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SCIENCE AND THE PROTECTION OF THE ENVIRONMENT

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SCIENCE AND THE PROTECTION OF THE ENVIRONMENT

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SVMMARIVM — Auctor de biosphaerae pollutione tractat, cuius varia problemata et exhibet et perpendit, indagationes proponens, quae a complurium scientiarum doctoribus fiant, ad grave illud incommodum extirpandum.

INTRODUCTION

It is well known that during the last years the development of man's activity has deeply affected the biological and physico-chemical equilibria all over the world inducing general and local modification in the composition of the whole environment.

The concern of scientists for this progressive change has now reached governments and public opinion who call on scientists for remedies and guidelines in order to protect one of mankind's greatest treasures, the environment, and thus, human health and welfare.

Throughout the ages the environment, air, water and soil, reached an average composition which remained constant for

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Invited lecture held in April 16th, 1970 during the Plenary Session of the Pontifical Academy of Sciences.

years, as any modification was counterpoised by a series of biological, chemical and physical reactions.

Recently, the rate of growth of human activities which involves population increase, social transformation, improvement of economic and health conditions as well as the new economic and technological development, has deeply modified the equilibria in the world. Moreover, the effects of these changes have greatly affected the environment with a number of pollutants which have caused a modification in the composition of air, water and soil.

We cannot now forecast what influence these factors will exercise not only upon men but upon any form of life in the future.

Science, which in recent years has created the basis of the present erupting technological progress, has now been called to study and solve the problems of the environment which at present are conditioning the further development of mankind.

If we consider the environment formed of air, water and soil, we may assume that it becomes « contaminated » when its average composition is modified. On the other hand we define as « polluted » the environment when the modification induces damage to persons or to any living matter.

We shall examine separately the background contamination which can be generally widespread all over the world and the contamination which for its quantitative character is generally confined to determined areas and may sometimes be considered pollution.

Contamination of environment

The environment contamination may be due to natural phenomena or to human activity.

Among natural causes we may recall dusts from erosion or other natural events such as volcanic eruptions or collapsing

of river banks, like the dusts brought by wind from the Sahara to Europe or the mud and trees in equatorial rivers.

The carriage by the winds of pollen, spores, insects, fungi and other micro-organisms may also be regarded as natural contamination.

According to the agent which modified the biogeochemical equilibrium, the contamination due to man's activity can be defined as chemical, microbiological, radioactive and even physical if we consider the acoustic and thermal burden of our medium.

An example of chemical contamination is the presence of dusts in the atmosphere, of hydrocarbons in water, of pesticides in soil.

Microbiological contamination is due to the presence of wastes and sewages in rivers, lakes and in the sea.

We may define as radioactive contamination the presence of artificial radionuclides in the air, water and soil, as well as in the food chain. We may define as thermal contamination the modification of the temperature of rivers and lakes due to heat generators or to cooling devices of industrial plants.

Acoustic contamination, which is presently confined to towns, factories, airports, highways, is the trouble produced by an excess of noise in the environmental equilibrium.

The primary causes of these alterations of the environment are due to the presence of man and to his activity.

The production and metabolism of goods yield solid, liquid and gaseous wastes which cannot rapidly re-enter the biological cycle, thus upsetting the environmental equilibrium.

At present the main cause of contamination is that elimination of wastes does not keep pace with production.

In fact, man with his cities, his industries and his cultivated lands has deeply modified the natural environment causing by the products of his activities its contamination and even its pollution.

The polluted environment acts on the ecosystems, upsetting them and thus modifying biological equilibria.

The modifications of ecosystems may influence man's life and activities, increasing through biological cycles the rate of pollution of the artificial environment he has created.

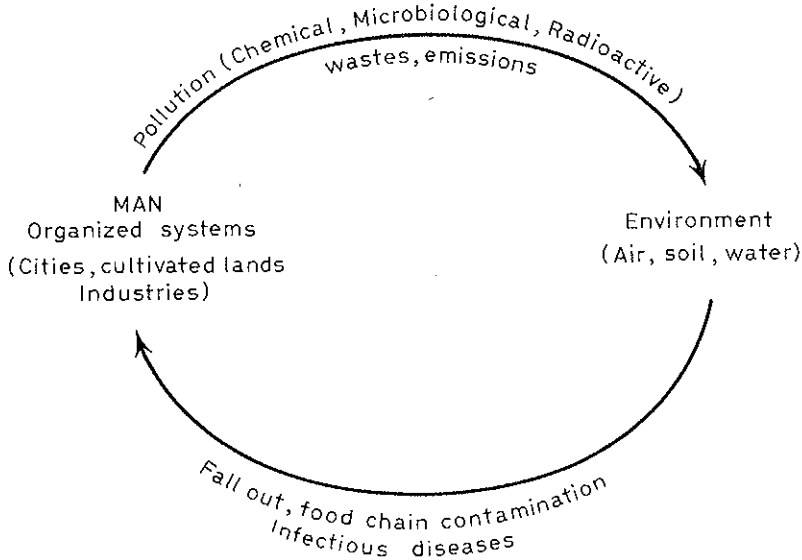

FIG. 1

Pollution of ecological cycles

It is obvious that the development of mankind is now intimately connected not only with the availability of energy and food but also with the protection of his environment.

Therefore it is essential to envisage realistically all the means for preserving the integrity of the human environment by reinserting the wastes in their ecological and biological cycles and avoiding further alterations. Science as the most qualified expression of man's activity is now called to solve the various

problems connected with the elimination of impurities without modifying our environment.

This fact poses a lot of problems to which there is no common solution, since they are extremely heterogeneous.

In some cases all the data are available for planning the reduction of pollution and it will merely be a question of choosing the most favourable solution both from its technological and economical aspects.

But in the majority of cases any possibility of solution must be preceded by the acquisition of all the data connected with the various aspects of pollution. Only on this basis it will be possible to face the various problems both globaly and individually.

THE SOURCES OF BACKGROUND CONTAMINATION

On a theoretical basis the contamination of the environment should be considered as a whole, since the contaminations of air, water and soil are interdependent, but from the practical point of view it may be useful to examine the three aspects of the problem separately.

The production of energy by combustion of carbon or hydrocarbons both from industrial and domestic sources is the principal cause of air contamination. The main products of combustion are CO_2 and SO_2. The quantity of these substances produced is continually on the increase and is directly related to social development, with the increase of population and new needs. The modification of air composition by these substances may create some new and particular problems.

The balance CO_2/O_2 in the atmosphere was maintained practically unaltered down through the ages by the photosynthetic activity of plants and by the presence of the large masses of water in the oceans. But we are now envisaging a slight

but significant change in this balance as a result of increasing immissions due to man's activity (McCormick, 1968).

The increase of CO_2 in the atmosphere may lead to an increased average temperature, due to the effect of this gas on the *infra-red radiative balance of the earth*, i.e., to the fact that CO_2 is able to absorb the infra-red radiations reflected from the earth.

Composition of clean dry air

N_2	78.09 %	H_2	0.00005 %
O_2	20.94	CH_4	0.00015
Ar	0.93	NO_2	0.000000I
CO_2	0.318	O_3	0.000002
Ne	0.0018	SO_2	0.00000002 (0.0002 ppm)
He	0.00052	CO	0.00001 (0.1 ppm)
Kr	0.0001	NH_3	0.000001
Xe	0.000008		
NO	0.000025		

A thorough examination of the meteorological data over the last twenty years shows a slight increase in the CO_2 percentage in the air from 290 to 330 ppm in the last fifty years and a very slight increase of temperature.

Further increase could lead to modification of climate not only locally but all over the world. With 600 ppm CO_2 we can calculate an average temperature increase of 1°.5. The consequences could be the partial melting of ice in the polar areas with results which can be imagined on a basis of the prehistoric cataclysms which characterized the passage from the Ice Age to the present era.

On the other hand, SO_2 formed in the combustion of all sulphur containing substances, always present in every kind of fuel, constitutes the principal parameter of contamination of the civilized world.

Its irritatory properties, its easy transformation into sulphuric acid makes this substance a dangerous chemical agent both for man and *nature*. Its effects can be ascertained now hundreds of miles from its source.

Dusts produced by combustion and in all the big industries, when dispersed in the air, may produce a number of atmospheric phenomena of a certain importance.

In relation to the dimension of the particles, these dusts may produce an effect on weather, increasing fog and reducing rainfall mainly in urban areas, or they may affect the amount of solar radiation received by the ground (McCORMICK, 1967).

Another aspect of environmental contamination is the radioactive contamination due to the explosion in the atmosphere of nuclear experimental weapons. This aspect is not so urgent at present, since these experiments are limited.

The distribution of radioactive substances and their fall-out on the ground furnishes a model for investigation of the movements of particles in the atmosphere in cases where they can be detected.

The same model can also be used with regard to other substances dispersed in the atmosphere.

SOURCES OF LOCALIZED CONTAMINATION

In addition to worldwide contamination, pollution most frequently develops in restricted areas like river-basins, valleys, lakes etc. These can also contribute to worldwide contamination, but each of the above-mentioned cases constitutes a different approach, depending not only on the type of contaminant but also on the nature of the receptor and its environmental conditions.

We shall now consider the various receptors.

Air

The contamination of air can be due to fumes, dusts, chemical substances from domestic or industrial sources (first of all SO_2) or from motor traffic (CO, hydrocarbons, lead, aldehydes, nitrogen oxides) or from industrial emissions (several gaseous products, dusts or aerosols).

The effects of the aforesaid substances on natural equilibria, and in the first place on human well-being and health, generally depend on their concentration.

Concentration of substances in the air mainly depends on the manner in which they are discharged, i.e., the dimension of the stacks and especially the atmospheric conditions.

An industrial plant can rarely be considered a source of contamination in an area exposed to winds, but the same source can be the origin of heavy pollution if located in a valley or in an area subject to thermic inversion. The thermic gradients of air layers undergo several days a year an inversion, i.e., where the upper layers have a higher temperature than the lower, there are no convectional currents to lift and disperse emissions.

Sources of principal air pollutants and their relative ratio (in %)

Sources of pollution and their percent contribution	SO_2	CO	Hyd.	Nit. Ox.	Partic.
Industry (17%)	34.8	2.8	21	15.5	50
Electric power plants (14%) .	46	1.4	5.25	23	25
Domestic heating (6%) . .	11.6	2.8	5.25	7.75	8.33
Automobiles (60%)	3.8	91.6	63	46	8.33
Refuse disposal (3%) . . .	3.8	1.4	5.25	7.75	8.33

These inversions may reduce the disposable air layer, where emissions and dusts are discharged, to only a few feet.

In this « confined » space, a high concentration of aqueous vapour is also usually found.

This can enhance the effect of particles and other suspended matter, thus facilitating the formation of new chemical substances under the influence of sunlight, or of particulates and aerosols (fog or smog). This is the reason why under such conditions there is a marked increase in concentrations of noxious substances and hence pollution, damaging man and the environment.

Much attention was drawn to these particular phenomena in the past by reason of some spectacular happenings in the last thirty years both in urban and industrial areas. These facts which now belong to the history of air pollution have contributed substantially to creating in public opinion an awareness of the need for a new policy to solve these problems.

Water

Water contamination can be attributed both to indiscriminate sewerage, usually with a high microbical charge, and to industrial waste matter which is quite varied and unpredictable. The latter can be made up of residues of organic matter, or of concentrated solutions of salts, often toxic both to animals and vegetation.

Another source of water pollution is agriculture and cattle-raising. The solubilization of nitrates and phosphates from the soil (fertilizers etc.), causes an accumulation of large quantities of these salts in water and thus contributes to the modification of the biochemical balance which governs processes of self-purification.

A further source of contamination is the presence of petrol, our main source of power, in the sea, both through leakages

during worldwide transportation and through the presence of submarine wells which are now being exploited.

Water systems, as already shown, possess a great flexibility as a defence against pollution, due to the presence of dissolved oxygen and microbial flora. In these systems the transformation of organic matter into CO_2 and H_2O, is the basis for self purification (PILPEL, 1968).

If pollutants are discharged into a water system, in excess of the quantity it is capable of transforming, the water system loses its dissolved oxygen and its properties of self-purification.

The phenomenon is still more complicated in the case of lakes; sometimes high concentrations of nitrates and phosphates can produce an excessive growth of algae. Dissolved oxygen diminishes in such cases, animal life becomes impossible and the lake gradually becomes a marsh.

Sea contamination, due to the high power of selfpurification as a result of the presence of salts as well as micro-organisms, is characterized by localized pollution near the coasts and by widespread contamination by oil and radionuclides and even metal salts.

Localized pollution may take place especially along the coastline, near towns or estuaries and wherever high concentrations of urban or industrial waste matter is discharged into the sea. Lack of winds and of marine currents may sometimes cause higher concentrations of both microbiological and chemical pollutants.

The presence of some particular contaminant in the sea, such as oil, radioactive waste matter and pesticides and microorganisms may be of a certain interest, for by means of a concentration process (i.e. *Acantherus* for Sr^{90}; clams for hacteria and viruses etc.) these substances may also enter the food chain (SCHREIBER, 1959).

Soil

The disposal of solid waste matter deriving either from human life or from industry, poses a number of new problems affecting both water and air pollution at the same time. It has been calculated that in industrially developed countries there is a daily disposal of about 7 pounds of solid waste matter per inhabitant per day in urban areas, and about 4 pounds in rural areas.

The problem becomes very serious in large urban areas: the possibility of elimination of waste matter in the fields after composting is more and more difficult, while incineration causes air pollution. Furthermore, transportation to other areas gives rise to many difficulties. In recent years the overall composition of solid waste matter has changed and most of the substances cannot be easily reintegrated into natural biological cycles, because not attacked by soil micro-organisms. This is the case with plastic materials, metal food containers, used cars, rubber tyres and so forth.

Many of the solutions adopted have created new problems of air and water pollution. The incineration of chlorinated plastics (PVC) causes emission of gaseous chlorinated substances. The presence of metals may pollute water layers used for drinking.

Pollution from the disposal of chromium salts in Northern Italy is an example of this indirect contamination (MARINI-BETTÒLO, 1968).

Waste matter from industries and from mines has also determined various difficulties.

The disposal of solid waste matter, although less spectacular than air and water pollution is nevertheless a cause of concern, due to its dimensions. Moreover, disposal of solid waste matter must be considered together with the other problems of environmental protection.

The present situation shows the urgent necessity of a rational approach to this problem, also in view of the importance of

its direct and indirect effects on health and economy. In point of fact, the presence of organic matter subject to decomposition in wastes may be the cause of spreading epidemics. Rats, other rodents and flies, the vectors of many diseases, are attracted by these substances and therefore multiply rapidly.

* * *

Up to this point we have merely dealt with chemical and biological contamination of environment. We must now take a rapid glance at the effect of noise and heat. Both are linked with urbanization and with social and industrial development.

For the prevention of environmental noise in towns and cities, the technology of building and traffic problems must be taken into account.

The so-called « airport effect » and the noise due to the growing number of jet planes has created new problems with regard to the establishment of airports and the location of new urban installations.

The effect of noise on the human nervous system is well known and thus noise must be prevented as far as possible, reduced or abolished. The increase of mental illness in urban areas may in part be attributed to lack of rest and the frequent stress occasioned by noise.

Thermal pollution is connected with the presence of industrial plants: water used for cooling purposes in these factories is given back to rivers and lakes, causing a rise in the temperature of the water. This factor is of great importance, since it can modify the ecological balance in rivers and lakes, in favour of some species as opposed to others (COLE, 1969).

Guidelines for research on the protection of environment must be found as soon as possible, in order to study the problems arising from contamination. For the solution of these problems, an interdisciplinary effort is required, where all the sciences would cooperate to solve the various aspects of these problems.

RESEARCH

1) *Knowledge of the laws governing distribution of contaminants in air and water*

As previously explained, there is a worldwide contamination due to dusts, pesticides and chemical products. Although there has been much research in this field, we still know very little about the worldwide dispersal of pollutants. Research by MURGATROYD (1969) in Great Britain using easily detectable substances as tracers, as azone and radioactive substances, and the new technique of the constant level balloons, using the numerical forecast model developed by BUSHBY and TIMPSON (1967), afford results which should be extended.

Research carried out by the USAEC on the fission product of nuclear explosions has given much information on the distribution of particles in the atmosphere and on their fall-out condition (LOWMAN, 1960, 1968), (EISENBUD, 1963).

In addition, NEIBURGER'S (1969) data on the dynamics of air pollution in the United States show the great possibilities of these techniques in forecasting the areas which will be affected by pollution and throw some light on the mechanics of the processes by which pollutants are removed from the atmosphere.

Much information on the movement of particles in the air was obtained when accidents occurred in nuclear plants, such as that of Windscale in 1957. Nevertheless, we are still far from a complete knowledge of the movement of particles on a worldwide scale and their relation to meteorological conditions.

The results obtained by WOODWELL (1967) with regard to the dispersion of particles of pesticides in the air, which exactly follows the pattern of radioactive substances, as well as that of GATZ and DINGLE on pollens (1966), indicate that particles of

the same dimensions behave in the same way. The present criteria for the elimination of smoke and dusts through tall stacks could be completely changed if it could be clearly demonstrated that the dilution rate is not sufficient to disperse the contaminant but only to transfer contamination to other areas.

Recent results of measures taken in Sweden show a perceptible percentage of sulphuric acid in rainfall, probably due to the SO_2 air pollution of industrial centres in Germany.

It is thus important to establish mathematical models on the available meteorological data so as to forecast the movement of polluted air. Many models have been suggested up to the present time, but the great variability in space and time of the various parameters makes it very difficult to use them in a diffusion equation.

At this stage, we can consider as fairly realistic the project for a special satellite which would furnish all necessary data for worldwide information on the movement of pollutants and permit us to establish rules governing the distribution of particles in the atmosphere.

2) *Biotransformation of pollutants*

Although we possess a certain amount of information as to the fate of pollutants in the environment, many data are still lacking for a full pattern of the various contaminants in air, water and soil.

A number of data are available, for instance, on the fate of certain synthetic chemical substances, such as chlorinated hydrocarbons widely used as pesticides or weed killers, which are found practically unmodified in different parts of the earth after years.

The same substances are found in all the biological cycles: human fat both in the U.S. and in India contains a certain amount of DDT.

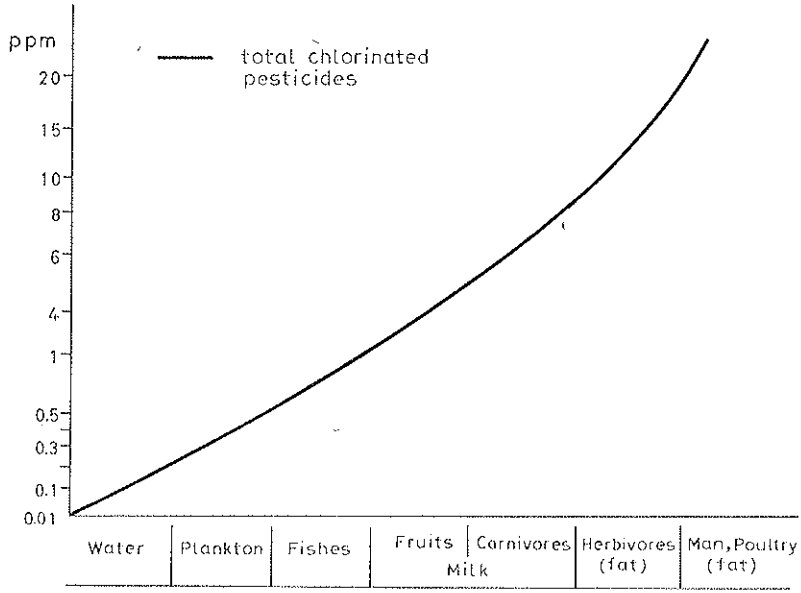

FIG. 2

Concentration of chlorinated pesticides in the food chain

Wild-life is also affected by the contamination of these substances which are concentrated in the biological processes of plants and animals (MARINI-BETTOLO, 1969).

It is now necessary to acquire new information with regard to the biogeochemical transformation of pollutants. The formation of aerosols and particles in the atmosphere as in the case of SO_2, and the chemical interaction between various contaminants, widely dispersed and under the influence of light, are questions which still need to be cleared up (CADLE, 1966).

What has already been established about the role of oxidants in the atmosphere in the presence of unsaturated hydrocarbons, indicates the possibility of a number of reactions related to the different kinds of molecules that may be present and even to different climates and atmospheric conditions.

These investigations may lead to a completely new approach to this problem. The appropriate use of radioactive tracers will be of great importance in such research.

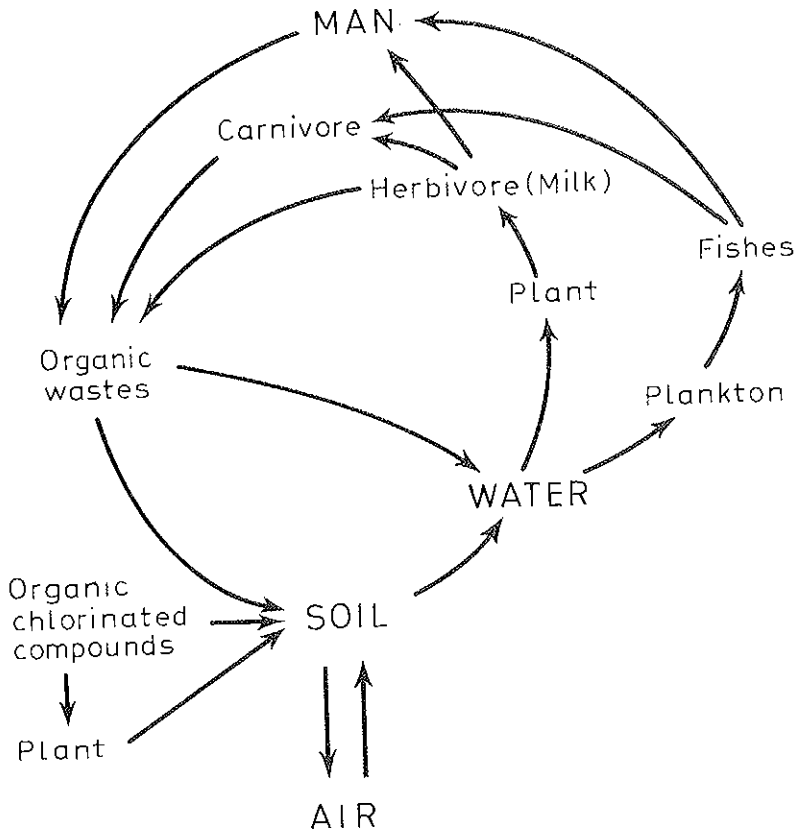

FIG. 3

Biological cycle of chlorinated hydrocarbons

Biotransformations due to oxygen and micro-organisms characterize rivers, lakes and the sea. Although many data are available, we still know little about many processes of new man-made molecules.

Recent observations on the metabolism of oil in the sea by an associate system of dispersion, self and microbiological oxidation, indicate the need to obtain further information on these natural processes which could be utilized for other purposes.

Further knowledge of the chemical microbiology of the soil constitutes a new approach to the disposal of man-made solid waste matter such as plastic materials, or to the transformation of chemical products such as chlorinated pesticides or synthetic detergents.

3) *Effects of contaminants on ecosystems*

Science knows very little so far about the effect of contaminants on ecosystems. For the purpose of reviewing our position on this subject, further research and information are required. We already have some data, generally uncorrelated, as to the effects of several known contaminants on ecosystems, e.g., the effect of dusts or SO_2 on plants, of fluorhydric acid on vegetation, the changes produced in biological equilibrium after the introduction of pesticides in agriculture, causing a deep modification in insect species in favour of the resistant ones.

The examples reported by RAY SMYTH (1969) as a result of his experiments in Peru, on cultivated areas practically isolated by sea or desert, have clearly demonstrated the negative effect of the uncontrolled use of pesticides on insect populations: induction of resistance on the one hand and the suppression of biological warfare.

Another point which needs to be cleared up concerns the biological balance which governs processes of self purification in rivers and lakes.

Further research and data are required not only in order to establish the means of reintegrating conditions of balance in some polluted rivers but also to get more information in order to impede biological processes such as eutrophication which are seriously affecting several lakes like Eyre and Zurich.

Morphological and limnological study may make it possible to establish, by means of the appearance in water of particular new species of micro-organisms and its biochemical interpretation, the basis of a new approach to the prevention of eutrophication.

It has recently been pointed out that relations between contaminants and ecology are so far very little known. The fact that the international biological program has taken over this study as one of its main topics indicates that this problem can only be solved on a multidisciplinary basis.

4) *Effects of contaminants on man's health*

Protection of the environment is only an aspect of what science really has in view, namely, the protection of mankind. It is therefore necessary to establish the effects of contaminants on man's health and on the artificial environment created by men (GOLDSMITH, 1968).

Although there can be no doubt that air pollution is irritating and a nuisance to man (dusts, smog odours) so far there is no evidence of direct correlation — after accurate epidemiological studies — between air quality and tumours. There are in fact so many independent variables to be considered, that only a very rough appreciation can be drawn from the fact that a higher rate of cancer is found in countries based mainly on industrial economy than in those which have a predominantly rural economy.

There is certain evidence to show that bronchitis can be partially dependent on the average concentration of SO_2 in the air, and to particulate pollution.

Obviously these investigations must be interdisciplinary. In the case of some characteristic industrial emissions, these correlations can be more easily found, as their specificity is not masked by other factors such as smoke.

These results, after a certain time, may make it possible to establish the critical levels for man's safety of the principal contaminants.

We may point out the fact that in urban areas in the presence of motorized traffic the air is contaminated by lead, originating in the motor exhaust from the tetraethyllead used in gasoline.

It was calculated that man's absorption may reach 22 μg per person per day for air containing 3 μg per cubic meter of lead. Although lead toxicity is well known, up to the present time no relationship has been established between diseases and lead absorption from the air. Nevertheless, there is at present under consideration the possibility to eliminate lead completely from motor fuels and to use gasolines of high octane content (DANIELSON, 1969).

From some points of view the relationship between water contamination and human health is clearer. It is a well-known fact that microbial or viral and even parasitic diseases may be transmitted to man directly or indirectly through water.

It is still necessary to establish the role of polluted waters in many diseases such as viral hepatitis. We must stress the function of man's absorption from water of both toxic agents and pathogens not only from microbial flora but also from aquatic animals, e.g. diseases transmitted by ingestion of polluted clams, or schizostomiasis transmitted through the aquatic snail (*Planorbis*).

In soil contamination, as we have already seen, the indirect

effects of metal salts on the contamination of drinking water and of the food chain should be considered.

Investigations are in progress with regard to the effect of pesticide on man. It is now considered that every man has an average of 20 ppm of chlorinated pesticides in his fat and even in the nervous tissue. In Italy a complete survey by PRATI, PAVANELLO and GHEZZO (1970) has shown even higher figures of contamination in agricultural areas of Ferrara province.

Levels of accumulation of chlorinated pesticides in ppm in different human tissues according to DE VLIEGER et al. (1968, CASARETT et al. (1968) *and* PRATI et al. (1970).

		DDT	Dieldrin	Heptachlor
Liver	1	0.14	0.034	—
	2	0.30	0.0037	0.0019
	3	1.3	0.088	0.72
Kidney . . .	2	0.31	0.0056	0.0009
	3	0.53	0.006	—
Brain	1	0.034	—	—
	2	0.104	—	0.0002
	3	0.28	—	—
Spleen	2	0.048	0.0021	—
	3	0.188	0.021	0.014

It is now necessary to establish through research the direct or indirect influence of these small quantities on health after long periods.

Levels of chlorinated pesticides in human fat (in ppm)

Year	State	N°. of samples	DDT	BHC	Hepta	Dieldrin	Authors
1961	USA	30	6.69	20	—	0.15	Dale
1962	GB	131	2.21	—	—	0.21	Hunter
1963	USA	282	11.1	0.57	—	0.11	Hoffman
1964	India	24	30.2	1.7	—	0.23	Dale
1965	Danmarck	18	3.3	—	—	0.20	Weihe
1966	Canada	47	4.39	0.07	0.14	0.22	Brown
1967	USA	29	6.28	—	0.032	0.063	Casarett
1966-1969	Italy	85	13.26	—	0.41	0.68	Prati

Although no perceptible « change » was observed in the « rate » of growth of five significant diseases after the introduction of DDT, we cannot disregard the effect of these substances on cells and especially on the cell wall membranes.

For these reasons it is most important to study these substances at molecular level, their influence in cell enzymes and the mechanism of their turnover, in order to accelerate their eventual elimination from the body.

The effects of contamination on the human environment, such as urban areas or cultivated lands, should be thoroughly investigated. Up to the present, the effects of pollution have only concerned man and his health, and to a partial extent his environment — housing and cultivation — but only from the economic point of view. From the scientific point of view we must now consider the effect on agriculture of waters polluted by chemicals, which alter the smell and taste of crops and also of noxious fumes from industries.

The injuries to buildings, monuments, power lines and building materials are known, but the study of the causes is still very incomplete, as is shown by research on the decay

of monuments in Venice and Florence. A thorough examination of the causes may bring to light some unexpected sources of pollution or establish the existence of special atmospheric conditions capable of carrying pollution from a distance. At the present time we possess very little knowledge with regard to the effects of pollutants on man's organized activities.

Scientific action

On the basis of many available data and of recent research it is now possible to adopt several measures to reduce both background and localized contamination of the environment.

We must consider, among these administrative measures, the reduction of the use of chlorinated pesticides, the abolition of nuclear explosions in the atmosphere, special care for the disposal of radioactive matter both in the soil and in the ocean, for the transport of oil by sea and for the reduction of the use of fuels containing a high percentage of sulphur.

Technical devices have also contributed to the reduction of pollution by cutting out fumes in factories or power stations, by eliminating solid waste matter on the soil and in the treatment of sewage before its release into rivers.

A number of good results have been obtained in various areas where air pollution was very detrimental to the atmosphere, as in London.

A great effort is necessary, however, in order to throw light on all the obscure aspects of this question, with a view to establishing the basis for a technological solution of the problem.

If we are to consider the order of priorities for the solution of this problem, we must first face the need for a modern analytical methodology for the determination of contaminants both in air and water. Present methods based mainly on the classical reaction of wet chemistry have now been surpassed,

especially if we are to follow the variations of concentration over a period of time (SMITH RALPH, 1968).

Today, we envisage directly responsive sensors based on quite different principles. For example by these new methods, ozone could be detected on the basis of the chemiluminescence induced by the introduction of an organic colouring matter, Rhodamin B; SO_2 could be determined by flame spectrophotometry on the basis of the luminescent emission when burned in a hydrogen-rich flame.

Gas chromatography can also determine SO_2 continuously. In addition, laser between two buildings in a town may be used to determine particulates and also chemical pollutants.

These are attempts to find new solutions to an old problem, indicating the need for new monitoring systems to cover the whole area of contaminants both in air and water, or to establish in continuation the value of certain parameters which are important for the quality of the medium.

In this field, if new methodologies are to be fixed, the most intimate collaboration of chemist, physicist and biologist is certainly required.

Only by means of analytical methodologies it will be possible not only to establish the levels of contaminants but also to follow their transformation and their fate.

In the case of air it is most important to develop on a basis of mathematical models and the use of tracers our knowledge about the distribution and movements of particles in the atmosphere.

The possibility of forecasting the distribution of contaminants in the air by means of mathematical simulants may furnish valuable information not only on a world scale, but also with regard to designing and planning industrial plant and working out urban schemes. As the factors which influence air movement are very numerous and results not always satisfactory, mathematicians and meteorologists should envisage

the solution on the basis of wide experimental work in which every possible variable is taken into consideration.

Obviously difficult and most important is the case of urban emissions, due to the composite nature of the source and the shape of the city itself.

Contribution of combustions and fuel to air pollution

FUEL (coal, oil, gasoline natural gas) 100 p	→ combustions and automobile traffic	AIR POLLUTANTS 10 p	5	p	CO
			1	p	Hydrocarbons
			1	p	Nitrous oxides
			1.5	p	Particulates
			1.5	p	SO_2

Recent work on the dynamic of air pollution over towns by SANTOMAURO has thrown particular light on this problem (1970).

These facts go to show that the development of atmosphere physics is now most important for the solution of many questions of air pollution.

Similar problems, though on a different scale, arise also in the movement of water systems, such as lakes and sea, which permit the exchange of water between different layers.

This study, in which the mathematician, the limnologist and the oceanographer must collaborate with the aid of modern techniques, may lead not only to more perfect knowledge of the dynamics of water systems bnt also to a better knowledge of the phenomena connected with eutrophication and water pollution.

Another most important aspect is the knowledge of the microbiology of treatments of sewage waters, the fate of various contaminants, from the microparticulate dispersion of pesticides in water to the biotransformation of detergents or the formation of new chemicals through the interaction of various substances (PFISTER *et al.*, 1969).

The first requisite in the approach to any problem is the

availability of data and information: on these results it will be possible to develop research programmes.

The influence of contaminants on environment as a whole and on ecosystems in particular should be the first consideration to gain more information with a view to establishing the effects on both vegetable and animal life.

The influence of pollutants on biological equilibria, which could be irreversibly altered, is most important. It is essential then that biologist, mathematician and chemist study all aspects, especially the statistical significance of these effects, so as to trace a guideline for future action in this field, based on purely scientific data (WOODWELL, 1962).

But the effects of pollution are not confined to ecosystems, or nature, or wildlife; as already illustrated, man himself is subject in his own environment (housing, crops etc.) to the action of pollutants.

In this field also we are in need of further information and results from a common effort by biologists, agronomists, hygienists and sanitary engineers.

The main point which science must face, however, is the collection of more and more data with regard to man's behaviour and reactions to the action of pollutants.

We have already shown how certain aspects of the influence of environmental pollution on health have been clarified almost on the basis of acute toxicity. Little is known up to the present about the long term toxicity of many pollutants.

The main task of science in this particular field should be to establish these correlations and other points which have never been considered.

We should emphasize the importance of knowing the effects of man's exposure to oxidants and ozone, the synergic action of more than one additive, the effect of CO on the cardiovascular system, on blood clotting and on the CNS; the effects of nitrogen oxides on lung proteins; the effects of lead exposure to porphyrin synthesis; the effects of community exposure to

berillium and asbestos; the significance of shifts in oxyhemaglobin dissociation consequent on our exposure to pollution.

These are not the only aspects to be taken into account. Contaminants may also act on the nervous system: the trouble caused by a contaminant may also be measured by the behaviour of the person or animal affected.

Recent behavioural techniques on conditioned rats have been used not only for the study of psycoactive drugs but also to investigate the effect of different concentrations of contaminants in the air. These techniques may constitute another type of evaluation of the biological effects of pollution.

In the sphere of epidemiology, the relation between air pollution exposure and asthma and emphysema should be clarified.

Epidemiology of air pollution effects is a very difficult matter, because of the difficulty of a differentiated diagnosis in subjects who are simultaneously exposed to the action not only of pollutants but also of other agents which may be the cause or the joint cause of the disease.

Special attention should be drawn to the long-term effect on man's health of small quantities of contaminants present in the food chain, of detergents, of metallic ions. Also further investigation is necessary on many enteroviruses whose distribution is very little known.

* * *

One of the most important tasks of science and technology today is the protection of man from his own pollution, and scientists throughout the world should unite in a common effort to achieve this end.

Science must not confine its action to the sphere of information: it is not only necessary to know the various terms of a problem — the results should be used to solve the questions posed by the problem.

In the case of environmental pollution it is necessary to apply the results of research to future action, aimed, in the first place, at facilitating development of man's activities, in the second place, at his protection from the byproducts of his activities and metabolism and, thirdly, to protect his own environment and the natural environment.

Modern technology, on the basis of new scientific results, is called upon to solve many aspects of pollution within an economic range.

Many new systems have been adopted recently to reduce the quantity of smoke and the SO_2 percentage in combustion by the use of modified burners, or by using oil and coal of low sulphur content, or by concentrating heat production in controlled power stations.

In order to reduce the emissions in air and water pollution from industrial sources, it is necessary not only to work out new systems for cutting out dust and for scrubbing in the case of gases or other chemicals so as to obtain greater efficiency, but it is necessary above all, in the case of new industries, to study new systems based on the more complete utilization of all byproducts which are now discharged into air or water.

In the case of automobiles, as soon as possible, with the collaboration of engineers and chemists, a study should be made of possibilities of reducing the percentage of carbon oxide in gas exhaust and hydrocarbons.

This fact may also push technology towards a new type of motor, since the present solution based on the use of catalysts for exhaust gas is not completely satisfactory.

We need new ideas on the treatment of sewage and solid waste matter; further information is required in this field concerning the effects of polyelectrolytes on flocculation of suspensions. New methods for sewage treatment have recently been proposed, based on non-biological systems using inverse osmose and for solid wastes on hydropulpers.

Microbiological systems, on the other hand, may be rend-

ered more efficient by the use of additional oxygen gas during the treatment.

A marked effort should be made in the practical setting up of a system to insolubilize phosphates and nitrates in water so as to avoid eutrophication, a problem not yet solved in the so-called tertiary treatment systems.

As regards solid wastes, a technological effort should programme the best utilization of many dangerous materials and the conditions for the transformation of the others into the biological chain.

* * *

These problems which we have rapidly reviewed have been known for many years to specialized technicians working in this field. The entire effort to control environmental pollution has been in the hands of these men on the basis of their personal knowledge. At present, in view of a considerable increase in pollution in relation to the explosive development of man's activity, scientists themselves must tackle the solution of this problem which is of vital importance for man's life on earth.

This represents a challenge which science must meet, because upon the solution of this problem depends the coexistence of man and environment, and the protection of our environment which we are bound to transmit to future generations as the most precious of our treasures.

REFERENCES

AMERICAN CHEMICAL SOCIETY: *Cleaning our environment. The Chemical basis for action.* Report 1969.

BOWEN V.T., NOSHKIN V.E., VOLCHOK H.L. e SUGIHARA T.T., *Strontium 90. Concentrations in surface water of the Atlantic Ocean.* «Science», *164*, 825, 1969.

BUSHBY F.H. and TIMPSON M.S., « Q. II. R. met. Soc. », *93*, 1, 1967.

CADLE R.D., *Particles in atmosphere and space.* Reinhold. New York 1966.

CASARETT L.J. FRYER G.C., YAUGER W.L. JR., KLEMMER A.W., *Organochlorine pesticide residues in human tissues. Hawai.* « Arch. Envir. Health », *17*, 306, 1968.

COLE L.C., *Thermal pollution,* « Bioscience », *19*, 989, 1969

COUNCIL OF EUROPE, *Declaration of principles on air pollution control.* Res. (68) 4 8 March 1968.

DALE W.E. and G.E. QUINBY, *Chlorinated insecticides in the body fat of people in the United States.* « Science », *142*, 593, 1963.

DANIELSON L., *Gasoline containing lead.* « Natural Science Research Council ». Stockholm 1969.

DAVIS J.B., *Petroleum microbiology.* Elsevier, Amsterdam 1967.

DE VLIEGER M., ROBINSON J., BALDURSI M.K., CRABTREE A.N., VAN DIJK M.C., *The organochlorine insecticide content of human tissues.* « Arch. Envir Health », *17*, 755, 1968.

EDWARDS C.A., *Soil Pollutants and soil Animals.* « Sci. American », *220*, 88, 1969.

EISENBUD M., *Environmental Radioactivity,* McGraw Hill, Chicago 1963.

GATZ D.F. e DINGLE A.N., *Air cleansing by convective rains.* « J. Appl. Meteorol. », *5*, 160, 1966.

GOLDSMITH J.R., *Effects of air pollution on human health in* Stern Air pollution II, pag. 547, Accademic Press, New York 1968.

GOLDSMITH J.R. e R. KARTMAN, *Air pollution medical research.* « Science », *163*, 706, 1969.

GREENDALE A.E., N.J. BALLOU, USNRDS. Doc. 436, I, 1954.

HOLM L.G., L. WELDON, R.D. BLACKBURN, *Aquatic Weeds*. « Science », *166*, 699, 1969.

JAFFE L.S., *CO pollution*. « New York, Ac. of Sciences ». 1970 in press.

JINGE C.E., *Air Chemistry and Radioactivity*. Academic Press, New York 1968.

LAURENCE KULP S., A.R. SCHUBERT and E.J. HODGES, *Sr. 90 in man. Animal increase of this isotope and its pattern of world-wide distribution in man defined*. « Science », *129*, 1249, 1959.

LOWMAN F.G., *Radionuclids in plancton near the Marshall Islands*, 1966. USAEC-UWFL 54 (1968).

LOWMAN G.G., USAEC-UWFL. *Strontium 90 in man*. « Science », *132*, 448, 1960.

MARINI-BETTOLO G.B., *Aspetti sanitari dell'inquinamento delle acque in Italia*. « Ann. Ist. Sup. Sanità », *4*, 412, 1968.

MARINI BETTOLO G.B., *Nuove prospettive della lotta contro gli insetti nocivi*. Atti Convegno Nuove prospettive della Lotta contro gli Insetti nocivi. « Accademia Lincei », *128*, 1, 1968.

MARINI-BETTOLO G.B., *L'inquinamento dei mari*. Atti S.I.P.S. 1969, in stampa.

MCCORMICK R.A. and L.H. LUDWIG, *Climate modifications by atmospheric aereosols*. « Science », *156*, 1358 (1967).

MCCORMICK R.A., *Air pollution climatology in* Stern id. II, 315, ibid. 1968.

MURGATROYD R.J., *World wide dispersal of pollutants*. « Phil. Trans. Roy. Soc. », London A. 265, 273, 1969.

NEIBURGER M., *The role of metereology in the study and control of air pollution*. « Bulletin American Metereological Soc. », *50*, 957, 1969.

ORGANISATION MONDIALE DE LA SANTÉ, *Recherches sur la pollution du Milieu*. « Rapports Techniques », n. 606, 1968.

PFISTER R., P.R. DUGAN, J.I. FREA, *Microparticulates; isolation from water and identification of associated chlorinated pesticides*. « Science », *166*, 878, 1969.

PRATI L., R. PAVANELLO e F. GHEZZO, *Indagine sull'accumulo di pesticidi cloroorganici di sintesi in organi e tessuti umani nella provincia di Ferrara*. In press. 1970.

PILPEL N., *The natural fate of oil at sea*. « Endeavour », *27*, 11, 1968.

SANTOMAURO L., *La dinamica dell'inquinamento atmosferico*. In press.

SCHREIBER B., « Int. Conf. Disposal. Rad. Wastes », Monaco 1959.

SMITH RALPH G., *An analyst view of our polluted planet.* « Anal. Chem. », *40*, 24-A, 1968.

SMITH RAY, *The new and old in pest control.* Atti Convegno nuove prospettive della lotta contro gli insetti nocivi. « Accademia Lincei », *128*, 21, 1968.

STEVENS R.K. and A.E. O'KEEFFE, *Modern aspects of air pollution moutoring.* « Anal. Chem. », *42*, 143 A, 1970.

STOCKINGER H.E. and COFFIN D.L., *Biological effects of air pollutants*, in Stern, Air Pollution, I, 445 Academic Press New York 1968.

TASSI PELATI L., *Importanza dei molluschi nel ciclo biochimico dello stronzio. Ist. Lomb.* (Rend. Sc.) B. 103-84-92, 1969.

U.N. *Science Committee on the effect of atomic radiation.* United Nations 1964.

WOLMAN A., *Metabolism of cities.* « Scientific American », *231*, 178, 1965.

WOODWELL G.M., *Effects of ionizing radiation on terrestrial ecosystems.* « Science », *138*, 572, 1962.

WOODWELL G.M., *Toxic substances and ecological cycles.* « Scientific American », *216*, 24, 1967.

WOODWELL G.M., *Effect of pollution on the structure and psysiology of Ecosystems.* « Science », *168*, 429 1970.

WURSTER C.F., *DDT reduces photosynthesis by marine phytoplancton.* « Science », *159*, 1474, 1968.

DISCUSSIONS

GHERZI

Pour ma part, je voudrais simplement compléter le discours de mon éminent collègue, le professeur MARINI BETTOLO, en vous mentionnant le programme de mesures et de calculs encore en cours auprès de l'Observatoire de Géophysique du Collège Brébeuf, à Montréal, et auquel j'ai contribué par de nombreux vols en hélicoptère et prélèvements d'échantillons atmosphériques; le but principal de notre étude est la détermination de la teneur de l'atmosphère de la ville en composés sulfureux, composée qui, comme vous le savez, sont parmi les plus nocifs pour les voies respiratoires.

LEPINE

L'augmentation progressive de la pollution ne menace pas seulement la vie de l'homme en tant qu'espèce animale, mais toute vie animale et végétale sur la surface de la terre. Vous avez justement insisté sur les origines différentes des contaminations et pollutions auxquelles nous sommes soumis, car leur importance, tant pour le présent que pour l'avenir, varie suivant la nature et la source de la pollution. C'est ainsi que les pollutions organiques, qui sont dues à l'homme et aux animaux — les pollutions microbiennes auxquelles on attachait autrefois tant d'importance — n'ont plus qu'une importance tout à fait relative; en effet, la matière organique est bientôt dégradée et tend à disparaître d'elle-même si elle est seule en cause.

Beaucoup plus graves sont les pollutions d'ordre chimique créées par l'homme et introduites par l'industrie. D'une part, parce qu'elles ont leur toxicité propre qui ajoute des facteurs nouveaux et, d'autre part, parce qu'elles tendent à détruire le cycle d'épuration naturelle qui existe normalement dans l'air, sur le sol et dans les eaux.

L'analyse des eaux de rivières industrialisées, comme l'eau de la Seine, en France, montre à l'heure actuelle que la pollution chimique arrive à détruire complètement le mécanisme d'épuration naturelle. Ce fait entraîne plusieurs conséquences: si nous analysons les effets de la pollution, nous voyons que si la conséquence la plus immédiatement évidente de l'industrialisation croissante est l'augmentation de la pollution par contamination, il faut aussi considérer la consommation accrue d'oxygène à la surface de la terre.

En ce moment, la consommation de l'oxygène augmente de façon logarithmique. Savez-vous qu'un jet de type classique — je ne parle pas des super-jets qui vont être bientôt en service — en traversant l'Atlantique, consomme 30 tonnes d'oxygène et même plus, et que plusieurs centaines en font autant par jour?

Par conséquent, le développement des moteurs à combustion interne, non seulement augmente la pollution, mais diminue notre oxygène vital. Normalement, cet oxygène est régénéré par le cycle chlorophyllien, et essentiellement par le plancton de la surface des mers qui couvrent les 4/5 de notre globe. Un bateau-citerne qui nettoie ses cales, contamine la surface de la mer sur une étendue qui peut atteindre quelquefois une centaine de kilomètres carrés où le plancton est détruit. La destruction des hydrocarbures peut se faire, vous l'avez rappelé, mais par la périphérie de la nappe et assez lentement, de sorte que si l'on multiplie cette pollution d'hydrocarbures à la surface du globe, on diminue d'autant le poumon par lequel nous devons tous respirer.

C'est un problème d'une grande complexité et on ne saurait trop souligner la gravité de la situation actuelle, étant donné les chiffres montrant l'accélération à la fois de la consommation d'oxygène et de l'augmentation de la pollution.

LECOMTE

Je voudrais dire que je donne mon accord complet à ce qui a été dit sur l'action du gaz carbonique, qui entraîne par des variations dans sa teneur une influence sur la température de la terre.

Cette hypothèse, d'ailleurs, avait été formulée, comme tout le monde le sait, il y a fort longtemps, par un savant suédois, Arrhénius, et même Arrhénius avait attribué l'existence des périodes glaciaires à une forte variation des teneurs en gaz carbonique de l'air. Par conséquent, sur le principe, il n'y a pas de difficulté. Je voudrais attirer l'attention sur la grande difficulté qui existe à traiter par des chiffres les résultats de variations de la teneur en gaz carbonique dans l'atmosphère, sur la température de la terre.

Effectivement, le gaz carbonique forme un écran pour empêcher la dissipation dans l'atmosphère du rayonnement terrestre, parce que le gaz carbonique a une très forte absorption dans une région du spectre infrarouge où l'émission de la terre est maximale. Mais, quand on veut envisager le problème complètement et le calculer mathématiquement, on arrive à des expressions mathématiques absolument insolubles. On a essayé de diviser l'atmosphère en tranches plus on moins épaisses. Chaque tranche est considérée comme se trouvant à une certaine température. Cette température, comme il a été très bien rappelé, dépend de la teneur en gaz carbonique de la totalité de l'atmosphère. Mais cette tranche, séparée du reste de l'atmosphère, va absorber une certaine quantité de rayonnement venant de la terre, empêcher cette dissipation dans l'espace et cette tranche va s'échauffer. De sorte que nous sommes devant un problème mathématique (d'équilibre entre la déperdition et l'accroissement de l'énergie de la somme de gaz carbonique) d'une très haute complexité et résolvable seulement avec des machines à calculer vraiment très puissantes.

Il y a encore un autre point, c'est que, lorsque la pression du gaz carbonique varie dans les couches, l'absorption varie suivant la pression, parce que le gaz carbonique s'étend précisément où se porte l'absorption de l'émission maximale de la terre .

Le spectre du gaz carbonique est composé d'une série de raies de rotation-vibration d'intensité variable en fonction de la pression. De sorte qu'on arrive à ce qu'à partir d'un certain point, lorsque la pression du gaz carbonique augmente, l'absorption croît également dans toute la région d'opacité jusqu'à une certaine limite. D'ailleurs, aux Etats-Unis, on a fait des calculs analogues pour la vapeur d'eau, malgré la complexité du spectre en raison des isotopes O_{17} et O_{18} et de la forme angulaire de la molécule. Pour le gaz carbonique, c'est relativement plus facile, car la molécule est linéaire et la position des raies de rotation se calcule plus aisément.

Enfin, je voudrais souligner que en réalité, les hommes, les animaux, les plantes, vivent dans un bain de radiations invisibles. Or, quand par suite des vents créés par les déboisements, des pollutions par les villes, des implantations de l'industrie, on change le rayonnement infrarouge dans lequel vivent les hommes, les animaux, les plantes, il est bien évident qu'il y aura des modifications considérables dans l'espèce humaine.

Je voudrais simplement vous donner un exemple: j'ai vu dans une forêt équatoriale des pygmées qui ne sont pas très laids. Ils sont petits, comme tout le monde sait, mais pas noirs! Au contraire, en dehors de ces zones forestières, il y a des noirs magnifiques. Il est évident que la pigmentation de la peau provient, au moins en partie, d'une défense de l'organisme contre les radiations calorifiques — ce mot est inexact, mais il rend bien ce que je veux dire — tandis que les pygmées, qui vivent à l'ombre de la forêt, n'ont pas besoin de cette protection.

Pour ces raisons, je m'associe aux conclusions de ce remarquable exposé. Nous espérons tous que l'Académie Pontificale, peut-être un jour, reprendra la question sous ses différents aspects.

TISELIUS

We all listened with great interest to the valuable exposé of Prof. Marini Bettolo. The problem is so extremely urgent, as a mat-

ter of fact, that it has become necessary to establish an international organisation for research on this subject. I am glad to notice that spontaneous research has been done in the single countries; however, at this point, it is essential that the countries join on an international scale to collaborate on this problem. For this purpose, the United Nations are going to sponsor a Conference in Stockholm which will be organized by the Swedish Government and will take place in 1972. The Conference aims to the discussion and recommendations for the solution of these problems.

These are extremely urgent — time is short. I believe we have the necessary tools, but we must join our efforts before it is too late. In my communication tomorrow, I shall deal with this problem further.

SIDDIQUI

I greatly appreciate the lucid exposition of health hazards involved in the contamination of our environment, and fully agree that well coordinated scientific research should be carried out to cope with the situation.

It is my opinion, however, that no end of research effort in this context can be of any consequence without adequate governmental measures for vigorous implementation of the research results.

As a matter of fact the corrosive situation we are facing can be appreciably mitigated if the already available knowledge can be brought to bear on it with a sense of urgency.

In reference to my own country and the other developing countries I known, I can say that owing to the lack of drive and proper resources the governmental administrations helplessy look on, they are not able to take any effective step to control environmental contamination.

I therefore feel that alongside the research effort to which reference has been made by Prof. Marini Bettolo, the international scientific community should actively exercise its influence in build-

ing up public opinion pressures and bringing home to the national and international bodies the urgent need for dealing with this whole complex problem.

CHAGAS

J'aimerais d'abord féliciter l'Académie Pontificale pour avoir choisi un des thèmes de la plus grande signification dans le monde présent et pour l'avenir, pour commencer une nouvelle activité dont l'essor sera certainement très important. Ayant été témoin de nombreuses initiatives prises dans les organisations internationales en relation avec ce sujet, j'aimerais signaler l'importance que doit recevoir de partout la conférence qui aura lieu à Stockholm, sous l'égide des Nations Unies, grâce à une initiative dont vient de nous parler notre Collègue le Prof. Arne Tiselius, du Gouvernement suédois.

Je me permets de dire que cette initiative a rencontré d'abord certaines difficultés même dans la communauté scientifique, que j'ai eu l'occasion d'évaluer à l'occasion de la Conférence sur la Biosphère, tenue à l'UNESCO en septembre 1968. Le fait que quelques mois après, à l'Assemblée Générale des Nations Unies, elle a été approuvée par acclamation, montre que le grand public commence — s'il n'est pas dupe complètement — à être sensible aux problèmes que présente l'environnement pour l'humanité. La conférence aura d'ailleurs une orientation qui plaira à notre Collègue, le Prof. Siddiqui. Elle est dirigée surtout aux groupes nationaux qui sont appelés en anglais « decision-makers ». Je crois aussi que quelques mots doivent être dits au sujet de l'anxiété que le problème de l'environnement suscite dans les pays en voie de développement. Pour quelques-uns, le sujet peut mener à des mesures qui limitent le développement économique. C'est le cas par exemple des pesticides. C'est dans ce domaine que les scientifiques ont aussi un grand rôle à jouer. C'est celui de rassurer la population en créant des moyens de remplacement ou en déterminant les conditions qui peuvent réduire la pollution — sensu lato — à des conditions compatibles avec le progrès et le bien-être de l'humanité.