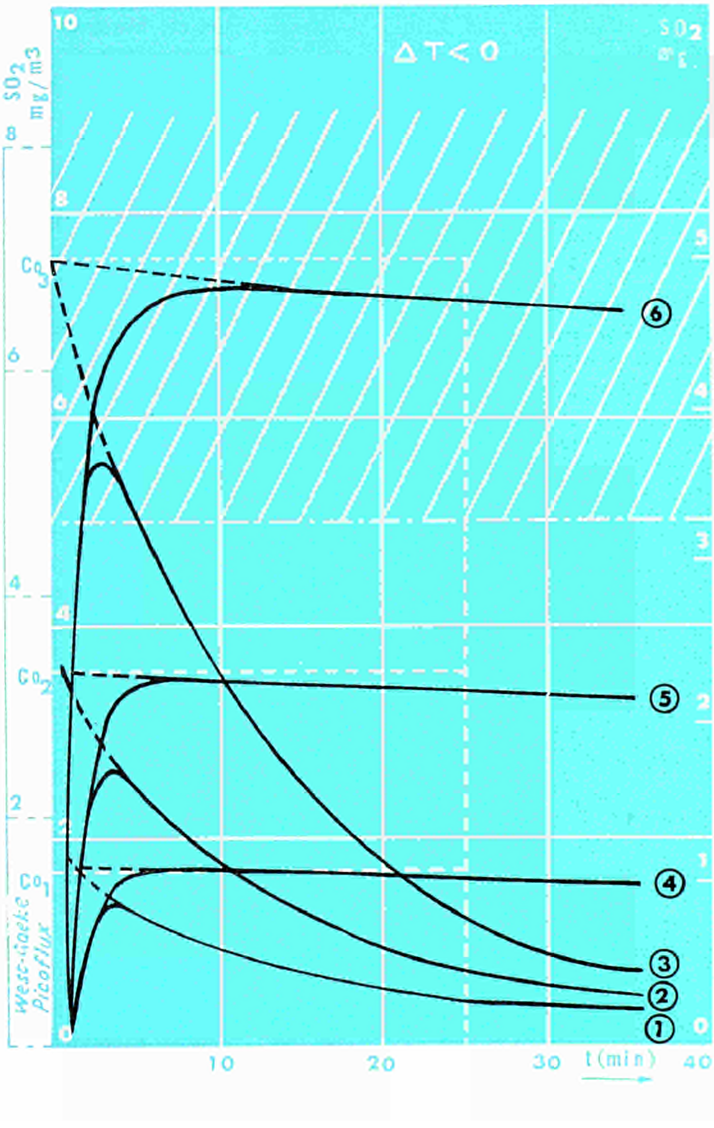
Furthermore, since other research has shown that atmospheric SO_2 acts as a fertilizer in the same way as soil sulphates, the plant requirements probably vary according to the N/S ratio of the proteins present in its tissues. This would result in differences in the absorption kinetics of the various species of plant.

For purposes of comparison (use of different soils and plants), these measurements can be taken in the laboratory, in the controlled atmosphere of a plexiglass tank or in the so called "phytotrons" (rooms with a strictly controlled atmosphere in which the samples are placed). Where distribution data are required in respect of a source of pollution, the measurements may be taken in the open air.

Depending on the aims in mind, methods of analysis in the laboratory vary. Thus, in the case of plants, it is possible to break down the substance in order to analyse the aggregate sulphur before and after SO_2 absorption. If the sulphur in the SO_2 is labelled, it is possible to identify the part of the plant in which the SO_2 tends to accumulate or to determine how its metabolism occurs. In the case of soils, a number of research workers have placed the sample in an air-stream polluted with SO_2 and have then measured the SO_2 retention by analysing the inflowing and outflowing air.

The most common method, which can be employed equally in the laboratory or in the fields, is the *aerodynamic method*. In the laboratory this consists in measuring the variation of the SO_2 concentration in the vicinity of the captor, i.e. soil or plant, in a tank. Where field work is concerned, the SO_2 flux deposited is determined by measuring the concentration gradient and other parameters vs the height above ground.

In any event, the procedure for determining the SO_2 concentration in the atmosphere involves pumping in a known volume of air and bubbling it through a solution that absorbs SO_2. The SO_2 is then determined by a variety of methods, the most common of which are the following.



The *West and Gaeke method* is based on the colorimetric principle. The SO_2 is absorbed by a 0.1 N aqueous solution of sodium tetrachloromercurate and produces non-volatile ions of sodium dichlorosulphite mercurate which react with formaldehyde and colourless pararosaniline acid to form the purple-red methylsulphonic pararosaniline acid. The colour intensity of the solution, which is proportional to the SO_2 concentration, is measured on a photometer at 560 mμ. This method is suitable for determining the ambient SO_2 in concentrations of 0.002 to 5 ppm.

The *hydrogen peroxide method* involves bubbling the air to be analysed through a solution of H_2O_2. The SO_2 present in the air samples forms sulphuric acid and the total acidity obtained is titrated against a reference base.

The *electroconductivity methods* consist in measuring the resistance between two electrodes immersed in a solution in which SO_2 dissolves. The conductivity of the solution is proportional to the quantity of SO_2 dissolved.

Two laboratory methods employed at the Ispra Establishment of the *JRC* allow continuous measurement of SO_2 absorption by plants and soils. The first is based on static measurement of the diminution of a concentration of SO_2 following the injection of a certain volume into the tank (Fig. 2). The second is based on measurement of the absorption; here the concentration is kept constant in the tank by adding more SO_2 as it is absorbed (Fig. 3). In both

Fig. 4: *Variation of the SO_2 concentration during the absorption test in the tank.*

The mode of variation of the SO_2 concentration, with (1, 2, 3) and without (4, 5, 6) soil present, is shown from the moment of injection, for three initial concentrations of SO_2. The abscissa gives the time axis in minutes, while the ordinate comprises three scales of measurement: mg/m³ shown by the analyser, mg/m³ shown by the West-Gaeke parallel assay, and mg · SO_2 present in the tank space (West-Gaeke values). The soil absorption is measured by calculating the difference. First the total absorption is measured, and then the secondary absorptions are measured under the same conditions but with the sample removed.

Thus it is possible to assess absorption by the tank walls and by the analysing equipment. (The line at the centre indicates the upper limit of Picoflux measurement).

instances the SO_2 analysis is carried out by electroconductivity.

Fig. 4 shows the mode of variation of the concentration when a soil sample is present in a tank of the Fig. 2 type. A quantity of SO_2 producing initial concentrations C_{01}, C_{02}, and C_{03} was injected into the tank at the outset.

Rates of SO_2 deposition on standard European soils

Certain "captors" are more absorbent than others and, in order to distinguish the differences in absorption capacity between a captor and a pollutant substance, meteorologists have introduced the "deposition rate" concept.

The rate of SO_2 deposition (v) over an absorbent substance is expressed by the equation:

$$v\ (m/s) = \frac{F\ (SO_2 \text{ flux deposited in } mg/m^2/s)}{C\ (\text{concentration in } mg/m^3)}$$

There are a number of methods for determining the rates of deposition in the open air. The most common consists in measuring the SO_2 concentration vs height above the soil surface being investigated. Wind-speed and temperature gradients are measured simultaneously.

The deposition flux F is expressed as the product of the concentration gradient $\frac{dc}{dz}$ and the turbulent atmospheric diffusivity, determined on the basis of the wind-speed gradients K (z). By taking the wind-speed and concentration profiles applicable at any given moment it is possible to calculate F:

$$F = K(z) \frac{dc}{dz}$$

The rate of SO_2 deposition is expressed by the equation:

$$v = \frac{F}{C}$$

where C is the concentration at a standard height.

The height at which the gradients need to be measured is determined by the aerodynamic roughness of the absorbent surface. The rate of deposition varies according to the height at which it is measured and is at its maximum when the concentration is measured immediately above the ground-level boundary layer. This boundary layer, which depends on the roughness of the soil (i.e., surface irregularities), is usually conducive to a greater degree of SO_2 diffusion. On the other hand, it has been found that above the boundary layer concentration increases with height, owing to the resistance to diffusion in this zone.

In practice, for measurements of absorption on soil without vegetation, the rate of deposition will be determined at a point a few centimeters above the surface.

If it can be shown that there is a ratio between the absorbed sulphur dioxide fluxes and the concentration which exists above the "captor", the rate of deposition can be used to calculate the fluxes deposited for different concentrations of SO_2. It thus provides a quantitative approach to the sulphur cycle.

The advantage of measuring deposition rates in a tank lies in the fact that the parameters can be appropriately controlled; it can thus be demonstrated that the variation of the reading is due to the parameter which has been varied.

Thus it is possible to take measurements for different types of soil and different types of plant in a given environment. Table I outlines the different characteristics of the various European soils, which vary in their composition, structural pattern and drainage properties. This representative selection, compiled by the Biology Division of the Ispra Establishment of the *JRC*, has enabled us to carry out a comparative kinetic study (Fig. 5) on the basis of the method expounded in Fig. 2.

If C_o is the initial SO_2 concentration, it will be found that the concentration/time variation is expressed by the exponential equation:

$$C = C_o\, e^{-kt}$$

$$\text{or} \quad \frac{dC}{dt} = -kC$$

When applied to the unit area of soil, this gives the equation:

$$[F] = kC.$$

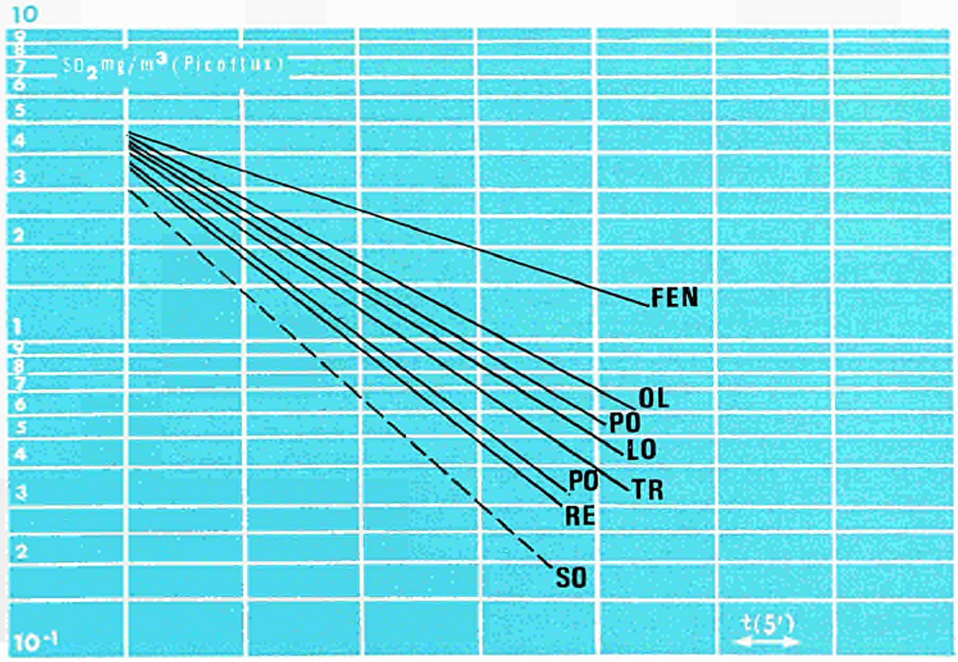


Fig. 5: *Variation of the SO_2 concentration in the tank in the presence of different soils.*

The tests were carried out in the tank under the same conditions (T = 22-23°; $H\%$ = 40-50; wind speed $\simeq$ 0.8-1 m/s) shown in Fig. 2, in respect of identical surfaces of 3 200 cm². The surface is considered in accordance with a meteorological concept: a macroscopic surface with a predetermined wind speed, where the soils have been filtered in an identical fashion.
This figure shows that the seven soils under investigation (SO = unspecified control soil) have different SO_2 affinities but that kinetically they are all of the exponential type. On calculating the values of k, one finds that the k value of RE *soil (chalky type) is 2.3 times of* FEN *soil (organic type).*

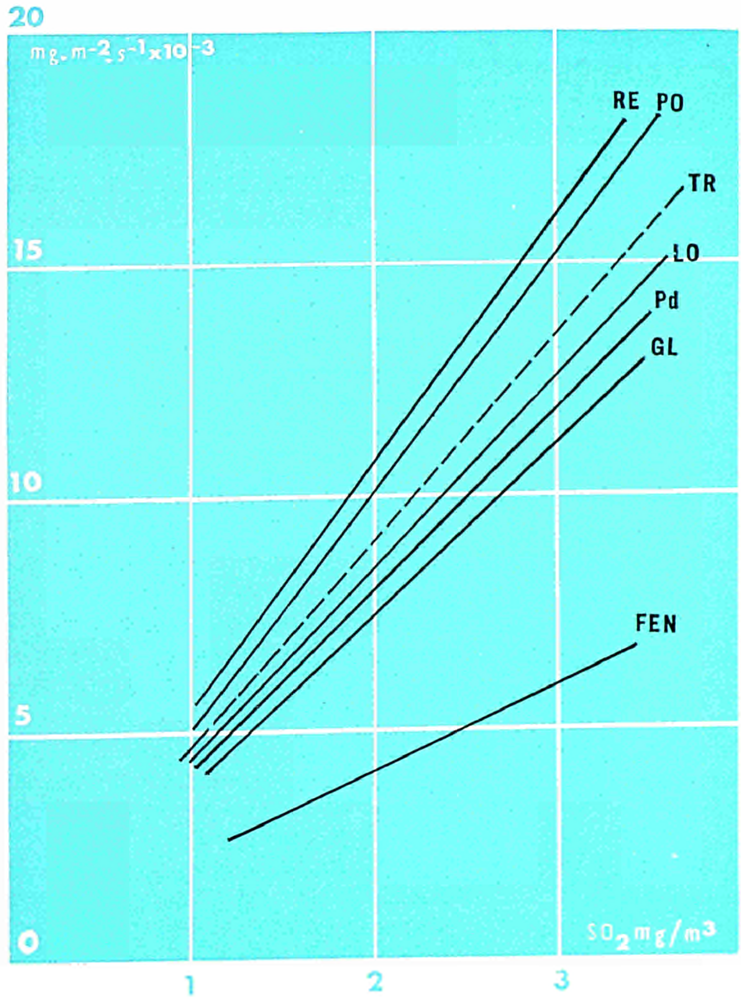


Fig. 6: *SO_2 deposition flux vs concentration.*

The concentration gradient and the height above the soil are disregarded and the concentration measured is considered as a mean value. Knowing the volume of the tank (720 litres) and the area of the sample (0.32 m^2), one can calculate the fluxes deposited in $mg/m^2/s$ by measuring the slopes of the curves log $x = f(t)$, where x represents the quantities of SO_2 present in the tank in mg ($x = 0.72$ C). From the gradients of the lines in the graph one can calculate the rates of SO_2 deposition with various soils present in the tank. These vary from 0.20 cm/s for the FEN *soil (organic type) to 0.52 cm/s for a* RE *soil (chalky type). Thus, over the same period and with the same area, nearly three times as much SO_2 is deposited on a* RE *soil as on a* FEN *soil.*

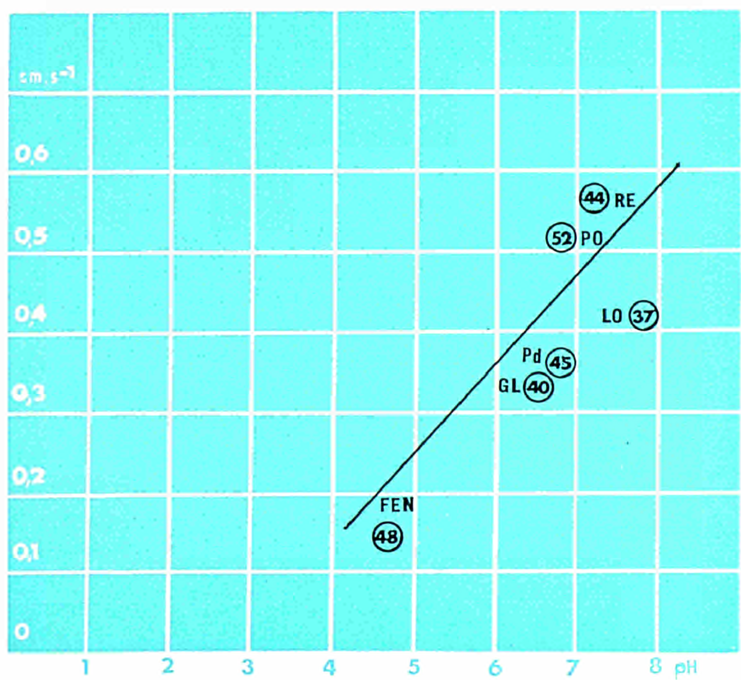


Fig. 7: *Variation of the rate of SO_2 deposition vs the soil pH.*

A comparison between the deposition rates obtained and the soil properties suggests that the pH of each soil plays an important part in determining the SO_2 absorption capacity (encircled values = % relative humidity).

Table I: *Characteristics of European soils*

Name	Abbr.	Geographical location	Specific surface m^2/g	pH (KCl)	Organic matter %	Clay %
Alluvial gley	PO	Porto Tolle (Veneto), Italy	99	7.4	3	70
Terra fusca	TR	Corato (Bari), Italy	144	6.2	5.2	71
Pseudo gley	GL	Ahrweiler, West Germany	53	6.2	2.1	49
Parabrown earth	LO	Allonville (Amiens), France	86	7.3	2.6	37
Rendsina	RE	Allonville (Amiens), France	70	7.6	7.6	17
Podsol	PD	Hannover, West Germany	56	6.4	6.6	8
Fen	FEN	Emmen, Netherlands	96	4.5	24.6	6

In other words, the deposited flux is proportional to the concentration of ambient SO_2 (Fig. 6).

The coefficient of proportionality k depends on the properties of the soil, the atmospheric conditions and the SO_2 burden in the soil.

Calculations show that, except for one coefficient of proportionality (a function of the geometrical properties of the tank), k is assimilated at the rate of deposition. The curves representing the SO_2 fluxes deposited vs the concentration are straight lines with gradient v (Fig. 6).

Having thus determined the rate of SO_2 deposition above a specified soil, one can then determine the quantities deposited per unit area of soil in respect of each concentration. The same applies where the ground is covered with vegetation and where absorption tests are carried out for different species of plant (subject to an evaluation of the foliar surfaces). After standardizing the laboratory tests, one could then determine the quantities deposited in the natural environment (using the equation $F = v \cdot C$).

In addition to providing relative data on the distribution of atmospheric SO_2 over the soil for a known geographical sector, measurements taken in the tank also provide information on the movement of the atmospheric SO_2 and the soil factors which influence it (Fig. 7).

It would be desirable, in the case of plants, to consider isolating the soil from the atmosphere before the measurements are taken. In this way it would be possible to observe how the plant assimilates the atmospheric SO_2. However, the presence of vegetation raises a number of serious problems regarding atmospheric control, and these problems will first need to be resolved.

In conclusion, these examples illustrate the potential value of differential measurement of ground-level absorption in relation to the environment. The main advantage is the acquisition of data whereby it is possible to obtain a better insight into the evolution of atmospheric sulphur in the biosphere, namely:

- qualitative data from a physical model of the air/soil/vegetation system, to discover how the sulphur is transferred through this system;
- quantitative absorption data on which to base mathematical models of the atmosphere in accordance with a given environment;
- quantitative data to help towards assessment of the natural and man-generated components in the sulphur cycle.

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Radioactive waste : present problems

FRANCESCO GIRARDI,
GIUSEPPE BERTOZZI

THE OIL CRISIS and the consequent need to speed up the quest for alternative sources of energy have abruptly pointed up the problems connected with the widespread construction of nuclear power plants and, in particular, the problems attendant upon the inevitable production of "nuclear waste" which must be stored in safety for periods of hundreds or thousands of years.

The energy produced from nuclear reactors is based on the fission of a uranium isotope, uranium-235, by neutron capture. The atom then splits into two fragments (thus producing two light elements, the "fission products"), energy is freed and neutrons emitted which in turn lead to the fission of other uranium atoms in a continuous chain reaction producing heat and fission products; these latter generally are radioactive, the activity varying considerably as regards type, intensity and life. From the point of view of protection, the most dangerous and troublesome products are the longer-lived substances such as strontium-90 and cesium-137, whose radioactivity is halved about every thirty years.

Before they can be regarded as completely decayed and harmless, a period of several hundred years must leapse, during which the products must be surrounded by suitable shielding to absorb the radioactive emissions, such as concrete or other heavy material of great thickness.

In addition to fission products, reactors produce another type of waste, which causes even greater problems in the form of α-emitting elements.

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The uranium atom, and particularly its isotope U^{238}, as well as undergoing fission, is able to capture neutrons and thus produce elements which do not exist in nature (neptunium, plutonium, americium, curium). These are also radioactive, but their decay characteristics are completely different from those of fission products: on decay they emit α particles whose biological effects are far more dangerous than those caused by the β or γ radiations from fission products, but which can nevertheless be shielded off with very thin material (fractions of a millimetre). In addition, these elements remain radioactive for a very long time, with half-lives varying from several hundreds to tens of thousands of years.

Since both fission products and α-emitters are always present in nuclear waste, monitoring will have to be maintained for thousands of years.

Nuclear reactors differ either in the fuel which is used (uranium, thorium, plutonium) or in the method of burning it, but they all produce similar quantities of radioactive waste in proportion to the amount of energy produced.

The problems associated with the elimination of radioactive waste are therefore very serious, particularly as they inevitably involve future generations. It is morally indefensible to profit from cheap energy while at the same time knowing that it will entail hazards and damage to our descendents.

These problems should be recognized and assessed by public opinion on the basis of totally objective and unalarmist information.

It is against this backdrop that this article should be viewed; its theme can be broken down into the following five headings.

1. All current methods of producing energy involve changes in the environment whose long-term effects cannot as yet be predicted

Admittedly, nuclear power plants create enormous waste problems, but they are not the only ones guilty of this. Mention should also be made of conventional power stations which, in addition to consuming vast quantities of precious reserves of raw material (oil and coal), produce suspended dusts and off-gases which are not measured in hundredweights or cubic metres, as is the case with radioactive waste, but in millions of tonnes and cubic kilometres.

Very little is known about the effects of these wastes except as regards their broader and more immediate implications.

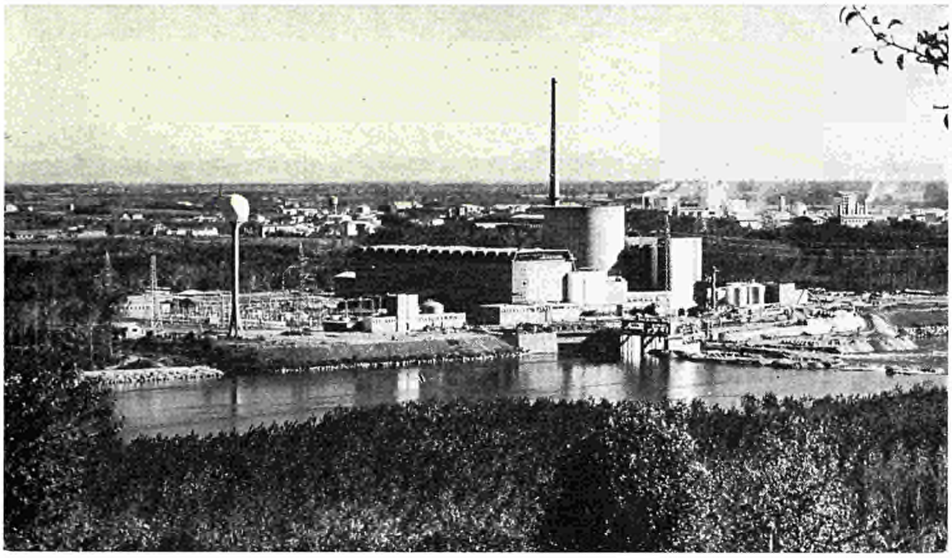
In the absence of enough specific scientific data to enable a long-term forecast to be made of the effects of environmental changes, it would be extremely hazardous to attempt to assess which of the two types of power plants is cleanest. It can only be stated, therefore, that they are both pretty "dirty" and that it will be a very good thing when they can be replaced by cleaner methods.

Other less polluting systems, such as thermonuclear fusion or the more rational use of solar or geothermal energy, do not appear capable, in the near future, of competing with the present energy sources.

It is, however, likely that a gradual process of substitution will take place over several decades, present energy sources being replaced by cleaner ones. The problem is to avoid creating, during the hundred years that our present energy sources may be expected to last, any changes which will have disastrous and irreversible effects on the environment.

2. Radioactivity was not invented by man but is a natural feature of the environment in which we live

At this juncture it is necessary to explode the belief that radioactivity is a product of the "sorcerers' apprentices", who created it but could not control it. Radioactivity is a reality of life, in the same way as air and light. A considerable amount rains down from outer space, it is constantly emitted from the earth's crust and it is to be found in seawater; a number of mineral waters are highly



radioactive and some elements of which the human body is composed, such as potassium and rubidium, are slightly radioactive.

Radioactivity varies very widely from one point of the earth's crust to another, and in fact the inhabitants of certain parts of the world (e.g., Egypt, India, Ceylon, Brazil, etc.), annually receive doses in excess of that laid down as the "maximum acceptable limit" for workers in the nuclear industry, who are considered to be "professionally exposed" and are subjected to particular rigorous medical checks.

Moreover, everyday life involves applications such as diagnostical radioscopy and radiography which no one would dream of abolishing or of regarding as dangerous; yet the amount contributed to the general public's uptake of radioactivity—over a lifetime—is far greater than that which could be attributed to the most ambitious nuclear power programme.

K. Z. Morgan, in a report to the *US* Senate, stated that more than 95% of the radioactivity received by the population of the *USA* from artificial sources in 1964 was due to their use for medical purposes, while less than 1% was due to nuclear power plants.

Thus we should not attempt to "eliminate" such radioactivity but to establish adequately low "limits" so that it is no longer possible to distinguish between these and natural radioactivity.

Step by step, as research instruments become more and more sophisticated, and reveal ever "finer" effects of radiation, these "limits" are under constant

Fig. 1: *The Enrico Fermi nuclear power plant at Trino Vercellese, Italy.*

About thirty 1 000 MWe nuclear reactors would provide enough electrical power to meet Italy's present energy requirements.

The radioactive waste produced in nuclear reactors is retained within the nuclear fuel, which must be periodically reprocessed in order to remove the radioactive waste products from the fraction which can still be used as a fuel.

A single reprocessing plant (such as those shown in Figs 2 and 3) is sufficient to process the fuels from the thirty reactors mentioned above.

revision. This should not cause surprise, nor should the validity of these limits be doubted. Nuclear research entered the international scene, not as the bringer of those benefits that are in fact a part of everyday life (consider the millions of human lives saved by the use of radioactivity for diagnostic and therapeutic purposes), but stalked by the spectre of Hiroshima and Nagasaki. It was the memory of those who died in these holocausts that led to the development of research and the nuclear industry in conditions of safety unequalled in any other type of research or industry. One need merely recall that, of the 8 437 incidents which occurred in the *US* Atomic Energy Commission establishments in the 25 years from 1943 to 1967, only 38 were due to radiation.

Furthermore, the same prophylactic and safety criteria adopted for the workers and the populations were applied to the environment.

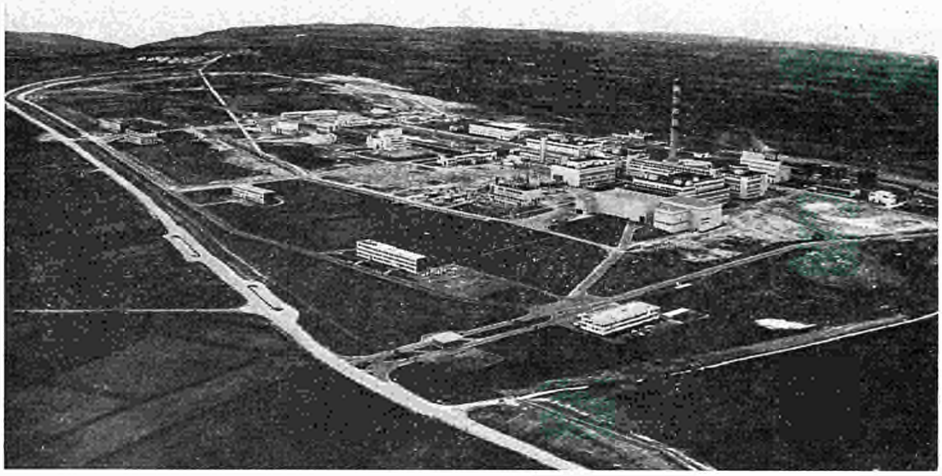


Fig. 2: *Aerial view of the French nuclear research centre at La Hague, near Cherbourg. The reprocessing plant at this centre is at present being modified in order to meet the needs of advanced power reactors. The design plant capacity is 800 tonnes/year.*

The pilot plant PIVER, for the vitrification of liquid radioactive waste, has also been in operation in France since 1969 at Marcoule Nuclear centre. By March 1972 this plant had produced 10 tonnes of glass, made up of waste solutions obtained from the reprocessing of 680 tonnes of spent fuels of various types.

"Radioecology" (the study of the distribution and effects of radioactive products on the environment) was already occupying the attention of hundreds of research workers 20 years ago at a time when ecology as such was still unknown to the general public and was being studied by only a few scientists.

In the same period, nuclear power plants dumped very small quantities of radioactive waste into the sea, taking infinite precautions, while conventional waste, both domestic and industrial, was disposed of with virtually no monitoring and with a very superficial knowledge of their effects. The result was the present pollution of the environment, in which radioactivity played a very minor part.

It is perfectly fair to say that, if the traditional industries had set themselves the same preventive criteria which apply to nuclear research and the nuclear industry, progress would have been slowed down to such an extent that the present prosperity would probably never have come about, nor the energy crisis which threatens to curtail it so severely.

3. Nuclear complexes upset the environment only slightly, but the radioactivity in them increases with time

The term "complexes" is used here rather than "power plants" since energy production involves the use of three types of installation which produce nuclear waste in a number of different ways and may be either completely separate or grouped together in independent units.

They are:

(a) *nuclear power stations*, which burn nuclear fuel to produce energy. The radioactive waste is contained inside the fuel which, for technical reasons, cannot be used up completely; when a certain burnup (which varies according to the type of plant) has been reached, the fuel is removed and conveyed to the reprocessing plant, where the part which is still useful is separated from the waste. Thus, strictly speaking, the nuclear power plant does not produce disposable waste, since the fuel element, although spent, still contains valuable material which is carefully kept. When the reactor is in operation, a small amount of medium-activity waste is produced, the removal of which raises minor problems which, as we shall see, can be solved quite easily.

(b) *reprocessing plants*, which are of the chemical type. The fuel is dissolved and the purified part of the radioactive waste (unburned uranium and plutonium produced by neutron capture) used again. This type of plant produces the most waste, which at present is stored in liquid form, ready for reprocessing, in the plant itself in large tanks with concrete walls one to two metres thick.

(c) *refabrication plants* receive uranium and plutonium in the form of chemical compounds, reconvert them into fuel elements and send them back to the power stations. Plants of this type produce a large amount of solid waste (unserviceable equipment or parts, paper, rubber, etc.) which is contaminated by α-emitters — mainly plutonium — which, as we have seen, must be stored for thousands of years. This waste is at present stored in steel drums, pending a more suitable solution.

A rough idea of the size of the various plants forming a "complex" can be obtained from the following:

- a modern reactor can supply about 1 000 MWe (2% of the electric energy consumed in West Germany in 1970), with an average fuel charge of about 90 tonnes, of which nearly 30 are replaced yearly;
- a modern reprocessing plant, able to process approximately 1 000 tonnes of fuel a year, can supply the needs of 30 reactors which, in turn, can supply all Italy's present electricity requirements;
- refabrication plants, which are closely linked with reprocessing plants, are of similar capacities.

According to the development models set up for the various European countries, the European Community in the year 2000 will have an installed nuclear power of about 600 000 MW (equivalent to about 600 reactors and 20 reprocessing plants, if present dimensions and capacities are maintained). If account is taken of possible technological improvements, it is likely that there will be less than 20 reprocessing plants, probably concentrated in not more than one or two places in each country.

Thus, as we have seen, practically all the radioactive waste is stored in the nuclear "complex". The only waste which leaves the site consits of small quantities of low-activity waste which comes from auxiliary plant operations and can be discharged under safe conditions with the assurance of suitable and continuous monitoring.

The quantity of radioactivity present in a "complex" increases in step with the output of energy while at the same time diminishes as a result of decay (although, as we have seen, in the case of some radioisotopes this is very slow).

The difference between oil- or coal-fired stations and nuclear plants is now clear:

- coal or oil plants dispose of the waste as they produce it, remaining "clean" themselves while the environment is gradually filled with pollutants;
- nuclear power plants keep the waste on site and become increasingly "dirty", while the surrounding environment remains clean.

However, when both types of plant have ceased to operate, being ousted by less polluting energy sources, the waste will nevertheless remain — either stored on the site of the nuclear plants (in quantities estimated in tonnes) or scattered about the environment (in quantities estimated in millions of tonnes).

The concern created by both types of waste is equally disturbing, albeit very different. Nuclear boffins must concentrate on devising reliable containment and storage conditions. The conventional power plant engineers must endeavour to produce fuels and plants which generate less waste and then make detailed study of the effects of such wastes on the environment in an effort to fill a gap which could become a source of anxiety.

In both cases, any simplification of the problem or any assumption that it has already been solved could lead to irreparable ecological damage, leaving behind a completely unquantifiable mortgage for future generations.

4. Radioactive waste can be rendered such as to cause minimum damage to future generations but research is still required on its processing and storage

It is clear that the conditions for the storage of radioactive waste previously described are provisional. There can be no question of increasing the number of plants to cope with increasing energy requirements and of continuing to accumulate casks full of radioactive waste and building new tanks once the old ones are full.

Moreover, whereas the present storage conditions may perhaps be feasible for a fully operational plant where trained technicians are on site to carry out periodic checks on the condition of the casks and drums, such checks cannot possibly be continued over the hundreds and thousands of years during which the waste remains dangerous, when all record of the plants themselves will have long been lost.

Research into the safe processing and storage of waste has in fact been under way for some twenty years and in 1955, at the first Geneva Conference on the peaceful uses of atomic energy, prominence was given to discussion of this problem. At the present time every country with a nuclear power programme is also conducting research into the processing and storage of waste, which inevitably involves duplication of effort, since the problems are virtually identical in every case.

As we have seen, nuclear complexes produce various types of waste which obviously have to be treated in different ways. For economic and practical reasons and in order to ensure that a wide variety of treatments are not developed, an effort is being made to group waste into a few basic categories.

SOLID WASTE. — This constitutes a very small fraction ($< 1\%$) of the total amount of waste produced and includes pieces of apparatus or material which are no longer being used, paper, material from associated laboratories; they are generally stored in steel containers in closed areas (warehouses) or in the open ("graveyards") in isolated and guarded places. This system, which up until now has not presented any major inconveniences, is, however, somewhat cumbersome and in 2000 will probably no longer be feasible, since it would take up too much space.

Some nuclear power stations have for some time and with considerable success used special incinerators to reduce the volume of large quantities of solid waste from reactor fuels.

Nuclear reactors which are taken out of commission after a service life of about thirty years can be classified as solid waste, albeit of a very special type, since they retain considerable residual radioactivity. In this area various solutions are under study ranging from simply retaining the reactor in its original state to complete decontamination, involving dismantling of the plant and subsequent

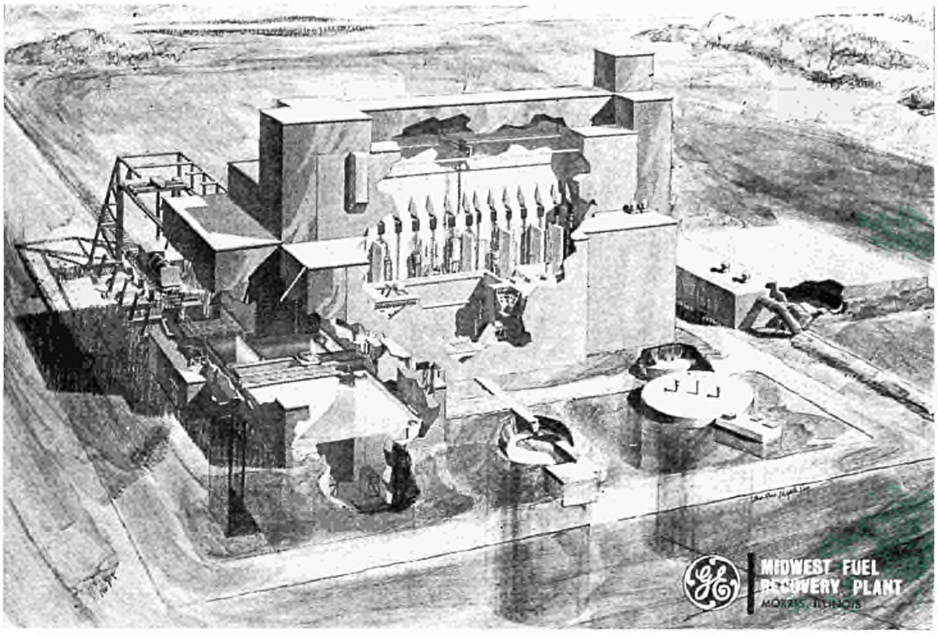


Fig. 3: *The General Electric reprocessing plant at Morris, Illinois, USA, completed recently.*

According to American federal regulations, the inventory of radioactive waste stored in liquid form at the reprocessing site may not be higher than that produced during the last five years of operation. The waste must at all events be converted into an approved solid form within ten years of production and stored in this form until it is transferred to a repository, which must be on federally owned land, and kept under federal control.

The radioactive waste storage zone can be seen on the front of the diagram. At the centre and on the right are two large tanks for the storage of liquid waste. The water pool in which containers holding solidified waste are stored is shown on the left.

restitution of the site to public use once the landscape has been restored.

Thus the problem of the elimination of solid waste lends itself to a variety of technological solutions which are all equally efficient but vary depending on the plant in question, since they are contingent on its characteristics and on the environmental conditions.

LIQUID WASTE. — This is the waste which is causing the greatest concern both to researchers, because it contains most of the concentrated radioactivity, and to the general public, which fears the disastrous consequences of accidents due to failure of the containers. Liquid waste can be divided up into three basic groups:

(a) *low-activity liquid waste*, which includes liquids produced as a result of operations which are ancillary to plant operations and have such a low level of radioactivity that they can be discharged without any special risk. This kind of discharging has already been in use for some time, with very satisfactory results from the ecological standpoint. If and when, as in the case of the methods described for solid waste, this particular solution is no longer feasible, it will become necessary to concentrate and solidify this type of radioactive waste by chemical treatment similar to that employed for the liquids in the next category.

(b) *Medium-activity waste*, which includes liquids which are too radioactive to be directly discharged and should not be mixed with highly radioactive liquids to avoid increasing their volume excessively. Liquids discharged from certain types of nuclear power stations come within this category, as well as some waste from reprocessing plants. These liquids often contain, albeit in small quantities, fission products and α-emitters; processes have been developed by which the liquids are evaporated and encased in cement or asphalt and can then be stored in solid form in "graveyards". While these methods are able to cope with the current situation, they are to be reviewed in view of the more extensive use of nuclear power stations since they do not provide sufficient assurances of safe storage over periods of a hundred years or so. There are a number of possible solutions, e.g.,

- the development of methods which offer greater assurances of safe storage, even if the relatively low level of radioactivity of the solidified effluents does not call for such drastic safety conditions as those required for effluents in the third group;
- chemical separation of long-lived fission products and α-emitters, followed by mixing with high-activity liquids for further treatment. In this case the resulting decontaminated liquid could be treated by current methods.

(c) *high-activity liquid wastes.* — These are liquids in which all the fission products and α-emitters which are not recovered during reprocessing of the fuel are concentrated. It is these liquids which are generally meant by the expression "nuclear waste".

They are at present stored in guarded containers in casemates with thick cement walls to protect personnel against radiation.

This method, which has proved very satisfactory hitherto (the first containers at the Windscale plant have been in use for over twenty years and are still quite intact) was, however, conceived as a temporary solution. No one ever thought that liquid waste would be stored for a period of centuries, since in this form it takes up a lot of space and requires constant and costly surveillance. However, studies have been carried out in several countries on solidification processes based mainly on transformation of the waste into glass, or vitrification. Suitable smelting products are added to the radioactive liquid and the whole mixture is then evaporated and heated until it melts, producing a glass which may contain up to 10-15% by weight of fission products.

Vitrification processes have already been tried out with excellent results in pilot plants; PIVER in Marcoule in France began operation in 1969 and at the end of 1972 had reduced radioactive waste from 680 tons of reprocessed fuel to 10 tons of glass.

By using vitrification processes it is thus possible to reduce the volume of waste significantly. To obtain a clearer idea, this means that the ideal reprocessing plant (capacity 1 000 t/year) would produce about 5 000 m^3 of liquid waste which could be concentrated by a factor of about ten and stored as such or, alternatively, could be reduced to approximately 60 m^3 of glass. The entire amount of radioactive waste produced by the British nuclear energy programme (up to 150 000 MWe) by the year 2000, vitrified and enclosed in stainless steel containers, could be stored in a 5 600 m^2 pool which would form a small part of the reprocessing plant and could be guarded fairly easily; at the same time the glass could be completely recovered once technological developments have provided a final solution to the problem.

In the case of such pools (and other similar solutions which require the glass to be stored in specially built structures under constant surveillance by man) there must be complete certainty that the stresses to which the glass is subjected during storage (high internal temperature, high radioactivity, change of composition due to radioactive decay), do not cause the container to crack and, should this happen, that the radioactivity remains mainly in the glass and does not contaminate the water of the pool to such an extent that it cannot be entered for the necessary repairs to be carried out.

Present experience as regards the storability of glass is very favourable but is based on a few years' observation only; it must therefore be expanded and factored into fundamental studies which will enable us to forecast the behaviour of the glass over several centuries.

The best and probably the final solution to the problem would be to put the waste outside the biosphere, e.g., in deep geological structures of proven stability, such as salt deposits and certain granite or clay structures now being studied. One such structure is in Germany, where the Asse II salt deposit, formed 220 million years ago, has particularly favourable characteristics and has already been in use for some years for medium-activity solid waste. German scientists are currently studying the possibility of storing high-activity vitrified waste in caverns dug out of the saline structure, the caverns gradually sealing up as the hole is filled so that recovery of the deposited material becomes virtually impossible. Before making use of this method, however, we must ascertain whether the geological structure will retain its stability over several millennia, a criteria imposed by the presence of α-emitters. The present state of the art gives grounds for a certain degree of optimism here, but before radioactive waste is stored in a non-recoverable state almost complete certainty is necessary. It should, however, be noted that the replacement of storage in man-made guarded structures by complete elimination in deep geological structures can be studied at leisure over some decades, during which time knowledge will be acquired which will enable us to resolve the remaining uncertainties and to take viable and safe decisions.

Long-term research programmes could render other "final solutions" feasible as an alternative to storage in the biosphere. It has been seen, for example, that the glass remains dangerous for several millennia because it contains α-emitters; if these could be chemically separated, two categories of waste would be obtained displaying very different characteristics:

- *fission products*, which could be vitrified and stored in one of the ways described above and would then have to be kept under surveillance for only hundreds of years as opposed to thousands;
- *α-emitters*, which would have to be prepared for storage over several millennia. The problems involved would in this case be very much simplified by the fact that the α-emitters separated in one year's operation of a reprocessing plant of any size (1 000 tonnes a year) amount to only about 200 kg.

In addition, as we have said earlier, although the biological danger of α-emitters is very high, they can easily be shielded off. Ideally, all the α-emitters produced in a year's operation could be stored in a container of a few dozen litres made of very thin steel. The total weight would not exceed one ton and the radioactivity emitted by the container would be virtually zero.

However, there are two other possible ways of getting rid of these α-emitters once and for all.

The first is to hurl them outside the earth's atmosphere into outer space (preferably into the sun, where they would be consumed in that vast nuclear furnace); this possibility is at present being studied in the United States.

The second involves reintroduction of the waste into a nuclear reactor and burning in the same way as uranium is burned; this solution is at present bein investigated at the Ispra establishment of the *CEC*'s Joint Research Centre.

The economics of reactor operation would probably not be greatly affected but it would be necessary to prepare the fuel elements under more stringent safety conditions than at present and thus at greater cost.

The crucial aspect of this new approach to the problem of radioactive waste, which is certainly a fascinating one, is the technical possibility of separating the α-emitters from the liquid waste in such quantitites that the decontaminated waste can be considered as "free of α-emitters". This possibility is also being studied at the Ispra establishment of the *JRC*.

Finally, the economic aspect must be considered. Whereas the cost of purifying the smoke or eliminating harmful products from the fuel of coal or oil-fired plants has a direct and marked influence on the cost of the energy produced, in the case of nuclear power *the cost of the processes which in the future may lead to an improvement in the processing and storage of radioactive waste will only have a marginal effect.*

At the present time, and assuming that waste is stored in very expensive vats tanks in liquid form, the cost involved is only 0.5% of the cost of the energy. In the future, although the cost of vitrification will be higher, this will largely be offset by a reduction in the cost of storage and surveillance. Economic considerations will therefore not prevent increasingly efficient methods being adopted for getting rid of radioactive waste.

5. Politically harmonious choices have to be taken concerning procedures for the storage of radioactive waste.

What has been said above shows that the problem of the safe storage of radioactive waste can be solved from both the economic and the technical standpoint even though there are some remaining uncertainties as to the long-term solutions to be adopted. Moreover, work in this field hitherto has had relatively low priority and it is reasonable to expect that by speeding up current research an acceptable degree of safety could be achieved

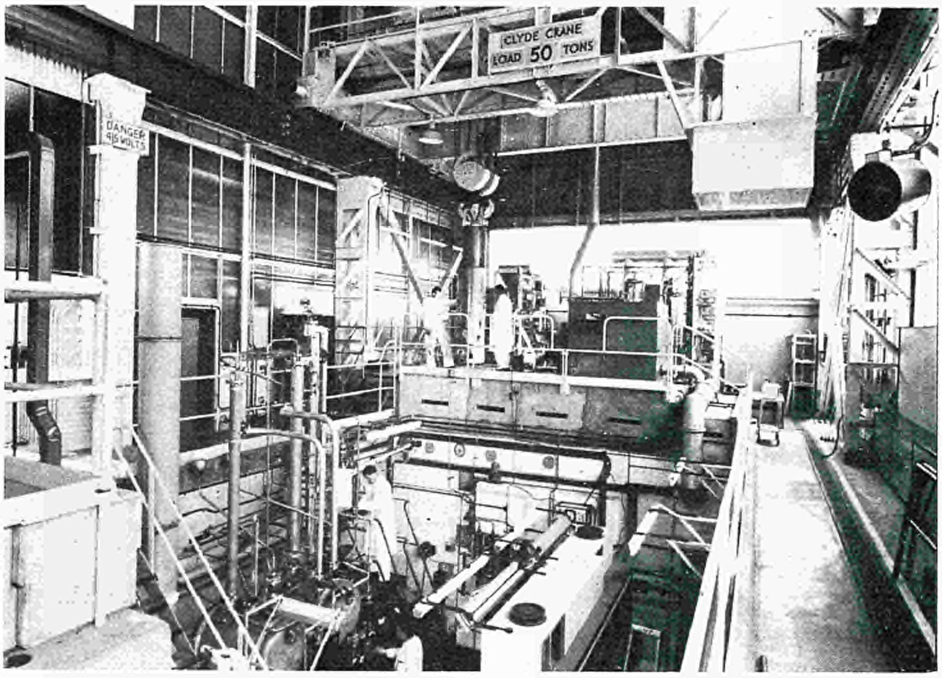


Fig.4: *The experimental unit FINGAL (Harwell nuclear research establishment, UK) for the vitrification of liquid waste. The vitrification technique has formed the subject of experiments for over fifteen years. It is used to transform radioactive waste solutions from reprocessing plants into much smaller and compact solids with a high chemical resistance. The radioactive waste produced by one year's operation of a 1 000 MWe nuclear reactor is contained, after reprocessing of the fuel and vitrification of the waste, in a volume of about 2 m³ of vitrified material.*

over periods of time which are compatible with current programmes for the installation of nuclear power complexes.

However, the human element remains an unknown quantity which is far less predictable than nature, whose laws, although in some respects obscure, are nonetheless immutable. Even if the studies currently under way were to lead very rapidly to the development of methods which were perfect from all points of view, the first dumps created would inevitably have to be accessible to man to enable a careful check to be maintained on whether the storage conditions actually applied corresponded to those laid down. Such checks will have to be continued for as long as possible, in the interest of mankind. Dumps should therefore be politically safe; that is to say, they must be completely immune to consequences of any political instability which might occur in the not so distant future.

Admittedly, recent events warrant a certain measure of pessimism about the chances for the creation of a human society based on mutual collaboration, but it is also true that most modern problems, from overpopulation to the depletion of energy reserves and raw materials to the deterioration of the environment, will not be resolved until such time as international collaboration is better than it is at the moment.

The problem of nuclear waste is only one of the minor worries facing mankind, and if it could not be solved some pessimism as regards our future would be justified.

The question was raised at the United Nations Conference on the Environment which was held in Stockholm in 1972 and recommended that governments "... help to promote international cooperation regarding the problem of radioactive waste through the International Atomic Energy Agency and the other competent international organizations".

The European Community is keenly aware of these problems; they were discussed in the European Parliament on 14 January 1973 after which a resolution was adopted inviting the Commission to present to the Council of Ministers "concrete proposals for the creation of a Community network of radioactive waste dumps and a Community policy for their operation".

In its turn the Council of Ministers, displaying a political will to take positive action about these problems, has taken two important decisions:

- The first was on 6 February 1973, when it was decided to include research on the treatment of nuclear waste and concertation with the national projects in the *JRC*'s multiannual programme in an effort to solve the outstanding technical problems; this programme was finally approved after years of uncertainty and hinges mainly on the problem of the conservation of the environment and of public service.
- The second, taken on 20 July 1973, provided that, under the *CEC*'s environmental protection programme, the Commission be invited to establish, in collaboration with the national experts, "a techno-economic inventory of projects which could be proposed regarding the treatment and storage of nuclear waste, initially in the short term and subsequently over the longer haul, and of their reprecussions on the harmonious development of nuclear energy. This inventory could then be used as the basis for action to be taken at Community level".

Conclusions

It would seem therefore that there is a good chance, even on the political plane, of solving the radioactive waste problems posed by the greater use of nuclear energy. It is reasonable to suggest that, by dint of perseverance, the nuclear industry could grow into the role it is being asked to play and for which it is eminently suited, without creating problems for man or fro his environment. While it would be foolish to underestimate the difficulties which still remain, it would appear, however, that the alarmist language in which these problems are so often couched in the press nowadays is unnecessarily exaggerated.

EUSPA 13-3

Technical Notes

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

— 2009: Asymmetrical magnetic coils

The invention relates to magnetic coils the conductor of which is completely asymmetrical in relation to the bore. If in particular cases cylindrical coils are not to be used, the conductor is asymmetrical on a plane of projection vertical the axis of the coil.

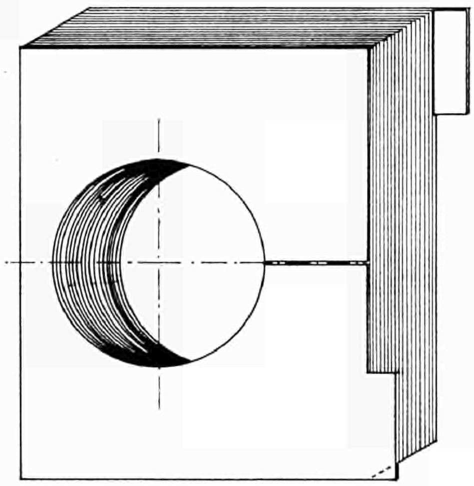
Although solely from the point of view of ohmic loss these coils are not ideal, there are cases in which asymmetry is an advantage. It saves space at the side of the coil where the conductor material is thin, and with more conductor material on the rest of the coil where there is sufficient space, electrical resistance and therefore the performance required are reduced.

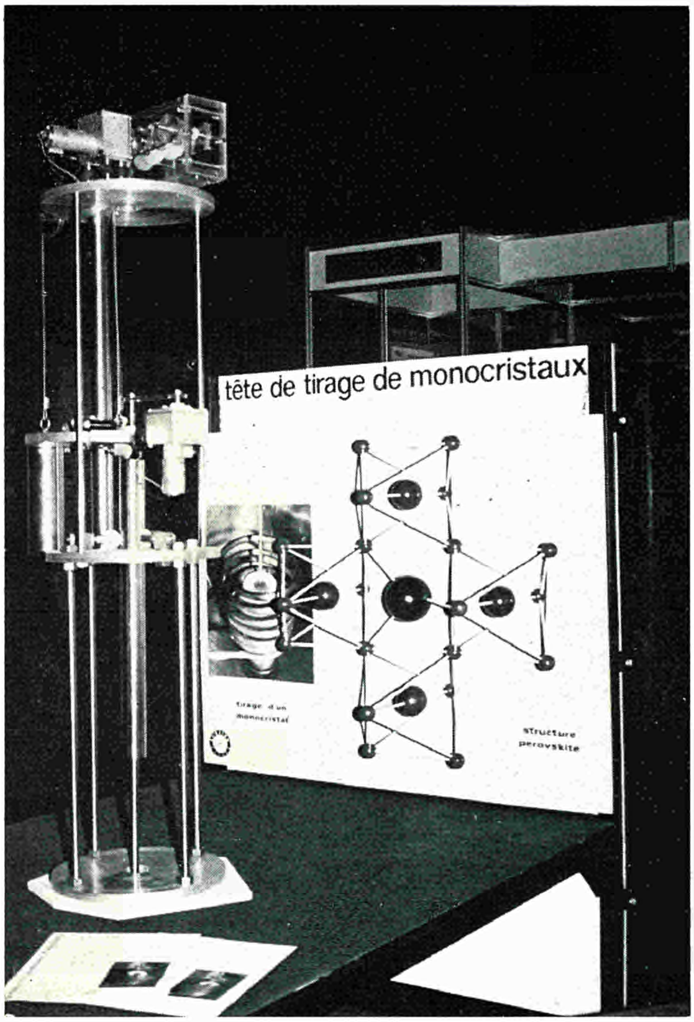
Asymmetrical coils also have the advantage that with curved magnetic fields the distance to the centre of curvature is reduced, while the wider area outside the plane of curvature may also be used.

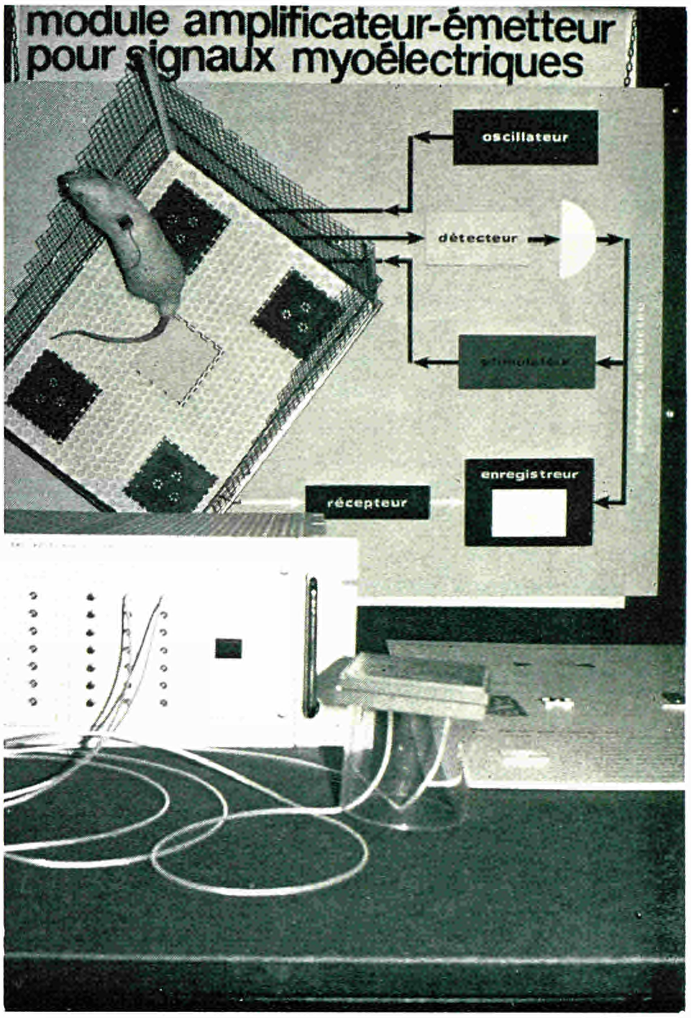
In cases where an induced electric field is required in addition to the magnetic field—as very often happens in plasma technology—any reduction in space from the coil to the centre of curvature is of the greatest value: it allows for a larger transformer and a higher electrical field intensity.

Asymmetrical coils may be made in a number of different ways. They are manufactured most easily from plate or sheet metal, and may consist of separate parts which are soldered, welded, clamped, or otherwise joined together, or they may be made of a single piece of metal.

This invention has been realized by Mr. H. B. Brandt in the *FOM*-Instituut for Plasma-Fysica—Jutphaas (The Netherlands).







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— **2010: Drawing head for single crystals**

This mechanical drawing head is able to produce high-purity crystals in a wide range of materials by means of molten baths. It is designed to operate with any type of oven—in ambient or vacuum or pressure controlled atmospheres.

Its design makes for extremely economical production and at the same time ensures uniform drawing and rotary action. The slow travel achieved in the usual screw and nut systems creates intense friction forces, thus producing stresses which release suddenly.

The resulting vibrations are transmitted along the rod carrying the crystal nucleus as far as the solidification interface and cause dislocations.

These problems are reduced by the present head; it is balanced and has a weak and constant tractive force, limited to the upthrust of the crystal. Bearing action replaces friction, as the parts in contact are fitted with high-precision ball bearings embedded in an insulating material. The movements are transmitted by means of reinforced plastic serrated belts which prevent slipping or oscillation.

Main characteristics:

Rate of rise: continuously variable from 0.1 mm/h to 20 mm/h.

Rotation of the crystal nucleus holder: continuously variable from 0 to 100 rpm.

Travel of crystal nucleus holder: 270 mm.

Maximum load: 2 kg without affecting regularity of drawing.

▲

— **2011: Amplifier-transmitter module for myoelectric signals**

Technical details:

Transmission frequency: 2.2 MHz.

Modulation: FM ± 100 mV/± 20 kHz.

Range: 1 metre.

Amplifier gain: 1 000 (60 db).

Input impedance: 5 MΩ.

Cell: lithium 3 V.

Current absorbed: 150 μA.

Service life: 3 weeks.

Volume: 3.5 cm^3.

Future development:

Reduction in size.

The size is in practice governed by the dimensions of the cell. It can be expected to reduce the volume to 2 cm^3 to 2.5 cm^3, by using the "thick films" technique with reported miniature components.

— 2012: Binary-decimal converter

Iterative circuits are a new type of circuit in which interest has, until now, been purely theoretical owing to their complexity. With the introduction of LSI circuits, however, it has become possible — and even quite simple — to produce iterative circuits, and it now seems feasible that they will be brought into general use. The proposed iterative circuit converts binary numbers into decimal numbers and vice versa.

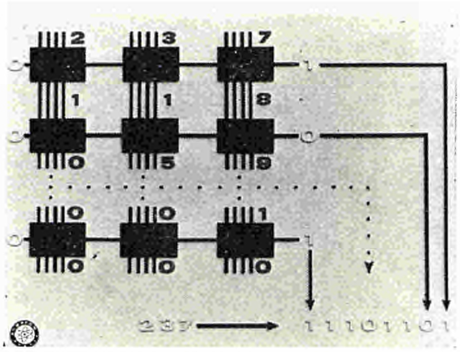
This new converter has certain advantages over existing conversion circuits:

1. The circuit converts both the integral parts and the fractional parts of numbers.
2. The same circuit is used to convert decimal to binary and vice versa.
3. All binary codes used to represent decimal digits can be used, and the method of determining the appropriate circuit is simple.
4. One last, important advantage is expansibility. If, for example, an LSI circuit is produced to convert numbers with 3 decimal digits, 4 circuits can be linked together to convert numbers with 6 decimal digits.

The size of a circuit is not limited by any theoretical considerations and it is possible to produce a circuit converting numbers of digits in any required size.

The size is limited only by technological considerations.

This type of circuit will have numerous uses, in small computers or pocket calculators and peripherals, to put the information into the correct form, or in large computers, to simplify microprogramming.



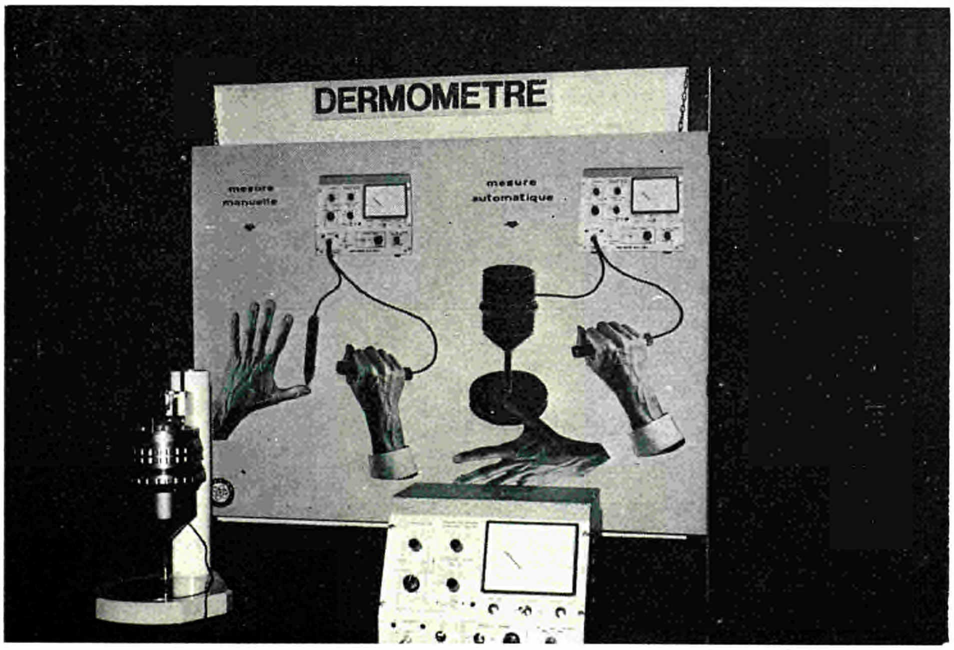
— 2013: Skinmeter, measuring electrical parameters of the skin with low irritation

The measurement of electrical skin impedance is increasingly applied in diagnostics and monitoring. It also might be of interest for research to measure by more reproducible methods the fine structure impedance patterns of the skin.

One of the obstacles to objectivation of impedance measurements of a physiological tissue is the possible falsification of the result due to alterations of the tissue introduced by the measurement method. Influences of mechanical electrode pressure will be rather difficult to avoid. To exclude changements caused by the applied current itself this has been reduced to very low values in the developed instrument.

Furthermore the time integral of the current has been kept zero and every bipolar measurement pulse is followed by a relaxation interval. For contemporary skin structure investigations under microscope a modulated acoustic signal indicates the measured value.

Provisions for capacitance and potential measurements are incorporated.



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