6. Environmental variables appropriate for monitoring

6.1. INTRODUCTION

Chapter 5 above outlined the three major problem areas considered to be most relevant for early implementation in any global monitoring programme as follows:

1. Potentially adverse climatic change resulting from human activities
2. Potentially adverse changes in biota and man from contamination by toxic substances, including radionuclides
3. Potentially adverse changes in biological productivity caused by improper land-use (reduced soil fertility, soil erosion, extension of arid zones etc.)

We now have to discuss which environmental parameters describe and quantify these problems in a useful way. These can be broadly classified under the following headings:

1a. Physical and chemical data from the atmosphere pertinent to climatic change potential
 b. Physical and chemical data from air, water, soils and biota pertinent to human health and welfare
2a. Physical, chemical and biological data reflecting the state of human health
 b. Biological data reflecting the performance of biological systems

6.2. PHYSICAL AND CHEMICAL DATA FROM THE ATMOSPHERE PERTINENT TO GLOBAL CLIMATIC CHANGE

In the previous chapter the important global environmental problems related to climatic change were discussed: increases of carbon dioxide and particulate matter in the atmosphere, changes in global albedo and the earth's surface, changes in cloudiness, production of waste heat, and contamination of the stratosphere. Since this discussion focuses on climatic changes of global significance the measurements and observations must be representative of large portions of the atmosphere (background values) and free of local contamination. The atmosphere has few mixing constraints and, therefore, this can be achieved by measurements in remote areas and in the upper atmosphere.

Carbon dioxide. Our knowledge of the historical trend of atmospheric carbon dioxide as well as estimates of future concentrations are based primarily on a sole set of continuous observations, which dates only from 1958. Additional and continuing baseline data are necessary to determine the global representativeness of the current trend, to verify the future estimates and to study the partitioning of CO_2 between the atmosphere, oceans and biosphere.

Aerosols and particles. Aerosols and particles in the atmosphere play a special role in the atmospheric energy balance and in physical processes important in the formation of clouds, precipitation, fogs, etc. Moreover their role depends not only on the total particle count but also on the number of particles of various sizes and their distribution with height. The rapid development of vertically directed LIDAR as a measurement technique gives promise of an early capability for monitoring the vertical distribution of particle loadings well into the stratosphere. This technique should be utilized as soon as feasible to complement or perhaps replace periodic aircraft sampling. By monitoring the intensity of solar radiation at selected narrow-bands in the visible and ultra-violet spectral regions (e.g., 0,50 and 0,38 micrometers), direct information can be obtained on the total atmospheric loading of aerosols (atmospheric turbidity) in the optically effective size range.

Solar radiation. Since solar radiation is the critical energy source to the earth and atmosphere, comprehensive monitoring is required for trends in the solar energy received at the surface. Instruments for the following measurements are commercially available and are used in operational programmes:

a) Broad-band direct and diffuse radiation (e.g., measurements of all wavelengths $>$0.40, $>$0.53, and $>$0.70 micrometers)

b) Narrow-band direct radiation (e.g., measurements between the wavelengths of 0.30 to 0.35, 0.35 to 0.40, . . . 0.55 to 0.60, 0.60 to 0.70, 0.70 to 1.00 and 1.00 to 1.80 micrometers)

c) Net (incident minus reflected) all-wave radiation.

Meteorological data. Standard meteorological surface observations, including wind, temperature, humidity, pressure, prevailing weather, etc., should also be obtained to complement the basic measurements. In addition, vertical observations of temperature, humidity, pressure and wind velocity by rawindsonde should be made.

The earth's surface. Various land-use practices that significantly alter the earth's suface such as deforestation and creation of man-made lakes, can affect local climate by influencing the energy balance. To determine whether large-scale changes have occurred, global land-use should be inventoried periodically, for example, every five years. Such a survey can best be carried out by satellite measurements.

Cloudiness and albedo. Since global climate is particularly sensitive to changes in cloudiness, surveys by satellite of this parameter should be encouraged even though there is no definite indication that man has as yet caused wide-spread alterations in cloudiness. Measurements of stratospheric cloudiness and water vapour may have to be made from aircraft. Another particularly useful satellite measurements is that of whole-earth albedo. Variations of the earth's reflectivity, which can be affected by land-use, cloudiness, etc., can be documented by such measurements.

Waste heat. Because of the increasing rate of energy consumption throughout the world, the amount of waste heat produced by man could become a significant regional climatic factor in several decades. Therefore, energy-use statistics should be inventoried continuously on a regional basis to determine their current importance.

Nitric oxide and ozone. Concentrations of these trace gases in the stratosphere may be affected by the operations of supersonic aircraft. Background concentrations of nitric oxide, a product of combustion, and ozone, a product of stratospheric gas reactions, should be determined before large scale supersonic flights begin.

On the basis of the above considerations we recommend as follows:

We recommend that the following variables be initially monitored at low exposure (baseline) stations: Atmospheric carbon dioxide content: atmospheric turbidity; solar radiation (including broad-band direct and diffuse radiation, narrow-band direct radiation, and net all-wave radiation); standard meteorological variables.

We recommend that the following variables be considered for inclusion at a later date: Vertical distribution of aerosols; size distribution of aerosols; rawindsonde data; surface vertical fluxes of carbon dioxide; global albedo (by satellite); ozone, water vapour and trace gases in the stratosphere (by aircraft).

We recommend that the following variables be monitored at medium exposure (regional) stations: Atmospheric turbidity; solar radiation (including broad-band direct and diffuse radiation and net all-wave radiation); standard meteorological data.

6.3. PHYSICAL AND CHEMICAL DATA FROM AIR, WATER, SOILS AND BIOTA PERTINENT TO HUMAN HEALTH AND WELFARE

6.3.1. The Media Approach

Before considering in detail, the range of variables from air, water, soils and biota for possible inclusion in a monitoring system it is useful to stress the dynamic interrelation of these media via the geophysical, geochemical and biological transport mechanisms operating in the environment. Effective analysis of any secular trends for potentially hazardous substance will be made much simpler and detected earlier if we know the flux rates of these transport mechanisms for each substance. This involves a study of the sources and rates of injection of each substance into each environmental medium and the rate of removal into other media, i.e., residence times. We must also know the ultimate fate of each substance, whether it accumulates irreversibly in any one medium or whether it continues to cycle indefinitely.

Air. Residence times of substances emitted to the lower atmosphere are generally short (weeks or less) unless they enter the stratosphere where they can remain for many months or years. The atmosphere is thus more appropriately regarded as a transport mechanism with rapid and efficient mixing, making it possible to obtain accurate representative measurements of atmospheric constituents by sampling at a few selected points only.

When monitoring the quantities of the different substances it is necessary to take into consideration whether the substance occurs as a gas, as particles or attached to particles. The actual size distribution of particles is very important when considering their availability to organisms, including man.

From the budgeting point of view it is important to monitor injections of substances to the air and the transfer mechanisms from the air to water and soil. The interfaces between atmosphere and water and between the atmosphere and the continents deserve particular attention.

Of special significance among the transfer mechanisms is precipitation since it has an important scrubbing action on atmospheric gases and particles. Its composition (precipitation chemistry) is a useful guide to the nature and amount of airborne substances carried to the earth's surface and available to interact with biota.

Water. Residence times in water are longer than those of air and the presence of serious mixing constraints in oceans makes representative sampling much more difficult unless many more sites are involved. Despite this qualification, bodies of salt and freshwater reflect the history of surrounding land use in an informative way. Substances released into rivers etc. find their way into aquatic biota and bottom sediments which may often irreversibly accumulate many substances and thus act as a valuable historical record of previous changes and trends. The output from rivers to the oceans is not only a national and regional problem but also of concern to any global budgeting of critical substances essential for the global monitoring system.

Soils. Soils like sediments are often the ultimate sinks of many important substances particularly in low rainfall areas. They are the most intensively used resource of any nation and the irreversible accumulation of substances in them is thus of critical importance. Mixing constraints are of course greater in soils than in air or water and there are large-scale geographical differences in the accumulation and loss of substances to soils, depending on local usage by man, soil chemistry, rainfall etc. They not only receive substances by dry deposition and precipitation from the air but are the source of dusts and gaseous exhalations which can be atmospherically transported over great distances. Volatile substances such as organochlorine compounds and dimethyl mercury are of interest in that they may evaporate from warmer soils and condense in soils of cooler regions. Special attention should be paid to the occurence of new technical substances in the soils of tropical regions.

Biota. The reason for monitoring certain substances in biota is twofold. They may cause adverse biological effects and they may be in greater concentrations and therefore more readily detectable. Knowledge about the levels found may be used in risk evaluation. For substances with threshold-effects the existing levels should be used for an estimate of the safety margin before effects appear.

Organisms are important as a means of transport for substances through the biosphere. They can take up and accumulate certain chemicals and transmit them through food chains, by a process of biological magnification, where an increased accumulation at higher trophic levels occurs. Therefore the effects are often most pronounced at the tops of the food chains. The transport of substances along food chains takes time and it is thus of great importance to detect any significant accumulation of substances at the lowest trophic levels. By using sophisticated chemical methods it is now possible to detect even very minute amounts of substances. Organisms at the bottom of the food chains contribute to an early warning system.

Even similar substances may behave differently in the same food chain. This depends on different metabolic patterns and abilities to excrete substances. We also have differences between sexes and individuals of the same species. This variability has a marked genetic component and is partly the explanation of the development of tolerance. In aquatic organisms, the direct uptake of substances from water may sometimes be more important than via the food chains.

When chemical methods are not sufficiently sensitive to estimate the trace amounts of a substance in the abiotic environment, accumulator organisms may be analysed instead. Bioaccumulators also often integrate the chemical environment both in time and space. A fish in a lake may integrate the conditions in that lake over a long period of time and wide ranging marine organisms may reflect the situation in extensive marine areas. In certain cases specific organs may give additional information on the chemical situation in the environment. For example, different amounts of mercury accumulating in the feathers of migratory birds formed at their summer and winter quarters respectively, indicate geographical differences in mercury exposure.

In certain cases organisms may be used as indicators of the presence or absence of a specific substance or of certain levels of it in the environment.

The foregoing discussion emphasizes the need to sample and measure environmental substances in such a way in all media that their flux rates can be calculated and an "environmental balance sheet" drawn up for each substance. This will help us to gather valuable information such as, for example, whether a detected increase of a substance in one medium represents a real overall global increase or merely the appearance of the substance working its way through the environmental cycles from another medium. We will also know how long such a process is likely to take and thus the overall exposure times for biota (including man).

Since nearly all scientific competence in investigating the environment is traditionally media oriented, it is unrealistic to erect a completely new system based on this dynamic approach. It is thus proposed to discuss below the range of monitorable parameters in each of the media separately and to attempt a synthesis at the end which once more emphasizes the need for a dynamic overview of the whole environment.

6.3.2. Atmosphere

Carbon dioxide. Land plants obtain all their carbon from atmospheric carbon dioxide and from carbon dioxide released from soil respiration. All animals, including man, exist from the carbon compounds made by plants. Changes in the amount of atmospheric carbon dioxide might have an influence on global climate as previously indicated or may alter primary productivity in green plants since carbon dioxide is sometimes a limiting factor to plant growth.

Sulphur dioxide and hydrogen sulphide. Numerous epidemiological studies clearly indicate an association between sulphur dioxide and health effects of varying severity. Other studies have shown that chronic injury to plants can occur with prolonged low concentrations of these gases as well as adverse economic and aesthetic phenomena related to atmospheric visibility, and the soiling, and corrosion of materials.

Carbon monoxide. This gas is known to have important physiological effects on man at the increased levels found in dense traffic. It is now known that the surface of the oceans releases substantial amounts into the atmosphere. However, its fate in the atmosphere is not known and it is of some importance to ascertain whether the gas is accumulating there.

Nitrogen oxide and nitrogen dioxide. These gases play important roles in the formation of "photochemical smog" which is being recognized as an increasing problem to man and plants in and about urban complexes in the temperate zone. When released into the lower stratosphere by high flying aircraft, these gases possibly may interfere with the ozone balance.

Ozone (and ozone precursors). These substances have an important chronic and acute impact on biological systems by the impairment of performance, on pulmonary function, and by vegetation damage.

Ammonia. Almost all of the ammonia in the atmosphere is produced by natural biological processes although considerable increases are found over industrial cities. The ambient air concentrations are lower than those hazardous to plants and animals. However, a long-term trend would have an important biological significance.

Aerosols and particulates. The impact of these substances on biological systems covers a wide range of important physical and pathological consequences, both direct and indirect. For instance, Aitken Nuclei of less than 0.1 μ radius are important in the formation of precipitation, fogs, and haze, etc. The so-called "large" particles in the 0.1–2 μ range affect optical phenomena such as visibility and turbidity and can be important lung irritants in man, especially the particulate decay products of sulphur oxides, which can carry absorbed or adsorbed gases deep into the respiratory system.

Insecticides, herbicides and other biotoxins (in air and precipitation). The bio-environmental problems associated with the use of insecticides and herbicides and a number of other biotoxins, particularly those from industrial processes, fuel and refuse burning have been well documented. Since one of the most rapid and effective methods for distribution of these materials on a global basis is via the atmosphere, early detection of significant changes in their distribution could be achieved by monitoring the concentrations of these materials in air and precipitation.

Chlorinated aliphatic hydrocarbons. Carbon tetrachloride, trichlorethylene and similar compounds used in cleaning may become important atmospheric constituents in the future.

6.3.3. Water

Although the organizational pattern required for monitoring freshwater is likely to differ substantially from marine monitoring, many of the critical variables to be studied are the same in both media. The following discussion, dealing principally with the marine environment, also applies to freshwater unless otherwise stated.

There are two major groups of parameters of potential importance in water monitoring.

1. Biological stimulants
2. Biological toxins including radionuclides

Biological stimulants. The problems of eutrophication were mentioned in Chapter 5 where it was concluded that they needed further study prior to their inclusion in any integrated monitoring system.

The effects of biostimulants on the environment are usually observed on a local scale and may result in unsightly blooms of aquatic vegetation, algae and bacteria. Unless these products are removed from the system and allowed to decay elsewhere, premature deoxygenation of the aquatic environment can occur. Chemical species known to stimulate the growth of primary and heterotrophic producers include NO_3^-, NH_3, PO_4^{3-}, K^+, CO_3^{2-}, HCO_3^- and organic matter, along with various trace metals.

Other substances regarded as biostimulants are a variety of organic compounds such as vitamins, hormones and other unidentified "growth factors" present usually in trace amounts, particularly in domestic sewage.

In coastal areas, estuaries, fjords, lagoons and epicontinental seas, the increasing input of nutrients and potential nutrients from sewage and industrial outlets as well as from dumping is often the cause of a disturbance in the normal biological equilibrium. Because of sampling and storage problems, it seems inadvisable at present to split up the different phosphorus and nitrogen containing nutrients into subgroups. However, total phosphorus and total nitrogen (excluding gaseous nitrogen) both in dissolved and particulate form should be included in a monitoring system for the seas. This restriction to total P and total N may be less satisfactory for freshwater.

Because of the anticipated effects that a rise in the carbon dioxide content of the atmosphere might have on climate, it is necessary to understand the circulation of carbon dioxide not only in the atmosphere but also in the oceans, and especially the exchange of carbon dioxide between sea-surface and atmosphere. It is expected that an increasing amount of information about carbon dioxide in the sea and components of the carbonate system will be achieved by ongoing research and survey activities within the next five years. This will be accomplished through improved methods and instrumentation.

Continental erosion, industrial activities, sewage injection and dumping of mass residues from chemical production e.g. red mud, nutrification and overproduction might change the turbidity of surface waters considerably. Such events might also effect offshore areas all over the world and become an international problem, especially when the dumping of large quantities of relevant material is carried out in off shore waters.

Unusual depletion of oxygen normally indicates high organic loading of water. This is certainly not a world wide issue, but may be a regional problem, especially in such areas where natural processes and man-included effects both lead to stagnation and emphasize an already existing natural tendency of oxygen deficiency as is the case in the Baltic. It is therefore desirable to include oxygen measurements in a monitoring system.

Biological toxins. Potential toxins include almost all heavy metals and many organic compounds. Toxicity may manifest itself at any level of the food chain or may significantly alter the species composition of biota by enhancing those populations of organisms differentially tolerant of the specific toxin involved. In other cases, where substances are not directly toxic, they may concentrate in tissues of living organisms making them unfit for consumption by other organisms, including man. Such materials, if they are persistent in the environment, can increase in concentration in aquatic systems.

Many metals, including mercury, lead, cadmium, vanadium, chromium, copper, zinc, iron, arsenic and selenium and their related inorganic and organic compounds are considered to be potentially hazardous. The levels of mercury and lead are believed to have risen considerably in the surface layer of the oceans through man's production and use of them. Both have regional if not global effects on the marine ecosystem and are accumulated in food chains. The other metals mentioned here are mostly of local or regional interest only.

Chlorinated organic compounds such as DDT and its metabolites, Aldrin, Dieldrin, Endrin, residues from the fabrication of polyvinyl chloride and similar chlorination products, i.e., aliphatic, chlorinated hydrocarbons, polychlorinated biphenyls, and residues from the fabrication of such compounds, alicyclic chlorinated compounds such as Lindane (γ – BHC) are considered to be potentially hazardous.

The toxicity of various oils and oil-products varies widely depending on the combination of environmental factors and also on the biological state of the organisms at the time of contamination. Different species and different life stages of organisms have been demonstrated to show different susceptibilities to pollution. Natural biogenic hydrocarbons on the other hand may have well defined biological functions. Therefore methods for oil pollution monitoring must be able to deal with the entire spectrum of oils and oil-products at high and low concentrations as well as with the natural hydrocarbons in sediments and organisms. Further, for pollution research and for law enforcement there is a need for differentiation between natural hydrocarbons and pollutants and for the recognition of oils form different sources and among oil-products resulting from different refining processes. Existing analytical technology, using gas-liquid chromatography is well on the way to achieving this.

Many organic compounds, which occur naturally or are emitted by human activity, may influence biota indirectly through their capacity to complex with or in other ways modify the chemistry of inorganic ions. These processes may alter the biological availability not only of the toxic heavy metals but also of essential trace metals required for the normal growth of organisms. The full magnitude of such problems cannot be understood until the organic contaminants are identified and their chemical stability and affinity for metals assessed. For the present, wherever possible, metal analysis should differentiate between species in ionic solution and those in organic combination.

The availability or toxicity of metal ions is also strongly dependent upon concentrations of accompanying ions, particularly hydrogen, calcium and magnesium. Metal toxicity to fish is known to be reduced by factors of ten to a hundred in "hard" as against "soft" waters.

6.3.4. Soil

Soil composition. A great deal is already known about the physico-chemical composition of the world's soils, largely as a result of the long-term painstaking surveys of surface geology and soil patterns necessary for mapping the potential mineral and agricultural resources of a nation. These are essentially national or regional problems. A recent and more sophisticated development has been the use of stream sediment analysis. Stream, lake and marine sediments average the prevailing soil chemical conditions for trace elements over a wide area and their use as indicators is proving a valuable tool in studying the occurrence of mineral deficiencies. In future it may be possible to use this method for studying the regional build-up of aerially distributed pollutants which fall onto and accumulate in soils often thousands of kilometers from their source. The great value of the analysis of plant and animal tissues as indicators of prevailing soil conditions is already well understood.

Non-ferrous (heavy) metals emitted to the air or directly deposited on soils can be fixed, particularly by soil organic matter. Many of the metals including lead, arsenic, antimony, nickel, indium, mercury, cadmium, zinc, cobalt and chromium are known or suspected to be a hazard to human and animal health, several having been linked with the occurrence of cardiovascular disease and gastric and other cancers. Mercury can be alkylated in certain soils to highly toxic forms by soil bacteria. DDT, PCB and other organochlorines may be fixed in certain soil horizons and also have significant effects on biota in soils. Any of these contaminants may undergo a process of biological concentration as they pass up the human food chain. Studies of the dynamics of their accumulation, movement, and their residence times in soils are needed using soil, plant and animal analyses. Macronutrients (S, N, P and C compounds) constitute major factors of soil fertility. Problems may arise in connection with the wide and intensive use of fertilizers or improper land use.

Soil structure and cover. Under intensive grazing and/or mineral fertilizing, soil structure and the vegetational cover of soils often suffer a decline. This is normally a local problem but may be a matter of international concern where extensive deforestation or overgrazing, overburning or other human pressure leads to a loss of soil organic matter, to bare soil, to windblown soil and even perhaps to the extension of arid zones. This can be particularly serious where plant regeneration is very slow. The extension of bare ground can be registered by satellite sensing.

6.3.5. Organisms

Organisms will collect and sometimes accumulate from air, water and their food, certain toxic substances and radionuclides. The relevant substances are those mentioned above in sections 6.3.2., 6.3.3. and 6.3.4.

The coverage of the monitoring programme should include monitoring at the four main trophic levels: primary producers (green plants); primary consumers (herbivores); secondary consumers (predators); decomposers and scavengers.

It also follows that particular attention must be paid to those organisms that show high accumulation rates. These can be used as test organisms and temporal integrators. It should also be recognized that organisms that feed over a wide area can effectively integrate geographical variation in contamination levels.

6.3.6. Critical Groups of Substances

The above general review of a wide range of variables needs to be followed by a discussion of groups of critical substances leading to a selection of the priority substances for the initial stage of the monitoring programme. We have here taken note of the preliminary results of a special working party of SCOPE dealing with: "Materials which may significantly alter the biosphere and their determination and assessment". This working party will later report on analytical methods for different critical substances. We have considered the relevance and technical feasibility of monitoring the priority variables and are satisfied that they are appropriate to the problems, and can be monitored with available techniques. Special operational manuals have to be prepared at a later stage when the final decisions about variables have been made.

Pesticides and related substances. DDT and its metabolites and degradation products may serve as a valuable model for the monitoring of pesticides in general. Our knowledge of the global circulation of this substance, although much improved during the last few years still needs many more data. It should be given high priority. Other persistent organochlorines are aldrin, dieldrin, BHC, endrin, methoxychlor, lindane and heptachlor. Some of these compounds are widely used, but it is not yet proved that they have the same general global distribution as DDT. Polychlorinated biphenyls (PCB) are very resistant to biodegradation, have a global distribution and marked effects on biota. They should be given high priority in any initial monitoring programme. Substituted phenoxy acetic acids (herbicides) and organophosphorus compounds may be considered later for further inclusion in the global system. It has yet to be established whether these compounds have a global distribution.

Non-ferrous (heavy) metals. Once liberated to the environment from mineral extraction and purification, these will always be a potential hazard as they are never biodegradable. It is possible that they may eventually become immobilized as very stable substances in marine sediments but more information is needed on this. We also need to know more about the chemical forms through which they pass during their residence in the environment. One particular difficulty is that unlike organochlorine compounds, metals already occur in the natural environment so the problem of arriving at natural levels is much more difficult. We have concluded that first priority should be given to lead, mercury and cadmium as these three metals are already significantly involved in environmental problems. Other metals such as arsenic, zinc, vanadium, selenium, berylium, nickel, chromium and manganese, may be included in the monitoring system at a later date.

Organic substances in the oceans. The occurence of petroleum products in the oceans is regarded by some scientists as a very serious global problem. The compounds from crude oil may enter the oceans from oil spills, during the transport of oil products over the seas or, in the case of volatile fractions, through aerial transportation. The oil problem is important and possible global effects are foreseen. Pilot activities are given high priority.

The chlorinated aliphatic hydrocarbons, waste products from the plastics industry, have been found to have an extensive distribution in the North Atlantic as a result of ocean dumping. Even if they are rather toxic, they are broken down within a comparatively short time. These substances do not have the same priority as PCB but may be considered for inclusion in a global system at a later date.

Substances in relation to geochemical cycles. Human activities may change the geochemical cycles of the major macronutrient elements at least in local areas. Much attention has been paid to the environmental problems relating to the sulphur cycle. As the man-made emissions of sulphur to the atmosphere have about the same size as the natural emission, it is possible that man's activities have changed the sulphur cycle in a profound way, with resultant effects on ecosystems. The "acid rain" problem is linked to this. For the present moment, extensive research activities are being undertaken which might contribute to a better understanding of the mechanisms involved. This work is an essential prerequisite to any future global monitoring.

Our knowledge about man's impact on the processes in the nitrogen cycle are still insufficient. Extensive emissions both to air (NO_x automotive emissions) to waters (sewage) and to the soils (artificial fertilizers) may have global importance.

Changes in the phosphorus cycle may also be critical as this element may play an important role in the eutrophication of water. On the other hand phosphorus is an element which might be limiting to agricultural productivity in the future and resource conservation and management may be very important.

Another critical substance is carbon, by some regarded as the limiting substance in eutrophication. Carbon dioxide levels in air are also of great importance for organic productivity.

We are not yet prepared to recommend immediate implementation of monitoring programmes for the geochemical cycles, but research and pilot activities directed towards their inclusion at a later stage are recommended.

On the basis of the foregoing considerations, we recommend as first priority that data be collected on the following substances in air, water, soils and biota, at a number of stations for the purpose of assessing secular trends in relation to the pollution of the biosphere:

1. Mercury
2. Lead
3. Cadmium
4. DDT, its metabolites and degradation products
5. Polychorinated biphenyls (PCB)

We further recommend that the following substances be considered for a later inclusion in this network.

6. Petroleum products
7. Persistent organochlorine compounds other than DDT
8. Chlorinated phenoxyacetic acid derivates
9. Organophosphorus compounds
10. Chlorinated aliphatic hydrocarbons
11. Other metals (As, V, Zn, Se, Cr, Cu, Be, Ni, Mn)
12. Relevant compounds in the cycles of S, N, P and C
13. Oxygen in water

6.4. PHYSICAL, CHEMICAL AND BIOLOGICAL DATA REFLECTING THE STATE OF HUMAN HEALTH

6.4.1. The General Problem

The interest expressed in the idea of environmental monitoring by various governments and by the world scientific community stems from a basic concern with the safeguarding of human health and well-being as defined in the very broadest sense, i.e., any phenomenon which can be detected as a significant disamenity to man. Thus, apart from the direct harm to human health, arising from exposure to incipiently pathogenic agents (e.g. harmful micro-organisms, toxic substances) in air, water and food, indirect harm could arise from: certain forms of climatic change; a reduction in the productivity of crops; other changes in livestock and biota; modified aesthetic values and environmentally induced social problems. This is the total human environmental problem and further clarification is required to obtain a more practical view of human health in the context of the present discussion.

The indirect effects referred to above, i.e. any future climatic change or future reduction in biological productivity, can influence nutritional and living-standard factors, which could predispose man to succumb more readily to pathogenic agents on a much wider scale in the future than he does at present. We are already familiar with the action of such indirect effects in areas of the world where because of adverse local climates or poor soils, underfed populations living in extreme poverty exhibit high moribundity and mortality rates from pathogenic agents. Such nutritionally generated health problems have been with us for many years, aggravated by bad housing, defective sanitation and pest-infestations. Existing national and inter-governmental health organizations still recognize this as their basic area of involvement and continue to be very active in this field.

6.4.2. The Special Problem

Apart from this more traditional area of concern, there exists a strong feeling that nowadays, man may be exposed to an additional and growing burden of environmentally induced health hazards generated by his intensive agricultural and urban-industrial use of the environment. Thus, superimposed on the patterns of disease characteristic of pre-urban-industrial or pre-intensive agricultural societies we can discern a newer component which is either known or suspected to be induced by exposure to these 20th century conditions. They include: diseases of the blood and circulatory system (e.g. anaemia, hypertension, arteriosclerosis and ischaemic heart disease): certain forms of cancer (e.g. leukaemia, kidney, liver, stomach, lung, bladder); respiratory complaints (e.g. asthma, emphysaema, chronic bronchitis); impairment of nervous function (e.g. encephalopathy, mental disorders); teratogenic effects (e.g. congenital malformations) and mutagenic or allergy effects. The possible causal agents here are generally agreed to be one or more of the following, some less certain than others: oxides of sulphur and nitrogen, ozone, carbon monoxide, non-ferrous metals (e.g. Pb, Hg, Cd, As, Be, Ni, Zn, Cr); radionuclides; nitrates and nitrites; organochlorine compounds (e.g. pesticides, chlorinated dioxans, polychlorinated biphenyls, chlorinated aliphatic compounds) and other more or less complex pharmaceutical substances and food-additives with poorly understood side-effects.

It is generally agreed that we need a more thorough registration of morbidity and mortality attributable to these diseases or some form of index-parameters to these (e.g. crude morbidity and mortality rates in excess of normalized data, perinatal mortality, rates of first admission to mental-care as against re-admission rates). This survey may be carried out in four broad strata or critical groups:

a) Very high exposure groups at special risk from the suspected causal agents listed above. We already have a considerable body of knowledge derived from workers with occupational exposure to these substances and this should be systematically extended.

b) High exposure groups below occupational exposure levels but having higher than average exposure on account of living in large cities, or intensively industrial or agricultural regions.

c) Medium exposure groups living in rural parts of densely populated countries with a high level of technology and/or intensive agriculture but not at risk levels (a) or (b) above.

d) Low exposure (baseline) groups living in remote regions of the world practising primitive agriculture, pastoralism or hunting.

Along with such studies, a simultaneous programme of exposure assessment should be conducted. This would attempt to evaluate the levels of the suspected causal substances in the local air, food (including imported food-stuffs) and drinking water and relate it to the levels actually present in human tissues (e.g. bone, liver, kidney, spleen, blood, skin, hair, body fat). It is important here to analyse materials for as many substances as possible at the outset. Multifactorial statistical processes will later enable the investigators to concentrate on a priority list of two or three substances for each disease category. The ways in which such causal substances accumulate with age in the various categories (a) – (d) above has already proved valuable for Cd and Pb.

This kind of knowledge, acquired directly from field studies can be effectively supported by long-term chronic toxicological studies carried out on experimental animals in order to induce experimentally the various types of illness by the administration of trace amounts of suspected causal agents, over several generations if necessary. Another valuable experimental approach is a biochemical search for impaired enzyme activity, the apperance of intermediate metabolites accumulating in tissues or body-fluids of affected organisms, including man, as a result of impairment of metabolic function (e.g. δ-amino-laevulinic acid dehydrogenase activity and the appearance of this acid in urine of lead intoxicated subjects).

This combined field- and experimental- approach helps to associate with more certainly each disorder with its specific causal agents. It also provides information on what threshold levels of each substance are harmful to human health.

Without these critical values it will not be possible to assess the seriousness of current global levels of the various substances and much time and resources will be wasted in a costly and elaborate monitoring process which cannot be evaluated.

Many technical problems exist in obtaining representative sampling, natural ranges of genetic tolerance, synergistic effects and the computation of reliable threshold dose levels. This latter difficulty has been avoided for radionuclide exposure by adopting the simple concept that there is no zero-effect dose of a radionuclide and that all exposures are cumulative and additive with an effect proportional to the final dose received by the body or population studied. This operational concept used by UNSCEAR and IRCP of calculating the so called "overall harm commitment" of a population and relating it to a stochastic index of damage to a human population merits attention for pollutants. There is already some evidence indicating that some pollutants may act like radionuclides are supposed to behave in having no toxicity threshold, and attempts to follow this radionuclide approach for contaminants such as lead or methyl mercury where we already know a good deal about the clinical symptoms of chronic toxicosis may well break new ground. Again it is important to recognize from the outset that in assessing "total harm commitment" for a contaminant it is necessary to make an "ecological" approach to the dynamics of the substance studied. Thus, one must know its rate of supply to the body via food-webs, its absorbtion rates in gut and lung, its elimination rate by the body as well as its environmental stability or persistence.

It is also important to continue to review new chemical substances for their possible long term harm to man.

In the light of the above remarks we recommend that the geographical distribution of the following be periodically surveyed wherever data can be obtained:

1. Human life expectancy
2. Population age-structure
3. Excess crude mortality
4. Growth rate in terms of body weight and height
5. Frequency of diseases of blood and cardio-vascular system (anaemia, ischaemic heart-disease, arteriosclerosis, hypertension)
6. Frequency of certain forms of cancer (leukaemia, cancer of stomach, liver, kidney, bladder, lung)

   Surveys should be carried out in various age groups and in the following four critical groups representing various degrees of exposure:

   (a) Very high exposure (occupational)
   (b) High exposure (urban-industrial, or intensive agricultural exposure)
   (c) Medium exposure (rural populations in densely populated countries)
   (d) Low exposure (populations from remote regions)
7. A simultaneous programme of tissue analysis (bone, blood, liver, kidney, spleen, body fat) for lead, mercury, cadmium, DDT and its metabolites, polychlorinated biphenyls, should be carried out on postmortem and other material, carefully selected to represent various age-groups and levels of exposure.

Data collected under 1–6 above should be correlated using traditional threshold-dose-level quality criteria and also attempts made to use the "no zero-dose effect" method used for radionuclides.

8. We recommend a periodic review of other potentially hazardous substances, including new chemicals, to help determine whether they have any long-term effect on human health.
9. We recommend research to establish biochemical monitors of disease e.g. accumulation of intermediate metabolites in the human body.

6.5. BIOLOGICAL DATA REFLECTING THE PERFORMANCE OF BIOLOGICAL SYSTEMS

Relevant physical and chemical measurements of the abiotic environment will not in themselves be informative concerning actual effects on biota. The rationale for monitoring animals and plants and their associations is that only by doing this can we obtain information on these effects. Moreover, the whole concern about the environment has evolved because from time to time directly adverse effects on biota and man have been observed.

Biological parameters therefore constitute an indispensible, if not the most important part of any comprehensive environmental monitoring system. Monitoring of the physical or chemical properties of the environment is relevant only in conjunction with established or strongly suspected effects on biota. The view taken in this report, that biological parameters constitute effect parameters means that there is motivation for biological monitoring even if a direct and specific cause and effect relationship has not yet been established. Observed adverse changes in the living environment will provide warning signals and detection mechanisms and will draw attention to the fact that research is needed to clarify the underlying cause as a preparation for corrective management.

Biological systems are extremely complicated and possible variables for monitoring very numerous. It is thus essential to find those biological variables that most efficiently provide reliable information about effects on biota. However, our existing knowledge is too limited to do this at once. We have instead to approach the problems in a more practical way. We have to consider first the feasibility of performing observations and measurements most likely to be informative and then, by developmental research, further refine them into workable parameters.

The effects on biota that need to be monitored are caused by (1) more or less direct human impact, (2) climatic changes and (3) biologically active chemicals introduced into the environment. The variables selected should be informative regarding at least one of these three groups of causes.

The biological parameters may be sought at different levels of biological organization, from the lowest level of molecules, via populations to the levels of whole communities and biocoenoses. When looking into the problems at the highest levels it is necessary to take the totally integrated picture of the biotic and the abiotic environment into consideration. Therefore studies on ecosystems and biomes must be carried out and the biological monitoring activities integrated with physical and chemical monitoring.

Our approach here will be to make a broad review of different possible areas where effects can be expected and to isolate those where monitoring is both feasible and relevant. The following list includes those kinds of biological parameters that will be considered in the evaluation of a minimum programme.

1. Biome studies
2. Distribution of vegetation types
3. Species diversity
4. Primary productivity, biomass and growth rate
5. Size and distribution of species populations
6. Specific population characteristics: reproductive success, mortality, age structure and migrality
7. Physiology, ontogeny and pathology
8. Genetics
9. Behavioural responses and mental performance
10. Phenology
11. Registration of short lived biological phenomena

Biome studies. When trying to improve our knowledge on the structure and function of the biosphere in order to provide a basis for rational management of its natural resources we recognize that we have to deal with a multitude of different ecosystems, all with different floras, faunas and edaphic conditions. It is an impossible task to analyse each of them separately. However, there is enough evidence to indicate that a number of basic principles are the same over large regions with roughly similar ecosystem structures, e.g. within tundra ecosystems or within tropical forest ecosystems. Regions with similar ecosystems are called biomes, and the logical approach is to call for studies in representative ecosystems within each biome, i.e. biome studies.

From the monitoring point of view, biome studies should provide information on where in the total circulation of energy and substances the critical points are located in terms of sensitivity to environmental stresses and to human control. Information of this kind is of great importance for the determination of the most efficient biological and other parameters for monitoring.

By comparing states and processes of comparable ecosystems in low, medium and high exposure situations it will be possible to detect effects caused by human impact without time-consuming long-term monitoring at fixed plots.

The biome studies will, if properly designed, constitute indispensible parts of a global monitoring programme as centres for research and analysis activities directed to the integrative evaluation of complex biological processes and to the isolation of specific parameters suitable for large scale routine monitoring.

Distribution of vegetation types. The surface of earth is continuously changing. Ecosystems are disappearing and being replaced. It would be an important task to make repetitive surveys of the occurrence and distribution of different ecosystems on a global scale. The amount of work involved is however so great that we do not see any possibility to implement such a programme in the near future. We therefore have to make a more simple and practical approach. We believe that it will be feasible to use remote sensing techniques for general surveys of the distribution of different gross vegetation types. Such surveys would be of great value even if the whole globe could not be covered. A concentration on critical regions, for example regions where we already know or suspect that major changes can occur (desert borders, intensively grazed or cultivated areas in dry regions etc.) would be enough. We also recognize the importance of continous monitoring of the so called endangered or vanishing ecosystems of the world. Such a programme will be fairly easy to implement since activities in that direction are already going on.

Species diversity. It is well known that one of the major criteria for the health of ecosystems is their degree of stability. A useful measure of the degree of stability is species diversity. Agents causing environmental damage generally cause decreased species diversity. Measurements of species diversity are difficult to carry out expect for very limited parts of total biota because we cannot as yet identify or quantify the occurrence of all the different species accurately enough by present methods. We therefore hesitate to recommend that species diversity in general be applied as a routine variable in environmental monitoring. Instead we suggest that pilot research for the development of suitable methods be included in the biome studies. We particularly recommend that these studies include activities in three groups, namely soil organisms, marine algae and air plankton.

The soil still remains the most important and intensively used part of the biosphere, and soils are not renewable in the same way that air or water is. Toxic substances often accumulate in soils and changes in soil quality tend to be more or less irreversible. It is therefore particularly important to detect changes in soil quality as early as possibble. We therefore recommend that a programme for monitoring species diversity of certain groups of soil organisms be developed. The programme should include sampling of representative soil transects from low exposure to high exposure situations in relevant biome types. Identification of species will generally not be possible and therefore the relative occurrence of different ecological groupings of organisms has to be used.

An interim approach to soil health monitoring pending the development of methods for a more detailed programme is to use gross soil respiration as an index of biological activity of soils.

Aquatic algae often show very early and characteristic reactions to changes in the physical and chemical properties of water. They are particularly sensitive to increased levels of nutrients but also to toxic chemicals. Paricular attention should be paid to changes of the algal communities in the marine environment, since changes there may mean that global effects of pollution are occurring. We therefore recommend that a programme is developed to register changes in species diversity of algae in the seas covering areas of different degrees of exposure.

Air plankton (pollen, fungal spores, bacteria, etc.) are often carried long distances by moving air masses. The quantitative and qualitative composition of air plankton may provide information on the movements of specific air masses across continents, assist in forecasting animal and plant diseases and allergies in man and contribute to the detection of major changes in the general composition of vegetation and microfauna and microflora. We therefore recommend that a pilot study be initiated for the assessment of the relevance of aerobiology in global environmental monitoring.

Primary productivity, biomass and growth rate. These variables depend primarily on climate, water and soil quality but may also be affected by toxic chemicals. It seems however that the prospects for detecting effects of human impact upon these parameters are not great. Natural ecosystems have generally a high buffering capacity and modified ecosystems are generally managed with the purpose of preventing changes of any kind. However, these are a group of parameters that should be carefully analysed in connection with the biome studies for possible future inclusion in the routine programme.

Size and distribution of species populations. One of the most characteristic and significant adverse effects of man's impact on the environment is that many species decrease in number or in distribution range. Some species even become extinct. These effects have been observed particularly in birds and mammals but also in other vertebrates, plants and in some invertebrates and micro-organisms. The decreases in population size in many birds, particularly birds of prey, as a consequence of reproductive failure induced by mercury compounds and organochlorines have been particularly instructive. These decreases in population size, whether caused by toxic chemicals or by other forms of human impact, have been of tremendous importance in establishing the present concern about the environment.

When looking further into the problems of defining suitable organisms it is recognized that a very restricted number of groups are suitable for monitoring. These groups are: (1) Vanishing or endangered vertebrates, because they are sensitive to environmental changes and because monitoring programmes already exist which have provided useful information, and (2) Birds, because they have proved to be responsive to a wide range of environmental changes, because they are easy to monitor (taxonomically well known and easy to count) and there are numerous reputable ornithological organizations capable of taking part in a programme at minimum cost.

Specific population characteristics: reproductive success, life expectancy, mortality, age structure and migrality. Certain specific population characteristics may often be detected much earlier than changes in population size or distribution because most species reproduce at a rate much higher than necessary to keep the population level constant. It is now known that the decreases in population size of many birds of prey is caused by reproductive failure, i.e. decreased natality. However, it takes some time before this affects the population size. Increased mortality has been observed for many animal species without accompanying population decreases. Life expectancy and age structure are important from the point of view of evaluation of the cause and effect relationship. Migrality is also necessary in the same context.

We are not in the position to recommend any routine monitoring programme for any of these parameters. But we strongly recommend that pilot research be initiated to isolate those that are relevant and feasible for monitoring and to design methods for measuring them. This can be done in association with the biome studies.

Physiology, ontogeny and pathology. Organisms respond to environmental stresses in many different ways. Effects of air pollution can be detected in the blood of vertebrates, congenital malformations are known to be partly environmentally induced and it is well known that plants react to different toxic substances with sometimes very specific pathological symptoms.

We believe that the use of certain sensitive plants for the detection and monitoring of effects from air and other forms of pollution is promising. In many cases naturally occurring plants such as mosses, liverworts, lichens, may be used, particularly in high exposure situations. Promising results have been obtained with specially planted species selected either because of their general sensitivity to pollutants or because of their specific sensitivity to certain other substances.

Genetics. A number of substances released into the environment including the radionuclides are known to cause genetic changes, either affecting genetic variability or mutation rates. We see a number of possible ways to monitor the effects of such substances: studies of the genetic variability and mutation rates of a number of natural and laboratory populations of standard strains of animals, plants and micro-organisms. Suitable organisms include genetically well known standard strains of cultivated plants, *Musca, Drosophila* and laboratory mice and rats. There are however for the present no preparations for such a programme. We recommend that pilot research into this area be initiated as soon as possible.

It is known that some organisms may rapidly become adapted to tolerate elevated levels of toxic chemicals. This property provides a possibility of determining recent history of exposure by tolerance bioassays or by following gene-linked morphological changes as with industrial melanism.

Behavioural responses and mental performance. Extremely early effects from low levels of toxic chemicals can be detected on a laboratory scale in the behaviour and performance of animals, for example in relation to mating behaviour, learning ability. The techniques available are however not yet standardized. We cannot propose the setting up of a programme immediately but recommend that pilot research be initiated for the development of routine procedures for monitoring behavioural responses from low level chronic exposure of contaminants.

Phenology. The biological effects of climatic change are expected to be apparent first as changes in the seasonal timing of different biological phenomena (flowering of plants, arrival of migratory birds, mating, pupation and flying of insects etc).

Extensive observations have been made of regional and local variations in time of flowering of widely distributed and genetically uniform species such as the common lilac *(Syringa vulgaris).* German foresters have made extensive use of phenological observations in the planning of forest operations. Worldwide studies of phenology were proposed as a part of the International Biological Programme, but this work was carried out only in a few countries. Such a programme requires a large number of observations with a representative geographic distribution.

A principal advantage of the use of phenology in environmental monitoring is that many competent amateur observers can be enlisted. It might also be possible to use remote sensing techniques for registering the flowering of certain trees.

Short-lived biological phenomena (local catastrophes). A number of short-lived biological phenomena may serve as very informative detectors of unknown environmental problems. Extensive kills of sea-birds have occurred from time to time along most coasts of the world. To some extent they may be caused by bad weather conditions but toxic chemicals and/or heavy metals have been supposed to constitute an important contributary factor. Thus, such observations may deserve monitoring in order to be reported in a systematic way so that research efforts can be diverted to the problem immediately in order to find out what the cause was. If the results show that some neglected environmental factor was responsible, it should be decided whether it deserves more or less permanent inclusion in the monitoring system.

Other short-lived phenomena that could be mentioned as possible candidates for inclusion into the reporting system are sudden plankton blooms in the oceans, certain kinds of pest outbreak, certain rapid and unexpected species extinctions etc.

In the light of the above considerations we recommend that biome studies be started immediately. These biome studies should be designed to provide information on the structure and functioning of representative ecosystems pertinent to the rational management of their resources and to obtain methods for monitoring the effects of environmental change on biota.

We recommend that systems be immediately developed for monitoring the following groups of biological parameters.

1. Vanishing or endangered ecosystems
2. Vanishing or endangered vertebrates
3. Population size and distribution of birds
4. Short-lived biological phenomena

We further recommend that pilot research programmes be immediately started in order to prepare early implementation of monitoring systems for the following groups of parameters.

5. Global distribution of major vegetation types
6. Species diversity of soil organisms, marine algae and air plankton
7. Specific population characteristics: reproductive success, life expectancy, mortality, age structure and migrality
8. Pathology of selected standard plants
9. Phenology

We also recommend that a number of additional parameters be carefully considered for relevance and feasibility, viz. species diversity as a general index of ecosystem stability; primary productivity and biomass; genetical changes in selected standard strains of organisms and behavioural responses.