# MAN'S IMPACT ON THE GLOBAL ENVIRONMENT

Assessment and
Recommendations
for Action

## Part I Summary of Findings and Recommendations

## 1.1

## The Problems Studied

Over the past few years, the concept of the earth as a "spaceship" has provided many people with an awareness of the finite resources and the complex natural relationships on which man depends for his survival. These realizations have been accompanied by concerns about the impacts that man's activities are having on the global environment. Some concerned individuals, including well-known scientists, have warned of both imminent and potential global environmental catastrophes.

Theories and speculations of the global effects of pollution have included assertions that the buildup of $CO_2$ from fossil fuel combustion might warm up the planet and cause the polar ice to melt, thus raising the sea level several hundred feet and submerging coastal cities. Equally foreboding has been the warning of the possibility that particles emitted into the air from industrial, energy, and transportation processes might prevent some sunlight from reaching the earth's surface, thus lowering global temperature and beginning a new ice age. Demands to ban DDT have been increasing steadily as its effects on the reproductive capabilities of birds have been determined, and as evidence is found of its accumulation in other species including man. Serious questions have been raised about the effects on ocean and terrestrial ecosystems of systematically discharging into the environment such toxic materials as heavy metals, oil, and radioactive substances; or of nutrients such as phosphorus which can overenrich lakes and coastal areas.

This Report of the one-month, interdisciplinary Study of Critical Environmental Problems (SCEP) presents an assessment of the existing state of scientific knowledge on these and related global environmental problems and contains specific recommendations for action which would reduce the harmful effects of pollution or would provide the information required to understand more adequately the impact of man on the global environment. If such information is not obtained, some critical environmental questions will remain unresolved and we may never be able to identify potential crises in enough time to avoid them and possibly to prevent irreversible global damage.

For each of these global problem areas, Work Groups of the Study addressed the following questions:



What can we now authoritatively say on the subject?

What are the gaps in knowledge which limit our confidence in the assessments we can now make?

What must be done to improve the data and our understanding of their significance so that better assessments may be made in the future?

What programs of focused research, monitoring, and action are needed?

What are the characteristics of the national and/or international action needed to implement the recommendations of the Study?

## 1.2

## The Focus on Global Problems

In order to use most effectively the resources and time available for this Study, it was necessary to limit the scope and character of the problems that were chosen for intensive investigation. SCEP focused on environmental problems whose cumulative effects on ecological systems are so large and prevalent that they have worldwide significance. Thus the Study was primarily concerned with the effects of pollution on man through changes in climate, ocean ecology, or in large terrestrial ecosystems.

In general, local and regional environmental problems, the first-order effects of population growth, and the direct health effects of pollution on man were not considered by the Study. This choice does not imply that these latter problem areas are not of critical concern. Indeed, they are so important that many organizations are deeply concerned with studying and ameliorating them. However, no organization is charged with the responsibility for determining the status of the total global environment and alerting man to dangers that may result from his practices. SCEP attempted to perform this function.

It should be noted that the existence of a global problem does not imply the necessity for a global solution. The sources of pollution are activities of man that can often be effectively controlled or regulated where they occur. Most corrective action will probably have to be taken at the national, regional, and local levels. In research and monitoring programs, however, the potential for international cooperation is high. Effective cooperation now might increase the likelihood of smooth international relations should a global problem ever demand strict international regulation or control of pollution-producing activities. In discussing global environmental problems, it is also necessary to consider the different perspectives of highly industrialized and developing countries regarding pollution.

## 1.3
## The Quality of Available Data and Projections

Before discussing the findings, conclusions, and recommendations of the Study, it is important to note the deficiencies in the data and projections related to problems of global concern. In the process of making judgments we found that critically needed data were fragmentary, contradictory, and in some cases completely unavailable. This was true for all types of data—scientific, technical, economic, industrial, and social. These conditions existed despite a year of planning, extensive preparation of background materials, the presence among Study participants of some of the world's leading scientists, and the generous access to data provided by virtually every relevant federal agency.

With respect to economic and industrial statistical data and projections needed to determine trends of environmental contamination, we found firm data only up to 1967 or 1968 for the United States. International compilations of such data are often incomplete and are of questionable reliability because of uncertainties and inconsistencies in reporting, and because of lack of mechanisms to verify or standardize reports of cooperating nations. Very few projections exist for rates of growth of various industrial sectors, relevant domestic and agricultural activities of man, and energy demands. Those that are available are often based on different and sometimes questionable assumptions and methodologies.

Data on important physical, chemical, and ecological phenomena and parameters are also inadequate for providing the foundation for definitive statements about environmental effects. Specific recommendations for obtaining these data appear throughout this Report. The present data base for global problems is so poor, however, that three general recommendations are necessary.



### Recommendations

1. We recommend the development of new methods for gathering and compiling global economic and statistical information, which organize data across traditional areas of environmental responsibility, such as air and water pollution. We further recommend the propagation of uniform data-collection standards to ensure, for example, that industrial production data collection across the world will be of comparable precision and focus.
2. We recommend a study of the possibility of setting up international physical, chemical, and ecological measurement standards, to be administered through a monitoring standards center with a "real time" data analysis capability, allowing for prompt feedback to monitoring units in terms of monitoring or measurement parameters, levels of accuracy, frequency of observation, and other factors.
3. We recommend an immediate study of global monitoring to examine the scientific and political feasibility of integration of existing and planned monitoring programs and to set out steps necessary to establish an optimal system.

2.
Climatic Effects of Man's
Activities

## 2.1

### Introduction

There is geological evidence that there have been five or six glacial periods (ice ages); the most recent (the Pleistocene) lasted 1 to 1.5 million years. In the past century there has been a general warming of the atmosphere of about 4°C up to 1940, followed by a few tenths degree cooling. It seems clear that our climate is subject to a wide variety of fluctuations, with periods ranging from decades to millennia, and that it is changing now.

We know that the atmosphere is a relatively stable system. The solar radiation that is absorbed by the planet and heats it must be almost exactly balanced by the emitted terrestrial infrared radiation that cools it; otherwise the mean temperature would change much more rapidly than just noted. This nearly perfect balance is the key to the changes that do occur, since a reduction of only about 2 percent in the available energy can, in theory, lower the mean temperature by 2°C and produce an ice age.

That there have not been wider fluctuations in climate is our best evidence that the complex system of ocean and air currents, evaporation and precipitation, surface and cloud reflection and absorption form a complex feedback system for keeping the global energy balance nearly constant. Nonetheless, the delicacy of this balance and the consequences of disturbing it make it very important that we attempt to assess the present and prospective impact of man's activities on this system.

The total mass of the atmosphere and the energy involved in even such a minor disturbance as a thunderstorm (releasing the energy equivalent to many hydrogen bombs) should convince us immediately that man cannot possibly hope to intervene in such a gigantic arena. However, in reality man does intervene, because he can—without intending to do so—reach some leverage points in the system.

All the important leverage points that this Study has identified control the radiation balance of the atmosphere in one way or another, and most of them control it by changing the composition of the atmosphere. For example, man can change the temperature of the atmosphere by introducing a gas such as $CO_2$ or a cloud of particles that absorbs and emits solar and terrestrial infrared radiation, thereby altering the delicate balance we have described. He can also affect the heat balance by changing the



face of the earth or by adding heat as a result of rising energy demands.

A thorough understanding and reliable prediction of the influence of atmospheric pollutants on climate requires the mathematical simulation of atmosphere-ocean systems, including the pollutants. At present, computer models successfully simulate many observed characteristics of the climate and have significantly advanced our knowledge of atmospheric phenomena. They have, however, a number of drawbacks that become serious when modeling new states of equilibrium or changes of climate in its transition toward these new states. Unless these limitations are overcome, it will be difficult, if not impossible, to predict inadvertent climate modifications that might be caused by man.

### Recommendations

1. We recommend that current computer models be improved by including more realistic simulations of clouds and air-sea interaction and that attempts be made to include particles when their properties become better known. Such models should be run for periods of at least several simulated years. The effects of potential global pollutants on the climate and on phenomena such as cloud formation should be studied with these models.
2. We recommend that possibilities be investigated for simplifying existing models to provide a better understanding of climatic changes. Simultaneously, a search should be made for alternative types of models which are more suitable for handling problems of climatic change.

## 2.2

### Carbon Dioxide from Fossil Fuels

All combustion of fossil fuels produces carbon dioxide ($CO_2$), which has been steadily increasing in the atmosphere at 0.2 percent per year since 1958. Half of the amount man puts into the atmosphere stays and produces this rise in concentration. The other half goes into the biosphere and the oceans, but we are not certain how it is divided between these two reservoirs. $CO_2$ from fossil fuels is a small part of the natural $CO_2$ that is constantly being exchanged between the atmosphere/oceans and the atmosphere/forests.

A projected 18 percent increase resulting from fossil fuel combustion to the year 2000 (from 320 ppm to 379 ppm) might increase the surface temperature of the earth 0.5°C; a doubling of the $CO_2$ might increase mean annual surface temperatures 2°C. This latter change could lead to long-term warming of the planet. These estimates are based on a relatively primitive computer model, with no consideration of important motions in the atmosphere, and hence are very uncertain. However, these are the only estimates available today.

Should man ever be compelled to stop producing $CO_2$, no coal, oil, or gas could be burned and all industrial societies would be drastically affected. The only possible alternative for energy for industrial and commercial use is nuclear energy, whose by-products may also cause serious environmental effects. There are at present no electric motor vehicles that could be used on the wide scale our society demands.

Although we conclude that the probability of direct climate change in this century resulting from $CO_2$ is small, we stress that the long-term potential consequences of $CO_2$ effects on the climate or of societal reaction to such threats are so serious that much more must be learned about future trends of climate change. Only through these measures can societies hope to have time to adjust to changes that may ultimately be necessary.

### Recommendations

1. We recommend the improvement of present estimates of future combustion of fossil fuels and the resulting emissions.
2. We recommend study of changes in the mass of living matter and decaying products.
3. We recommend continuous measurement and study of the carbon dioxide content of the atmosphere in a few areas remote from known sources for the purpose of determining trends. Specifically, four stations and some aircraft flights are required.
4. We recommend systematic scientific study of the partition of carbon dioxide among the atmosphere, the oceans, and the biomass. Such research might require up to 12 stations.

## 2.3 Particles in the Atmosphere

Fine particles change the heat balance of the earth because they both reflect and absorb radiation from the sun and the earth.



Large amounts of such particles enter the troposphere (the zone up to about 12 km or 40,000 feet) from natural sources such as sea spray, windblown dust, volcanoes, and from the conversion of naturally occurring gases into particles.

Man introduces fewer particles into the atmosphere than enter from natural sources; however, he does introduce significant quantities of sulfates, nitrates, and hydrocarbons. The largest single artificial source is the production of sulfur dioxide from the burning of fossil fuel that subsequently is converted to sulfates by oxidation. Particle levels have been increasing over the years as observed at stations in Europe, North America, and the North Atlantic but not over the Central Pacific.

In the troposphere, the residence times of particles range from 6 days to 2 weeks, but in the lower stratosphere micron-size particles or smaller may remain for 1 to 3 years. This long residence time in the stratosphere and also the photochemical processes occurring there make the stratosphere more sensitive to injection of particles than the troposphere.

Particles in the troposphere can produce changes in the earth's reflectivity, cloud reflectivity, and cloud formation. The magnitudes of these effects are unknown, and in general it is not possible to determine whether such changes would result in a warming or cooling of the earth's surface. The area of greatest uncertainty in connection with the effects of particles on the heat balance of the atmosphere is our current lack of knowledge of their optical properties in scattering or absorbing radiation from the sun or the earth.

Particles also act as nuclei for condensation or freezing of water vapor. Precipitation processes can certainly be affected by changing nuclei concentrations, but we do not believe that the effect of man-made nuclei will be significant on a global scale.

### Recommendations

1. We recommend studies to determine optical properties of fine particles, their sources, transport processes, nature, size distributions, and concentrations in both the troposphere and stratosphere, and their effects on cloud reflectivity.
2. We recommend that the effects of particles on radiative transfer be studied and that the results be incorporated in mathe-

matical models to determine the influence of particles on planetary circulation patterns.

3. We recommend extending and improving solar radiation measurements.

4. We recommend beginning measurements by lidar (optical radar) methods of the vertical distribution of particles in the atmosphere.

5. We recommend the study of the scientific and economic feasibility of initiating satellite measurements of the albedo (reflectivity) of the whole earth, capable of detecting trends of the order of 1 percent per 10 years.

6. We recommend beginning a continuing survey, with ground and aircraft sampling, of the atmosphere's content of particles and of those trace gases that form particles by chemical reactions in the atmosphere. For relatively long-lived constituents about 10 fixed stations will be required, for short-lived constituents, about 100.

7. We recommend monitoring several specific particles and gases by chemical means. About 100 measurement sites will be required.

## 2.4
## The Role of Clouds

The importance of clouds in the atmosphere stems from their relatively high reflectivity for solar radiation and their central role in the various processes involved in the heat budget of the earth-atmosphere system.

### Recommendations

1. We recommend that there be global observations of cloud distribution and temporal variations. High spatial resolution satellite observations are required to give "correct" cloud population counts and to establish the existence of long-term trends in cloudiness (if there are any).

2. We recommend studies of the optical (visible and infrared) properties of clouds as functions of the various relevant cloud and impinging radiation parameters. These studies should include the effect of particles on the reflectivity of clouds and a determination of the infrared "blackness" of clouds.



## 2.5
## Cirrus Clouds from Jet Aircraft

Contrail (condensation trail) formation, which is common near the world's air routes, is more likely to occur when jets fly in the upper troposphere than in the lower troposphere because of the different meteorological conditions in these two regions.

There are very few, if any, statistics that permit us to determine whether the advent of commercial jet aircraft has altered the frequency of occurrence or the properties of cirrus clouds. We do not know whether the projected increase in the operation of subsonic jets will have any climate effects.

Two weather effects from enhanced cirrus cloudiness are possible. First, the radiation balance may be slightly upset, and, second, cloud seeding by falling ice crystals might initiate precipitation sooner than it would otherwise occur.

### Recommendations

1. We recommend that the magnitude and distribution of increased cirrus cloudiness from subsonic jet operations in the upper troposphere be determined. A study of the phenomenon should be conducted by examining cloud observations at many weather stations, both near and remote from air routes.

2. We recommend that the radiative properties of representative contrails and contrail-produced cirrus clouds be determined.

3. We recommend that the significance, if any, of ice crystals falling from contrail clouds as a source of freezing nuclei for lower clouds be determined.

## 2.6
## Supersonic Transports (SSTs) in the Stratosphere

The stratosphere where SSTs will fly at 20 km (65,000 feet) is a very rarefied region with little vertical mixing. Gases and particles produced by jet exhausts may remain for 1 to 3 years before disappearing.

We have estimated the steady-state amounts of combustion products that would be introduced into the stratosphere by the Federal Aviation Agency projection of 500 SSTs operating in

1985–1990 mostly in the Northern Hemisphere, flying 7 hours a day, at 20 km (65,000 feet), at a speed of Mach 2.7, propelled by 1,700 engines like the GE-4 being developed for the Boeing 2707-300. We have used General Electric (GE) calculations of the amount of combustion products because no test measurements exist. In our calculations we used jet fuel of 0.05 percent sulfur. We have been told that a specification of 0.01 percent sulfur could be met in the future at higher cost.

We have compared the amounts that would be introduced on a steady-state basis with the natural levels of water vapor, sulfates, nitrates, hydrocarbons, and soot in the stratosphere. We have also compared these levels with the amounts of particles put into the atmosphere by the volcano eruption of Mount Agung in Bali in 1963.

Based on these calculations, we have concluded that no problems should arise from the introduction of carbon dioxide and that the reduction of ozone due to interaction with water vapor or other exhaust gases should be insignificant. Global water vapor in the stratosphere may increase 10 percent, and increases in regions of dense traffic may be 60 percent.

Very little is known about the way particles will form from SST-exhaust products. Depending upon the actual particle formation, particles from these 500 SSTs (from $SO_2$, hydrocarbons, and soot) could double the pre-Agung eruption global averages and peak at ten times those levels where there is dense traffic. The effects of these particles could range from a small, widespread, continuous "Agung" effect to one as big as that which followed the Agung eruption. (The analogy between the SST input and that by the Mount Agung eruption is not exact.) The temperature of the equatorial stratosphere (a belt around the earth) increased 6° to 7°C after the eruption and remained at 2° to 3°C above the pre-Agung level for several years. No apparent temperature change was found in the lower troposphere.

Clouds are known to form in the winter polar stratosphere. Two factors will increase the future likelihood of greater cloudiness in the stratosphere because of moisture added by the SSTs: the increased stratospheric cooling due to the increasing $CO_2$ content of the atmosphere and the closer approach to saturation indicated by the observed increase of stratospheric moisture. Such



an increase in cloudiness could affect the climate. The introduction of particles into the stratosphere could also produce climatic effects by increasing temperatures in the stratosphere, with possible changes in surface temperatures.

A feeling of genuine concern has emerged from these conclusions. The projected SSTs can have a clearly measurable effect in a large region of the world and quite possibly on a global scale. We must, however, emphasize that we cannot be certain about the magnitude of the various consequences.

## Recommendations

1. We recommend that uncertainties about SST contamination and its effects be resolved before large-scale operation of SSTs begins.
2. We recommend that the following program of action be initiated as soon as possible:
   a. Begin now to monitor the lower stratosphere for water vapor, cloudiness, oxides of nitrogen and sulfur, hydrocarbons, and particles (including the latter's composition and size distribution).
   b. Determine whether additional cloudiness or persistent contrails will occur in the stratosphere as a result of SST operations, particularly in certain cold areas, *and* the consequences of such changes.
   c. Obtain better estimates of contaminant emissions, especially those leading to particles, under simulated flight conditions and under real flight conditions, at the earliest opportunity.
   d. Using the data obtained in carrying out the preceding three recommendations, estimate the change in particle concentration in the stratosphere attributable to future SSTs *and* its impact on weather and climate.
3. We recommend implementation now of a special monitoring program for the lower stratosphere (about 20 km or 60,000 to 70,000 feet) to include the following activities:
   a. Measurement by aircraft and balloon of the water vapor content of the lower stratosphere. The area coverage required is global, but with special emphasis on areas where it is proposed that the SST should fly.

b. Sampling by aircraft of stratospheric particles, with subsequent physical and chemical analysis.

c. Monitoring by lidar (optical radar) of optical scattering in the lower stratosphere, again with emphasis on the region in which heavy traffic is planned.

d. Monitoring of tropospheric carbon monoxide concentration because of its potential effects on the chemical composition of the lower stratosphere.

## 2.7
## Atmospheric Oxygen: Nonproblem

Atmospheric oxygen is practically constant. It varies neither over time (since 1910) nor regionally and is always very close to 20.946 percent. Calculations show that depletion of oxygen by burning all the recoverable fossil fuels in the world would reduce it only to 20.800 percent. It should probably be measured every 10 years to be certain that it is remaining constant.

## 2.8
## Surface Changes and the Climate

The most important properties of the earth's surface that have a bearing on climate and are likely to be affected by human activity are reflectivity, heat capacity and conductivity, availability of water and dust, aerodynamic roughness, emissivity in the infrared band, and heat released to the ground.

Since the amount of carbon dioxide in the atmosphere is dependent on the biomass of forest lands which serves as a reservoir, widespread destruction of forests could have serious climatic effects. Population growth or overgrazing that increases the arid or desert areas of the earth creates conditions that allow the introduction of dust particles to the atmosphere.

Other important surface changes are from man's activities that modify snow and ice cover, particularly in polar regions, and from some possible projects involving the production of new, very large water bodies. Increased urbanization is of possible global importance only as it produces extended areas of contiguous cities. Still, it is not certain whether effects of urbanization extend far beyond the general region occupied by the cities.



### Recommendation

We recommend that before actions are taken which result in some of the very extensive surface changes described mathematical models be constructed which simulate their effects on the climate of a region or, possibly, of the earth.

## 2.9
## Thermal Pollution

Although by the year 2000 global thermal power output may be as much as six times the present level, we do not expect it to affect global climate. Over cities it does already create "heat islands," and as these grow larger they may have regional climatic effects. We recommend that these potential effects be studied with computer models.

3.
Ecological Effects of Man's Activities

3.1
General Effects
Man produces more than a million different kinds of products, both as waste and as useful products that eventually end up as waste. We are mobilizing many materials at rates greater than the global rates of geological erosion and deposition, great enough to change their global distributions. We are using more than 40 percent of the total land surface and have reduced the total amount of organic matter in land vegetation by about one-third.

An estimate is needed for the ecological demand, a summation of all of man's demands upon the environment, such as the extraction of resources and the return of wastes. Such demand-producing activities as agriculture, mining, and industry have global annual rates of increase of 3, 5, and 7 percent, respectively. An integrated rate of increase is estimated to be between 5 and 6 percent per year, in comparison with an annual rate of population increase of only 2 percent. It is only through such a concept as ecological demand that man can assess his impact on the biosphere.

Natural ecosystems still provide us many services. Almost all potential plant pests are controlled naturally. Insects pollinate most vegetables, fruits, berries, and flowers. Commercial fish are produced almost entirely in natural ecosystems. Vegetation reduces floods, prevents erosion, and air-conditions and beautifies the landscape. Fungi and minute soil animals work jointly on plant debris and weathered rocks to produce soil. Natural ecosystems cycle matter through green plants, animals, and decomposers, thus eliminating wastes. Organisms regulate the amount of nitrates, ammonia, and methane in the environment. On a geological time scale, life regulates the amount of carbon dioxide, oxygen, and nitrogen in the atmosphere. Natural ecosystems also serve important recreational and aesthetic needs of man.

While some of these services will cease only when life is virtually annihilated, many others are easily impaired. However, these losses are gradual and progressive without discrete steps of change. The gradual attrition of natural systems results from most types of environmental pollution and thus measures the total impact of man upon his environment.



The health and vigor of ecological systems are easily reduced if (1) general and widespread damage occurs to the predators, (2) substantial numbers of species are lost, or (3) general biological activity is depressed. Most pollutants that affect life have some effect on all three processes. To prevent further deterioration of the biosphere and to repair some of the present damage, effective environmental management systems are urgently needed.

**Recommendations**

1. We recommend an intensive program of technology assessment. Research on the toxic effects of pollutants needs to be greatly expanded, especially to include the difficult experiments that are based on low levels of chronic exposure. We also need to have much better knowledge of the current sources of pollution, their kinds and rates, as well as projections of future trends. Both of these information needs should be part of continuing studies of the impact of technology that are closely integrated into the time phasing of planned technological development.
2. We recommend a systematic program of environmental assessment. We need more information on the routes of distribution of pollutants, their eventual distribution in the environment, and their passage through ecosystems. The present disorganized system leads to faddism and thus to the development of information on one pollutant with the neglect of others and develops no regular assessment of trends through time. Specifically, we recommend the following:
   a. Early establishment of ecological base-line stations in remote areas that would provide both specific monitoring of the effects of known problems and warnings of unsuspected effects.
   b. Central coordination and, where necessary, modification of national and regional surveys of critical populations of fish, birds, and mammals from commercial catches, harvests, and surveys. This would provide an early warning system by monitoring highly sensitive and vulnerable species.
   c. Implementation of a number of simple measures to determine the present states of ecosystems. Collected systematically the following information would be of great value: the rates of recruitment (the reproduction and survival of

young to maturity) of populations of birds and fish; the area damage to leaves of trees; the degree of oxygen depletion in deep water; and the diversity of species collected in plankton nets, soil samples, and insect light traps. All of these are indicators of ecosystem function.

d. Implementation of a 1,000-sample base-line survey of the oceans to provide general knowledge of the distribution of man-made products in the oceans. The results of such a survey would make it possible to specify the volume and distribution of observations necessary to monitor critical environmental problems in the oceans.

e. Examination, either as part of the ocean base-line survey or independently, of glaciers and sediments to help remedy the current lack of adequate historical record of the oceans and of world climate and, especially, to clarify at least the recent variations of atmospheric and oceanic particulate content.

3. We recommend a comprehensive program of problem evaluation. Existing and emerging environmental problems must be analyzed in the broader context of social, economic, and political problems. We need think centers devoted to conflict resolution between man and environment. Substantive issues include growth in population, growth in ecological demand, a new land ethic, achieving early action in high-risk situations, allocating costs to promote better technical solutions, and obtaining effective management in international waters and airsheds. Analysis should include value changes in the traditional rights and goals of individuals, industry, and government. Fundamental changes in life style should be identified that will permit us to develop a system in which freedom from the constraints of nature is compatible with the continuing function of ecological systems.

4. We recommend an extensive program of public education. The results of the programs here recommended must be presented to the public in a simple and understandable form through educational institutions and the news media.



## 3.2
## DDT and Related Persistent Pesticides

Pesticides can have widespread ecological effects. The use of pesticides on crops generally requires continued and increased use of different and stronger pesticides. This is the result of a complex ecological system in which the reduction of one pest and several innocuous (to man) predators allows new pests to become dominant.

DDT can also have specific effects on species other than pests. For example, the eggshells of many birds are becoming thinner, reducing hatching success. In several species these effects now seriously threaten reproductive capabilities. Damage to these predators in an ecological system tends to create a situation in which pest outbreaks are likely to occur.

The concentrations and effects of DDT in the open oceans are not known. There are no reliable estimates and no direct measurements have been made. It is known that large amounts leave the area of application through the atmosphere and are transmitted through the world, and some portion of this falls into the oceans.

DDT collects in marine organisms. Detrimental effects have not been observed in the open ocean, but DDT residues in mackerel caught off of California have already exceeded permissible tolerance levels for human consumption. It is known that reproduction of fresh-water game fish are being threatened.

The effect of DDT on the ability of ocean phytoplankton to convert carbon dioxide into oxygen is not considered significant. The DDT concentration necessary to induce significant inhibition exceeds expected concentrations in the open ocean by ten times its solubility (1 part per billion) in water.

### Recommendations

1. We recommend a drastic reduction in the use of DDT as soon as possible *and* that subsidies be furnished to developing countries to enable them to afford to use nonpersistent but more expensive pesticides as well as other pest control techniques.

2. In order to obtain information about the concentrations and effects of DDT in the marine environment, a base-line pro-

gram of measurement should be initiated (also recommended in the previous section). This might involve taking about 1,000 samples at selected locations and analyzing them over the course of a year. A full-scale monitoring program should await the results of such a program.

3. We recommend greatly increased effort and support for the research and development of integrated pest control, combining a minimal use of pesticides with maximal use of biological control.

3.3

Mercury and Other Toxic Heavy Metals

Many heavy metals are highly toxic to specific life stages of a variety of organisms, especially shellfish. Most are concentrated in terrestrial and marine organisms by factors ranging from a few hundred to several hundred thousand times the concentrations in the surrounding environment.

The major sources of mercury are industrial processes and biocides. The former are often introduced into waters through municipal sewage systems. Although the use of mercury in pesticides is relatively small, it is a direct input into the environment.

Recommendations

1. We recommend that all pesticidal and biocidal uses of mercury be drastically curtailed, particularly where safer, less-persistent substitutes can be used.
2. We recommend that data be obtained on the concentrations of mercury in selected organisms and on its effect on ecosystems.
3. We recommend that all industrial wastes and emissions of mercury be controlled and recovered to the greatest extent possible.
4. We recommend that world production and consumption figures for mercury be obtained.

3.4

Oil in the Ocean

It is likely that approximately 2 million tons of oil are introduced into the oceans every year through ocean shipping, off-



shore drilling, and accidents. Very little is known about the effects of oil in the oceans on marine life. Present results are conflicting. The effects of one oil spill that has been carefully observed indicates severe damage to marine organisms. Observations of other spills have not shown such a marked degree of damage. Different kinds of damage have been observed for different spills.

Potential effects include direct kill of organisms through coating, asphyxiation, or contact poisoning; direct kill through exposure to the water-soluble toxic components of oil; destruction of the food sources of organisms; incorporation of sublethal amounts of oil and oil products into organisms, resulting in reduced resistance to infection and other stresses or in reproductive failures.

Recommendations

1. We recommend that much more extensive research be undertaken to determine the action of oil in the ocean and its effects on marine biota. Future oil spills should be systematically studied beginning immediately after they occur so that a comprehensive analysis of the effects can be developed over time. Sites of previous spills should be reexamined to study the effects in sediments.
2. We recommend that political and legal possibilities be explored for the establishment of more effective international control measures for oil-carrying tankers.
3. We recommend that the possibility of recycling used oil be explored.

3.5

Nutrients in Coastal Waters

Eutrophication of waters through overfertilization (principally with phosphorus and nitrogen) produces an excess of organic matter that decomposes, removing oxygen and killing the fish. Estuaries are increasingly being eutrophied. Pollution of coastal regions eliminates the nursery grounds of fish, including many commercial species that inhabit the oceans.

Approximately 60 percent of the phosphorus causing overenrichment of water bodies comes from municipal wastes. Urban and rural land runoff contribute the remainder. A major contributor to the latter is runoff from feedlots, manured lands, and eroding soil.

Trends in both nutrient use and loss are rising. Fertilizer consumption is expected to increase greatly in both developed and developing countries in the next decade, increasing the nutrient runoff from agricultural lands. Concentration of animal production will continue, with the result that losses of nutrients from feedlot runoff will rise sharply. Urban waste production is also expected to increase rapidly, resulting in greater potential loss of nutrients directly into coastal waters.

### Recommendations

1. We recommend that technology be developed to reclaim and recycle nutrients in areas of high concentrations, such as sewage treatment plants and feedlots.
2. We recommend that the dumping of industrial wastes into sewage systems be restricted so that toxic wastes do not interfere with nutrient recovery and recycling.
3. We recommend that the use of nutrients in materials that are discharged in large quantities into water or air be avoided. For example, phosphates in detergents should be replaced with new materials, being certain that the substitute does not itself create a new problem.
4. We recommend that the institutional structures responsible for defining, monitoring, and maintaining water-quality standards over large areas be improved. The multiplicity of authorities involved in river basins, estuaries, and coastal oceans makes effective control nearly impossible.

## 3.6 Wastes from Nuclear Energy

In our selection of problems for intensive study, it was necessary to omit some areas of great importance. One of these areas is that of perpetual management of large quantities of radioactive wastes which are by-products of nuclear power generation. No other environmental pollutant has been so carefully monitored and contained. This class of pollutants will, however, grow significantly in quantity over the next several decades. There-



fore, it is important that attention be focused on any environmental problems that might arise.

### Recommendation

We recommend that an independent, intensive, multidisciplinary study be made of the trade-offs in national energy policy between fossil fuel and nuclear sources, with a special focus on problems of safe management of the radioactive by-products of nuclear energy, leading to recommendations concerning the content and scale and urgency of needed programs.

4.
Implications of Change and
Remedial Action

## 4.1
## Introduction

The expansion and refinement of our knowledge and understanding are the necessary conditions for effective change in the present state of environmental management. However, these are not sufficient conditions. Even after optimal improvements have been made in our knowledge concerning the nature of key pollutants, their effects, their sources, their rates of accumulation, the routes along which they travel, and their final reservoirs, the questions will remain of how to apply our knowledge constructively and how to cope with the collateral consequences. As a practical matter, questions of environmental management will have to be faced before we have all the appropriate scientific and technical data, and this further complicates efforts of change or of remedial action.

In examining a wide range of specific problems at this Study, we have identified several aspects that are common to most of them and to many other critical environmental problems. These implications of change and remedial action are briefly discussed now.

## 4.2
## Establishing New Priorities

Earlier in our history, the prevailing value system assigned an overriding priority to the first-order effects of applied science and technology: the goods and services produced. We took the side effects—pollution—in stride. A shift in values appears to be under way that assigns a much higher priority than before to the control of the side effects. This does not necessarily imply a reduced interest in production and consumption. When the implications of remedial action and the choices that must be made become clear, there may be second thoughts, confusion, and feelings of frustration.

In the effort to arrive at an optimal balance in specific situations, something will have to give. But the old routine assumption that it is the environment that must give has become intolerable. This assumption must be rejected in favor of an optimal balance to be reached from a point of departure in affixing the responsibilities for pollution.



## 4.3
## Affixing Responsibilities

As a point of departure for taking action, we recommend a principle of presumptive "source" responsibility. While remedial measures can be attempted on the routes along which pollutants spread or in the reservoirs in which they accumulate, we believe that these measures should be generally taken at the "sources," which we define broadly to include (1) sources or the points in the processes of production, distribution, and consumption, at which the pollutant is generated, for example, factories, power plants, stockyards, bus lines; (2) protosources or earlier points that set the conditions leading to the emission of pollutants at a later stage, for example, the manufacturers of automobiles that emit pollutants when driven by motorists, or the brewers of beer sold in nonreturnable cans that are tossed aside by the consumer; and (3) secondary sources or points along the routes where pollutants are concentrated before moving on to the reservoirs, for example, sewage treatment plants or solid waste disposal centers.

The principle does not connote any element of blame or censure, nor is it intended to foreclose a judgment concerning where the financial costs of correction should ultimately be borne. It is intended, however, to indicate a point of departure for analysis and action. It rests, in part, on the basis that, if something goes wrong, it should be traced to its origin and corrected in terms of its cause; in part on a hypothesis that the source, protosource, or secondary source will typically be in the best position to take corrective measures, whether alone or with help from others; and in part on the view that the remedies available, the criteria for choice among them, and the implications of remedial action can best be appraised at the sources as here defined.

## 4.4
## Accepting the Costs

Remedial changes will ordinarily involve financial costs, and the costs may be large in relation to the scale of the source enterprise. If the source enterprise can neither absorb the cost nor pass it on, it will be necessary to face a choice among failure of the enterprise, continuance of the pollution, or financial assistance out of public revenues. The initial change may have consequences reaching past the source enterprise to its employees, its suppliers, and its customers and beyond in widening waves of change that may engulf deep-rooted patterns of economic and social behavior. Our society is familiar with far-reaching readjustments caused by technological innovation or organizational change in the past. Comparable readjustments may be required by changes instituted to control pollution.

### 4.5
### Assessing the Available Means for Action

The means available within the political process and legal system to encompass remedial changes include taxes designed as incentives, stimuli, or pressures, regulations, typically involving a statute, an administrative agency, and supplementary action through the courts; common-law remedies in the courts, incrementally adjusted to contemporary needs; governmental financing of research and assistance to facilitate costly adjustments to desired changes; and governmental operations, civilian and military. Governmental action in its own house can have a dual importance: in itself and as a model for others to follow.

### 4.6
### Stimulating Effective Actions

The political, legal, and market processes of our society are profoundly affected by the nature and quantity of information available and the manner in which the information is infused into them. It is neither necessary nor feasible to postpone recommendations for action until scientific certainty can be achieved. The political process is accustomed to decisions in the face of uncertainty on the basis of a preponderance of the evidence or substantial probabilities or a reasonable consensus of informed judgment.

Thus, it is not enough for scientists and technologists to expand and refine their knowledge. They must also present their knowledge in a manner that clearly differentiates fact, assertion, and opinion and facilitates the task of relating the data to the possibilities of corrective action. But if such information is to be



used, the Congress and state legislative bodies must be provided with instrumentalities and qualified staff to enable them more effectively to sort out and utilize the input of data, proposals, complaints, and suggestions that will flow into them in increasing volumes from all sectors of our society.

### 4.7
### Developing New Professionals

In addition to general public education, we stress the special importance of some changes in scientific, technical, and professional education and training. A sensitivity to the relations between the processes of production, distribution, and consumption, on the one hand, and the processes of pollution, on the other, and a disposition to explore all the potentialities of technology and organization in the search for an optimal balance should be incorporated into their training. This applies to economists, lawyers, and social scientists as well as to scientists and engineers. Individual contributions may be undramatic now, but over time they will be critical.

### 4.8
### Cooperating with Other Nations

Although many problems are global in nature, the solutions to these problems will generally require national as well as international action. Typically, remedial measures within one nation will need support from parallel actions within other nations. Frequently, collaborative international action will be required. The prospects for such cooperation are best for programs of collection and analysis of data. International cooperation on monitoring may also increase the likelihood of smooth relations should a global program ever demand strict international regulation or control of pollution-producing activities.

In the foreseeable future the advanced industrial societies will probably have to carry the major burden of remedial action. Developing nations are understandably concerned far more with economic growth and material progress than with second-order effects of technology. Similar attitudes were prevalent in the early stages of growth of present industrialized nations.

The challenges of international cooperation and collaboration in the critically important environmental areas studied by SCEP will be before the United Nations Conference on the Human Environment in 1972. We hope that this Report will provide useful inputs to that Conference and that the Study model furnished by SCEP will be applied to other critical problems of the environment.