Science

A Resource For Humankind

Proceedings of the

National Academy of Sciences

Bicentennial Symposium

SCIENCE: A RESOURCE FOR HUMANKIND

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Bicentennial Symposium

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PREFATORY NOTE

In view of the fact that the United States observed its Bicentennial in 1976, the International Council of Scientific Unions (ICSU) accepted an invitation from the United States National Academy of Sciences to hold its General Assembly in Washington, D.C., during the period of October 10-16. This brought to our nation's capital prominent representatives from many of the more than fifty academies, royal societies, research councils and other scientific bodies comprising the National Members of the Union, the principal officers of the seventeen scientific unions which make up the Scientific Members of ICSU, and representatives of the Scientific Committees, Special Committees, Commissions, and Permanent Services that have been established by ICSU to deal with matters that transcend a single discipline.

In addition to the regular business of the General Assembly and the social and cultural events which traditionally contribute notably to international understanding at an ICSU General Assembly, the United States National Academy of Sciences presented, as a part of our nation's Bicentennial observance, a three-part symposium of special presentations aimed at illuminating the interaction of science and societal affairs.

Underlying the theme of the symposium, "Science: A Resource for Humankind," is the conviction that major developments in science and technology over the past few hundred years have brought society to a sort of crossroads.

The Symposium was developed in three topics. The first examined, retrospectively, the role of science and technology in the social and economic development of seven selected countries with the objective of providing new insights into this complex interaction. The second topic addressed the contemporary problem of successfully managing the quality of the human environment and our global supply of natural resources. It focused on the adequacies and inadequacies of our knowledge base for this task. The third topic dealt with innovations in science and technology, desirable or otherwise, that, over the balance of this century may affect such interrelated problems as world food supply, the nutrition, health, and size of human populations, utilization of natural resources and adequacy of energy supplies so that we may realize the attractive opportunities and avoid the hazards which appear to lie ahead.

Several audiences were addressed, viz., the formal delegates representing major scientific bodies and institutions at the General Assembly of ICSU, especially invited decision makers from the public and private sectors and selected promising young individuals from developing countries, as well as interested general citizenry reached through the public media.

This document is a summary of these deliberations. Topics I and II will be presented in full in a book to be published by Holt, Reinhart and Winston, Inc. and John Wiley and Sons, Inc., respectively. The full text of Topic III is attached to this summary as an appendix.

The Steering Committee is grateful to the many individuals and institutions which contributed to this undertaking. We are particularly indebted to Dr. William Beranek, Jr., who guided the effort so skillfully.

Thomas F. Malone
Chairman
United States National Academy of Sciences
Bicentennial Symposium Steering Committee

WELCOME FROM THE UNITED STATES NATIONAL ACADEMY OF SCIENCES

George S. Hammond
Foreign Secretary
National Academy of Sciences
Professor of Chemistry
University of California, Santa Cruz
Santa Cruz, California

It is my priviledge and honor to welcome all of you to this symposium: delegates attending the ICSU General Assembly, friends of the Academy, interested people from science and government affairs, from the Washington area and throughout the country.

As this is our Nation's Bicentennial year, this is a signal event in the history of our Academy. We are caught up in the low level exultation that occurs with realizing that our country is 200 years old. As I look at the nations represented by the ICSU body, this makes us a middle aged nation. There are many countries far older than the United States. Yet, of course, there are many nations whose present national status was established far more recently than the United States.

So as a middle aged country, we have a right to reflect on what has been good for us and what has been bad for us both as a nation and as a member of the international community of nations. Once in this frame of mind it is natural and our duty to ourselves and to the people of the world, to look at the world as a whole and reflect on the same kinds of questions.

During this symposium, the Academy will present some ideas on the subject of science as a tool of humankind because surely science and the derived high technology have been used as tools of the human species in an enormously effective way. The results of that use have not always been beneficent, although it is my own conviction that on the whole the lot of Man, the quality of the life of Man, has been enormously enhanced by uses of science. At the very least, we are awed by the accomplishments, both because of the potency to help and the potency to hurt.

In our retrospective reflection on the effect of science and technology on the process of economic development in this country and in others, we pay special attention to the dependence on foreign science and technology which is imported and adapted to purposes of weak, young nations. Lessons here may have application to today's world.

We look also at what is happening to us today as a nation sharing the commons of the earth with all of the other people of the earth. We must consider the problems of the global environment both as a consequence of and as a problem to be solved by known science and the technology derived from it.

In the closing thrust of the symposium, we look ahead and, with trepidation, attempt to speculate about what may happen in the future. Since the acceleration and development of human affairs means that new things appear and become active in our impact on men's lives at a terrifyingly rapid rate, this is an enormously difficult thing to do. In fact, Alvin Toffler, a few years ago in his popular book Future Shock, pointed out the question, and a serious one, as to whether or not the human organism has the capacity to accomodate the rate of change which can be brought about by the ever accelerating development and accumulation of human knowledge and the limitless capacity of people to put that knowledge to work in various ways for various ends.

It is toward these questions that we will be turning our attention during the symposium this week. I hope that you will think with us and reflect with us, because we will not be giving answers. We will be giving reflections, examining small bits of history, and trying to wonder why it is that we have arrived where we are at this time, and how we may go on from here.

Science is truly an international activity and for this reason it is especially important to us that we are able to present the symposium at the time of the General Assembly of the International Council of Scientific Unions. There is no such thing as French chemistry, of British physics or Chilean astronomy. There is chemistry, physics and astronomy done in those places, but it is one universe which is under scrutiny. Science is the understanding of the ways in which the physical universe works. Through science, we have an automatic and absolutely necessary vehicle for outreach which joins the people of the world in a common enterprise perhaps unparalleled in its self-sustaining nature by any of the other many and important common enterprises of humankind.

We are humble and grateful that the officers and members of the International Council of Scientific Unions have chosen to come to meet in Washington at this time in deference to the fact that we are as a nation celebrating our bicentennial anniversary.

APPRECIATION FROM THE INTERNATIONAL COUNCIL OF SCIENTIFIC UNIONS

Harrison Brown
President, ICSU
Professor, Division of Humanities
California Institute of Technology
Pasadena, California

Tonight I would like to express, on behalf of my colleagues in the International Council of Scientific Unions, our deep appreciation to the National Academy of Sciences for its hospitality and for making these very interesting arrangements with respect to this symposium. I have followed the organization of the symposium itself for some time and it certainly, in my opinion, is going to be a symposium of extraordinary interest to all of us and will be intimately related to the goals and objectives of the International Council of Scientific Unions.

For those of you who are not here for the General Assembly of the Council, you should know that we are a world-wide non-political organization of scientific organizations. In a very real sense, we are more universal than the United Nations, because we embrace parts of the world which the United Nations has yet to admit.

We have several important principles. One is the principle of universality, in which we stress that scientists no matter where they are in the world, should have the right to participate in the international collaborative efforts of our organization. We also have another principle which is corollary to the first one, and that is the principle of free circulation of scientists. This means that scientists, no matter where they live, should be able to participate in scientific congresses no matter where they are held without prejudice by the political relationships between the country in which they live and the country in which the meeting is held. These principles apply as well to the very large number of international collaborative scientific programs which we help organize and sponsor.

The National Academy of Sciences has been a leader in subscribing to these principles and in helping to develop them. And, in part because of that, we are particularly grateful to President Handler and Foreign Secretary Hammond for making these arrangements. I should say that the institutions and the individuals who are involved with ICSU activities are very concerned about the development of science but they are equally concerned about the uses and the misuses of science. And all of us recognize that scientific and technological developments are determining the nature of the world in which we will be living in during the course of the next decade. They are determining human destiny. It is because of this that the symposium is so very important.

Again, on behalf of my colleagues and ICSU I thank you and we look forward to a most stimulating experience.

SCIENCE: A RESOURCE FOR HUMANKIND

Thomas F. Malone
Chairman, Bicentennial Symposium Steering Committee
National Academy of Sciences
Director, Holcomb Research Institute
Indianapolis, Indiana

It is timely that the interaction of science and societal affairs be examined before an international audience as the United States observes its Bicentennial. This interaction over the past two hundred years has profoundly affected the national character of our country and that of many other nations. Much of the hope and a great deal of the apprehension over the prospects for world society during the next two centuries are rooted deeply in the nature of this interaction. And yet just as it would be a mistake to allow our exploration of the past to be limited to the last two hundred years, so would it be unrealistic to believe that some spontaneous burst of foresight would permit us to see beyond the next several decades and anticipate the state of mankind two hundred years hence. The retrospective view must be very long, while the prospective view can scarcely go beyond the end of this century.

It is well to remember that spaceship Earth was launched (in a manner we do not yet fully understand) nearly five billion years ago. Three billion years ago life began. Clusters of simple chemical reaction systems in warm waters gradually increased in complexity until unicellular organisms appeared.

From these organisms evolved others which could use the energy of sunlight to drive their chemical reactions. These photosynthetic organisms stored the sun's energy by creating organic molecules. In the process oxygen gas was released. Slowly the chemical composition of the earth's surface and the atmosphere changed allowing new and "higher" forms of life to evolve.

Invertebrates appeared about 500 million years ago, vertebrates 400 million years ago. The dinosaurs reigned during the interval from 200 million years to 60 million years before the present. Man emerged less than five million years ago and so-called Modern Man dates back several tens of thousands of years.

The pattern of evolution changed with man. He learned from experience and could change the environment around him to his advantage. Tools were fashioned, animals and plants domesticated, water diverted for irrigation; man learned to use copper, bronze, iron, canoes, and sailing ships. A better food supply meant a greater population and gradually the number of homo sapiens increased.

As conditions of civilization developed, thought was given to human values and human hopes. During the Age of the Great River Valley Civilizations people more or less simultaneously in India, Mesopotamia, Egypt and China, looked beyond their present to dream of a better order. Later the classical miracle of Greece and Rome took to an even higher level the new frameworks for relationship among men.

Since those times three major developments have altered our living conditions and our understanding of human existence. The first was the Scientific Revolution in the 16th and 17th centuries. From Copernicus, Kepler and Newton, we learned we are on a small planet, circling about an insignificant star in a vast universe. We learned where we are. From Bacon, Galileo and Newton we learned the new structure of a disciplined mathematical and experimental science that opened doors in our understanding by giving men both new evidence and new methods to reason about it.

The second was the Industrial Revolution beginning in the late 18th century with the transformation of the textile industry in England and flowering in the 19th century with the industrial development of Europe and the United States, bringing the transformation in the quality of life and the nature of production as well as a new consolidation and integration of scientific scholarship. New mathematical theories encompassed all of physics. The chemistry of organic and inorganic substances was firmly founded. The Darwinian Revolution led to an understanding of what we are - a complex product of a process that proceeded from polyatomic molecules, to cells, to organs, to organisms, to colonies, packs, flocks, tribes and nations over several billion years.

The third development was the Scientific-Technological Industrial Revolution which has since World War II changed social and environmental conditions so rapidly that many persons have lost their traditional role in society. The basis of the wealth of nations has been transformed. The struggle against nature for existence is no longer a prime human goal and this latest Revolution has now reached a stage at which the natural processes that link each of us to the world around are being perturbed on a global scale. The four major processes are:

+ the conversion of light energy from the sun into the chemical energy which sustains plant and animal life

+ the biogeochemical cycling by which essential nutrients are passed through the biosphere to sustain plant, animal, and human life

+ the biological processes by which all living things reproduce, flourish and die

+ the perceiving, gathering, processing, and communicating of information which makes possible the interaction of living things with each other and with their environment.

By tapping the stored solar energy available in fossil fuels and the energy in the nucleus of the atom, by our ability to manipulate natural materials and to synthesize new materials, by an enhanced understanding of life processes, genetic laws and the chemical nature of a gene, and by our recently acquired and rapidly expanding capacity to handle information, we are introducing truly significant perturbations in these four processes. The implications are many:

+ the capacity to use energy multiplies the work-performing capability of an individual hundreds of times, makes possible modern transportation, construction, and manufacture. It threatens the world with nuclear destruction and with dissipation of the ultraviolet-shielding layer of ozone in the upper atmosphere. A century or two of the unrestrained growth in energy production could have a profound influence on the global climate.

+ the capacity to manipulate materials provides us a whole host of new and useful consumer goods, ranging from petrochemical products to hand computers. It makes possible the "Green Revolution" by providing new insecticides and fertilizers. It is also the source of air, water, and land pollution that pose serious toxic threats to human life.

+ the capacity to influence biological processes has led to new and more productive strains of grain and breeds of animals; it has prolonged human life expectancy. It has also aggravated the explosively expanding demands of more and more people for limited resources. It is posing profound ethical problems for medicine. DNA recombination and cloning are presenting ethical dilemmas to society.

+ the capacity to handle information may turn out to be the most portentous of all. We can observe parts of the universe veiled from the human eye; we can manipulate machines millions of miles away; we can be in instant audio and visual communication with tens of millions of our fellow men. We can perform calculations and solve problems that were impossible, in a practical sense, just a few years ago. But we are also jeopardizing privacy, and substituting an information processing capacity that has no ethical value system for one that does. We are in danger of losing control of the apparatus that converts natural resources into goods and services.

Taken altogether, these four implications bring within reach a human capacity to double, over a few decades, the per capita capability to transform the natural resources of the earth into the goods and services necessary to sustain life and to give meaning to life beyond sheer existence. Thus, the prospects for a better life for all in the near-term future are enormously brightened. On the other hand, together with this doubling, there is projected a doubling in the world population -- also over a period of decades. There then exists the possibility that the "carrying capacity" of planet Earth may be approached resulting in the potentially explosive problem of distributing the limited resources; in the extreme, the extinction of civilization.

Society is, then, at a sort of crossroads. Whether we select the road that will enable each individual to find self-fulfillment in a harmonious relationship with fellow beings and with nature, or, alternatively, follow the path that leads to a successively escalating series of catastrophes of famine, misery, terror, inequitable sharing of diminishing natural resources, violent conflict between ideologies and between rich and poor, is our most crucial task. It will not be decided in the manner John von Neuman indicated twenty years ago, in answering his own question, "Can We Survive Technology?" In summary, he said, "yes, probably, provided that there is a long sequence of small but correct decisions ... the intelligent exercise of day-to-day judgment." The correctness of these decisions will depend to no small degree upon the character and the effectiveness of the interaction between science and society. This is a proper concern for scientists.

Many have argued that a change in human values is required before the small decisions will be made correctly. Others would say that the series of small correct decisions will, in the aggregate, result in a change in human nature. In either case a firm understanding of the scientific basis for societal options can only aid the decision-making process.

The realization that humankind is at this kind of a watershed has emerged relatively recently and seems not to be generally appreciated by policy decision makers if one may judge from the course on which human affairs appears now to be embarked. A carefully planned and sharply focused assessment of the elements of this situation might prove to be a catalyst which would help lead to a re-examination of the national thinking and policies all over the world -- national policies which aggregate into a global policy.

It would be tempting to urge the scientific community to move into a leadership role at this critical juncture in the national history, but it is questionable whether the scientific community is prepared to do this and even more questionable whether or not it would be the right thing to do. However, the thoughtful and constructive voice of science needs to be heard since it is the fruit of scientific inquiry which has helped to bring us to the present circumstances. Scientific considerations are now such a pervasive element in our society that for scientists to remain mute at this time would be to jeopardize the opportunity for an advance that seems to lie before society.

The sheer depth and scope of the effort to resolve interrelated, escalating and international problems such as population growth, food supply, energy demand, mineral resources, social and economic development, environmental quality, and obliterative weaponry make it desirable to discuss these issues as wisely as possible before an international audience.

There are many profitable ways to approach this set of problems. We have chosen to limit our attention to three. The first part is a scholarly investigation of the history of the impact of science on society - and of society on science - in a variety of developing and developed countries. The second part is an assessment of certain international environmental research activities. The third is an exploration of the interaction of science and technology, the interaction of disciplines and decision makers, and an attempt to sketch a flexible strategy for seizing the opportunities and avoiding the hazards that appear to lie ahead.

I would like to conclude by offering my profound gratitude to all of those who worked and thought hard to produce this symposium. Especially I would like to thank those from outside the United States whose efforts contributed to our Bicentennial Observation.

SCIENCE AND HOPE

Philip Handler
President
National Academy of Sciences
Washington, D.C.

Dr. Hammond, Dr. Brown, Lord Todd, Fellow Scientists, Distinguished Guests, Dear Friends:

The National Academy of Sciences of the United States of America bids you welcome. It is very good to have you with us in this temple of science, in the capital of the United States.

Our celebration of the Bicentennial anniversary of these United States, now drawing to a close, has been festive but not frivolous. It has been a thoughtful time, a year of stocktaking, of retrospection and introspection, of seeking to understand who we now are and how we came to be so. Because of our history, we have been joined in this exercise by the peoples and governments of many of the nations represented in this chamber this evening. Our people, our culture have been drawn from among all of you. In this year, we find special pleasure and satisfaction in that fact; hence, we are particularly delighted that you can share in our festivities.

But, mark you, although there is, indeed, much to celebrate, much reason to rejoice, the state of neither this nation nor that of the larger world would long permit mere self-congratulation. In the same spirit, we who have here gathered as the General Assembly of the International Council of Scientific Unions might well engage in stocktaking, even take a moment for self-congratulation as we plan for the future. Allow me to do so.

How very privileged we are - we who have lived through the last half-century of science, that historic few decades in which the mind of man first came really to understand the nature of the atomic nucleus; first learned the history of our planet and identified the forces that continue to refigure its surface, the habitat of our species; the time when man's mind first engaged the immense sweep and grandeur of the cosmos in what we believe to be its true dimensions; the time when our species commenced upon the physical exploration of the solar system. Ours is the fortunate generation that, for the first time, came to understand the essential aspects of the marvelous phenomenon which is life, a phenomenon describable only in the language of chemistry; came to understand the mechanisms that have operated over the eons of biological evolution. In short, ours may well be the first generation that knows what we are and where we are. That knowledge permitted the acquisition of new capabilities whereby we utilize an extraordinary assemblage of synthetic materials, each created for specific purpose, whereby we manipulate our environment, communicate, move about, protect our health, avoid pain and even extend the power of our own intellects. Historically, ours will surely be counted a generation distinct from all that went before, quite possibly distinct from all that will come after.

In a historic sense, the scientific endeavor began only yesterday, yet we have come a wondrous distance from our primeval ignorance in so short a time; 90 percent of all that science has learned has been gathered during the working lifetimes of those in this hall. And that fact indicates how rudimentary must be our understanding. Hence, it is fitting that, for a moment, each from the standpoint of his own discipline, we rejoice in what has been accomplished while we strengthen our resolve to continue this noble endeavor in the face of what are sure to be ever more difficult challenges.

Once the pastime of a band of dedicated amateurs, science has become an expensive, complex, organized enterprise, the support and management of which are a major responsibility of the modern nation-state. Scientific thought and understanding are now a cardinal aspect of our culture, the leading edge of our civilization. But governments support science on the premise that scientific progress will continue to contribute to improvement in the public welfare, be it in military security, agriculture, public health, transportation, communication, or in some aspect of the industrial economy such as mineral extraction, or materials fabrication. In almost every nation with a formalized, government-supported R&D endeavor, some part of this enterprise has been reserved for fundamental research, the detailed nature of which was left largely to decision by the scientific community. But this, too, rested on the tacit assumption that progress in the scientific disciplines, following the intellectual thrusts of the disciplines themselves, will also make for social progress, in due course, albeit the direction of that progress is not readily predictable. That philosophy sufficed to guide most national science policies during the few decades in which the modern scientific capability was being constructed.

From the standpoints of both citizen and scientist, this faith has been well rewarded; science flourished, scientific understanding exploded and the new capabilities thus generated have been used to transform our civilization. The scientific community more than fulfilled its obligation.

But, it would be unwise to expect peoples or governments to be grateful, certainly not to be grateful for very long. As the scale and cost of the enterprise grew, uncomfortable governments began to find it necessary to assure themselves that this activity would genuinely contribute to the management of those aspects of the national life for which governments must accept some responsibility. And so, increasingly, governments have come to take a utilitarian approach to the support even of fundamental disciplinary research. In countries the world over, clamor for social relevance of the scientific endeavor has become ever more demanding. The challenge to the guardians of science - and that includes many in this hall this evening - is for the scientific enterprise to be seen as honestly responsive to the needs and aspirations of the societies that nourish and support that enterpise while, at the same time, the fundamental scientific endeavor maintains its own momentum, guided by its own internal sense of direction. The latter is essential both because the intellectual progress of science is a human imperative in its own right and because history has afforded no better sense of direction by which to assure that the scientific enterprise may yield optimal social benefits.

External pressures for social relevance also create a painful dilemma for the individual scientist. He becomes unsure whether he may be completely candid and forthcoming when projecting the potential benefits of his own research or, indeed, those of science generally. And he becomes reluctant to admit his own reservations with respect to the limits of what science may do. As Edward Shils has said, "...much is being demanded of science which it cannot give." He is correct. Science cannot assure indefinitely continuing economic growth; science cannot wholly transform human life; science cannot guarantee that the poor shall all become rich or that human beings will be moral or that they will live forever. Science cannot protect humanity from the effects of pollution if we are unwilling to pay the price of avoiding pollution. Science cannot resolve the ecological and social problems of our society; science cannot answer the ultimate ethical problem of the meaning of life, nor can science disclose to us the ultimate principles by which we should individually conduct ourselves. Yet those are some of the demands which are being placed upon science by contemporary criticism.

But neither is science entirely useless in these regards.

If I may repeat a favorite quotation of Joel Hildebrand, the patriarch of American chemistry, taken from the writing of the philosopher W. R. Dennes: "Science is not the enemy of morality. But neither science nor metaphysics nor theology can yield a theoretical demonstration of moral norms or a theoretical establishment of moral ends. These are the objects and the goals not of knowledge but of love. Yet of all the servants of morality, science is the greatest for it is the one serious way we have to discover what means are likeliest to lead to the realization of the ends we cherish"

If there are limits to what science, of itself, can do, there is also the wide horizon of the many goals to which it can be expected to contribute. And, most assuredly, great surpirses remain in store. Meanwhile, scientists who themselves believe in a strictly utilitarian interpretation of the value of science force themselves into an untenable position; they place a burden on science which it cannot, and should not, have to bear. They force themselves to take a responsibility for technology which they should not have to take, because science is not technology and should not be held to account for those negative consequences which, rightly or wrongly, are being laid at the door of technology. Everyone in this hall recognizes, of course, the continuous spectrum from theoretical science at one end to applied technology at the other and the broad gradual transition between.

What is most sad, is to see scientists who do not really believe in the purely utilitarian argument for the support of science, nevertheless offer such because they cannot bring themselves to give a more truthful account of why they are committed to science. They deny themselves, while they deceive their fellow citizens, pretending a purely utilitarian excuse for what they do when, in fact, they desire only to expand their understanding of the natural world. Indeed, they are held in high regard by both their fellow scientists and their fellow citizens precisely because that is what they do. But some, today, find it necessary to offer the utilitarian argument out of concern that, otherwise, their research might find no financial support. I assert that the first obligation of scientists is to be true to themselves; in justifying what they do, those who choose to engage in disciplinary research at its frontiers need offer only the historically valid argument of the remarkable accomplishments of science in making the world and its creatures more understandable to all of us and the great benefits that have flowed therefrom.

The pressures for a utilitarian orthodoxy are but one manifestation of the current turbulence in the scientific community. That community everywhere is attuned to its supporting society; in many countries we are aware of a malaise of considerable dimension, aware of societal uncertainty concerning future goals and aspirations, aware of dislocations because social progress has failed to keep pace with technical progress, aware of individual uncertainty concerning individual worth and the meaning of life. And we are painfully aware of expressed doubts concerning the values of science, of allegations that science and science-based technology may have done as much harm as good, a remarkable distortion of human history.

Particularly troublesome is the ever more frequent expression of the notion that there are questions that should not be asked, that there are fields of research that should be eschewed because mankind cannot live with the answers. NONSENSE! No such decision can be rational, much less acceptable. Someone will learn, somewhere, sometime. It is both the glory and the curse of the human brain that we must forever live with truth, once it has been gained. And, surely, it is far more dangerous to live with ignorance than with truth.

From time to time there may be an honest basis for controversy concerning the wisdom of some investigation, not for what it seeks to learn, but because of uncertainty whether potential, associated risks - to the public or to the investigator - can be contained. Temporary, deliberate delay may then be acceptable. There can never be a time when highly desirable societal ends can be utilized to justify the conduct of intrinsically immoral research as the means. But there also can never be a time when badly done science is better than no science or when the avoidance of knowledge should be mistaken for wisdom. The foolish government that knowingly interferes with the course of science, delaying, corrupting or perverting its outcome, will itself be the inevitable victim of that crime.

The conditions for success in science, the minimum circumstance under which science flourishes, have long been obvious. Required are freedom for the talented investigator to pursue independent research and freedom for him to communicate the results of that activity. Restriction of these freedoms injures the quality of science, limits the contribution of science to mankind generally and to the society in which such infringement takes place. It remains a torment to the body of science to know that, in various places around the globe, on virtually every continent, there are colleagues who are denied these two vital freedoms: denied the right to participate in the normal functioning of the scientific community including the opportunity to participate in international scientific meetings. It is a torment to every scientist to know that in some instances scientists lose their positions and may be jailed or even tortured very largely for daring to be as forthcoming in other aspects of life as scientists must be honest in their professional lives, sometimes indeed losing their human rights for no reason other than the very fact that they are scientists.

I consider that the fabric of intellectual freedom, including the freedom of inquiry, is one with the fabric of human rights as these are asserted in the Bill of Rights of the American Constitution and particularly in the 1946 United National Universal Declaration of Human Rights. It is a single tissue that cannot be rent anywhere on the globe without being damaged everywhere, without damaging each of us and endangering the future of the entire species.

I am committed to defense of the human rights of all persons, but of those of scientists in particular, not only because humanity may be denied the fruits of their science, but because they are precious as human beings; because abrogation of their rights is injurious to all mankind; because as thoughtful intellectuals, scientists not infrequently become involved in the defense of the human rights of others - and, of course, because, as President of the National Academy of Sciences, I am likely to be best informed concerning the circumstances of scientists.

The record of ICSU in defending the free movement of scientists is a glorious chapter in its history. It is my hope that, in due course, ICSU will broaden somewhat this umbrella of concern for the status of scientists, because, regrettably, these challenges seem to be never ending.

In general, scientists have engaged either in the disciplinary expansion of the scientific knowledge base or in the development of new science-based technologies. Latterly, a new and large endeavor has arisen wherein scientific understanding is utilized to appraise the risks which may attend the utilization of diverse technologies in current use. The result has been a not always wholesome dialogue. Although much is written concerning the scientific method and the ethical code of scientists, these concepts reduce rather simply to the imperative of honesty, dispassionate objectivity, and the obligation to publish descriptions of one's procedures and findings in such way as to permit verification.

But establishing truth with respect to technical controversy relevant to matters of public policy, and to do so in full public view, has proved to be a surprisingly difficult challenge to the scientific community. To our simple code must be added one more canon: When describing technological risks to the non-scientific public, the scientist must be as honest, objective, and dispassionate as he knows he must be in the more conventional, time-honored self-policing scientific endeavor. This additional canon has not always been observed. Witness the chaos that has come with challenges to the use of nuclear power in several countries. Witness, in this country, the cacophony of charge and counter-charge concerning the safety of diverse food additives, pesticides and drugs. We have learned that the scientist-advocate, on either side of such a debate, is likely to be more advocate than scientist and this has unfavorably altered the public view of both the nature of the scientific endeavor and the personal attributes of scientists. In turn, that has given yet a greater sense of urgency to the public demand for assurance that the risks attendant upon the uses of technology be appraised and minimized. And what a huge task that is! A few weeks ago, this Academy issued a committee report on the consequences of release of halocarbons (freons) into the atmosphere; when the chairman of that committee was interviewed on television, he was asked, "Why is it that we are always finding ourselves in this position, where the things we are consuming are doing possible permanent damage to the environment? Where are the scientists ahead of time? Why aren't you people on top of these things before... the damage sets in? Are we not vigilant enough? That's a fair question, isn't it?"

Well - no, it isn't a fair question. Even an inadequate response would require the remainder of this evening; we, here, need not attempt to respond today. But that question does represent public attitudes; it describes the new public view of the responsibilities of those who place technology into the society, its view of an appropriate function of the scientific enterprise, and it illustrates the heavy burden upon the scientific community to educate the public while we monitor our own behavior.

Meanwhile, an additional set of great challenges concerned with the application of science and the uses of technology has begun to claim our attention - challenges that are almost self-evident when one considers the worldwide circumstances of humanity. Examination of these challenges is the subject of the symposium which the Academy has arranged for the benefit of our guests this week and I would like to take a few minutes to create a background for those discussions.

It is not difficult to persuade oneself that the world is in an unstable, transition state from which either we shall progress to a more desirable, steady state in which the lot of humanity is much improved, or the state of mankind will surely degrade very seriously. The question we shall consider is whether scientific understanding and wise use of technology can usefully be applied in such a way as favorably to influence the outcome.

What are the circumstances? First and foremost, population growth, proceeding at the historically unprecedented rate of about 2 percent per year, worldwide, and even exceeding 3 percent per year in a few countries, exercising a continuing and ever increasing pressure that similarly steadily amplifies each of the other unfavorable circumstances that we must note: serious malnutrition in some parts of the world with the prospect of starvation on a large scale one day as a consequence of inevitable regional crop failure; a half-billion people affected by age-old transmitted tropical diseases; massive illiteracy; the question of human settlements, that is to say, where to put the additional 250,000 human beings who will appear every 24 hours for the next several decades; and the finite, dwindling supplies of minerals in the earth's crust, particularly the declining supplies of fossil fuels. The questions are how to obtain for the masses of humanity an acceptable, at least minimal material life style and how the developed nations can help to accelerate the sound economic development of half the globe. And, finally, ugliness of uglinesses, there is the question of what to do about the worldwide nuclear arsenal which now exceeds 2 billion tons of TNT, equivalent.

Plainly, these are not scientific problems as we have, in the past, thought of scientific problems. Why then bring them to the attention of this body? Because we are a truly international body, because these are the most important global problems of which we are aware, and because, prerequisite to their management, is close attention by the analytical capability, the turn of mind, if you prefer, natural to the thought processes of the scientific community. The problems are brutal and can be managed - if they can be managed - only by the utmost candor and honesty in their confrontation. I believe that "the international scientific community" can be more than a pleasant phrase - it can be a meaningful reality of men and women of goodwill, linked by the joy of science, by a common set of understandings and values and by their intrinsic humanity; and you, ICSU, already exist as such a worldwide entity.

Even though science and science-based technology cannot hold all the answers to these grave problems they do have much to contribute. Hence, the worldwide scientific and technological community must provide some of the leadership required in addressing these problems. Internationally as well as nationally, policy is not determined by science. It is based on value judgments concerning what is good and what is bad, as to how a given society should be structured and operated, as well as upon beliefs with respect to fact. These valuations, even within a given country, are deep seated, conflicting, and powerful; the hierarchy of valuations will surely differ among individuals. Given the same data, analyses and seemingly scientific conclusions, individuals, groups and nations may be expected to arrive at different decisions regarding the most desirable policies. But the basic understanding and knowledge of the number and nature of potentially available options must first be placed on the table by the scientific and technical community. Let me be just a bit more specific.

It is very difficult to grasp the profound consequences which must attend the next doubling of the world population. To the extent that the time required for that doubling may be extended, the effects can be somewhat blunted. At this moment, more people on earth live well than at any previous time in history, but there are also more people who live barely marginal existences than at any time in history - simply because there are so many people. The percentage of the world population whose lives are truly limited by the quality of their nutrition may well be at an all-time low. But in absolute terms, their total numbers are intolerable. It is very difficult, at this time, to project these relative ratios as they will exist when the world population reaches 8 billions in about 2010. Patently, the problem is not merely the productivity of world agriculture. Even now the worldwide food-producing system could handily feed the world population quite adequately, were its product distributed differently. For me, the fundamental problem is best summarized by noting that nowhere on earth are there hungry peoples who have money; poverty is the primary problem. However, given the prospect of continued exponential population growth, there will surely come a time, perhaps rather soon, when potential agricultural production itself will become limiting. Knowing the terms and conditions of that circumstance will be critical to rational planning for the optimization of world agriculture in the years ahead.

There is a burden upon the knowledgeable community - however it be labeled - more deeply and certainly to understand the prospects for the future world food supply - and advise accordingly. Because that may involve large-scale manipulation of the environment, there is the burden to ascertain the real magnitude of the contribution of environmental factors to carcinogenesis, and to the etiology of other diseases, and to let us all know.

Progress in protecting the public health against a considerable variety of transmissible diseases has been little short of spectacular in the developed countries. And we can all take pride in the fact that 1976 may witness the last case of smallpox anywhere on earth. But that places in even more stark contrast the mass of human misery inflicted by such disorders as river fever, schistosomiasis and malaria. The means for their eradication may not be as simple as that for smallpox, but the challenge to our scientific capability is absolutely compelling.

The next generation is destined to be the major participant in the process whereby, in a brief instant of historic time, the entirety of the underground resources of liquid and gaseous fossil hydrocarbons will have been irreversibly consumed. Yet, we have scarcely begun to arrange for what is to happen when the stores of petroleum and natural gas will be exhausted during the lifetimes of persons already born. It is already very late to begin planning for the nature of the energy economy that must follow.

Modern civilization has also been profligate in its use of diverse other minerals. However, for none other does the situation appear to be as critical as for liquid and gaseous hydrocarbons. Although a one-century supply of all of the minerals critical to our civilization scarcely seems adequate for a species that expects to survive on the planet indefinitely, potential resources are still so large as compared to the rate of consumption that it will be a long time before physical scarcity, of itself, will drive up prices. That does not speak to the question of artificial cartel pricing. When, one day, the prices of these supplies become sensitive to ultimate scarcity, that will assist those developing nations within which such resources are to be found. But only for a few decades. Ultimate management of these minerals by recycling and by the use of much lower grade ores will require immense inputs of energy; plainly, the feasibility of such a program will depend upon the still uncertain supply of energy and the development of appropriate technologies. How that wll come out will determine the quality of civilization for the future.

I cannot present the fact of almost one billion illiterate persons as a scientific problem, but I can point to this as a prodigious waste of the human gene pool, remediable in some part by technological means.

The problem of human settlements was vividly described by Enrique Penalosa, Secretary General of the United Nations Conference on Human Settlements, when he said that "We are rushing toward the day when the great part of our species will live in a previously unconceived state of compaction," by which he referred to the fact that the equivalent of approximately 3,500 new cities, of one million inhabitants each, will have to be established and equipped over the next 30 years. Providing the physical plant, the facilities and the services, and coping with unemployment, pollution, congestion, crime and social alienation will be formidable challenges to the wise uses of applied science. Faith that applied science can assure the quality of human is wavering. But no other option is available.

Nor can I offer as a problem in classical science the fact that there is now in the hands of the military several hundred times more explosive power than was used in the totality of World War II. But because members of the scientific community, regardless of nationality, understand each other easily, the scientific arena offers a special platform for discussing the problems of arms control and disarmament, as the founders of the Pugwash movement recognized. Last year this Academy released a report indicating that, lest anyone harbor any notions that nuclear war and its consequences are containable, in addition to the local holocaust, and in addition to fallout on a continental scale, a major exchange of nuclear weapons could ravage the entire planet by destruction of the ozone layer in both northern and southern hemispheres. Already the East-West component of a nuclear confrontation is capable of placing one-half billion people in the northern hemisphere at fatal risk in any one day. A North-South component of the arms race - no more rational than the East-West version - is just beginning. Indeed, it threatens to develop even greater instabilities while consuming capital, material, and intellectual resources desperately needed for more noble purpose. If, at times, the world seems peopled with madmen, need the scientific community associate itself with the madness? And yet 25 percent of all the technical people in the world are involved in preparing for conflict. Annual global military expenditures, including those of developing nations, exceed 250 billion dollars - while some of us fret over the unavailability of capital to pursue relatively modest development programs in some of the very same countries.

In considering these problems, we need also note a serious lack of appropriate organizations chartered to address such problems. Only a few have so far been brought into being, such as the International Institute for Applied Systems Analysis in Vienna, and the network of International Centers for Agricultural Research. New multidisciplinary organizations, wherein a diversity of talent can address various aspects of these and related problems, are sorely required. One can imagine supportive links to the academic community, to national governments, to regional intergovernmental arrangements, perhaps to the UN.

We will bring these perplexities to your attention this week because they are the foremost problems of our time, because the degree of success in their management will determine the quality of life for our descendants. We believe that science and science-based technology can make very substantial contribution to their management, indeed, that they offer sound and exciting opportunities. Diverse suggestions in these regards will be brought before you in the next few days.

Please understand that I do not propose that the efforts of more than a very modest portion of the scientific community be redirected from the leading edges of the scientific disciplines to the matters that we shall discuss this week. But I do trust that some fraction of the scientific community will heed such a call and that ICSU, its national members, and some of the international unions, will find ways to generate new and appropriate opportunities to work on these vital problems.

Science and the products of science have lengthened and markedly enriched the lives of most human beings. In so doing, there has been generated yet another set of problems, to the management of which science and scientists, technology and technologists will, again, have much to contribute. "There is no opportunity for complacency, nor yet need to despair." Those of us who have had the high privilege of doing science, have experienced the exquisite and intrinsically unsharable exhilaration of understanding. Ahead still lies great adventure, new insights and the miracle of discovery, the emotions that, for scientists, make life worthwhile. And ahead also are vast challenges and great opportunities for service to humanity. I have little doubt that the world scientific and technical community will eagerly accept both. And, therein, lies the hope of mankind.

Thank you.

RETROSPECTIVE LOOK AT SCIENCE, TECHNOLOGY AND DEVELOPMENT

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To attempt to synthesize the seven commissioned studies is even more heroic than to write a brief historical analysis of science, technology and development which faced the seven country authors. Let me not spend time on emphasizing and re-emphasizing the difficulty of the task; but let me, to start with, emphasize that this is a personal synthesis, and that none of the seven authors are to be held responsible for how I used the building blocks which they so kindly provided.

I think I can speak for all of them when I say that we are quite sure that science, technology and development are related, and closely related. We are much less sure of exactly how, and even about the causal order in some respects. There is a general consensus, certainly among economists, that technology change is highly associated with, and even we might say, leads to economic development in terms of per capita income. I know that this is not the only measure of development, but we cannot, in the context of this symposium, go into the possible conflicts between the environment and growth. There are other occasions for this.

However, we are quite sure that technological change, in the advanced countries certainly, has contributed substantially to growth; in fact, in the advanced countries, most people think about 70 or 80 percent of the observed change in per capita income can be laid at the doorstep of technology change. But identifying the causes of technology change is a much more difficult matter. Economists like to call this area a "measure of our ignorance". Even the association between expenditure on R & D, and technology change is not very clear, certainly not at the individual country level.

There are many theories as to whether it is sufficient to have a capacity to accept the technology change or "manna from heaven", that happens to fall to you, or whether you have to spend a lot of energy producing this manna, or at least finding it, i.e. research and information costs. The relationships between technology change and development are thus unclear, but they are dwarfed by the obscurities with respect to the relationships between science and technology. These are much more indirect, more diffuse, more long term, and the causal change is often ambiguous. Many people believe that science is something you can afford once you are developed, rather than something which helps you to be able to afford development. Another question that is very much a puzzler is whether or not the relations between science and technology have changed since the early developers appeared, or even since the nations which developed later. Do we now have "big science", as opposed to "little science", and therefore is whatever may have been true in history no longer relevant?

What we are trying to do here, imperfect as it may be, is to pick from the experience of the seven countries we have looked at, to see what kinds of lessons, for us as well as for the developing countries, might be gleaned, with respect to technology and with respect to science. If we make only some small progress on this front, I think the two-thirds of humanity which wants to join the circle of developed countries will be well served.

What are some of the facts derivable from what you have heard, and from what you, hopefully, will read? We know that England had the leadership in technology and in growth before 1850. We all know and agree that it lost it thereafter, in some areas to Germany and France, in others to the United States. The question of why this occurred may be instructive for our purposes today.

Great Britain's initial lead may be ascribed to a number of things: higher levels of income than continental Europe, better distribution of income leading to a bigger domestic market, a more favorable geographic position, better natural resources, especially in coal and iron, and, perhaps most important of all, the earlier breakdown of the mercantilism and feudalism which inhibited similar progress on the continent for some time.

There is less agreement on the reasons for the loss of British leadership. And, among other things, Professor Cardwell discusses the shift from a basic Newtonian science leadership to what might be called a technology based on trial and error - an empirically based technology. Even the smelting of iron ore, he points out, was done without the knowledge of the basic oxidation and reduction processes. This type of technology change based on tinkering, trial and error, runs out of steam, and one of the factors leading to the decline of England was that there was no renewal of the basic scientific roots. Also the Empire, he points out, directed energies of people who preferred the Indian Civil Service exam over the mathematics tri-post at Cambridge. There was, in other words, a smugness that came with early leadership. The challenge to the nations of the continent, that British leadership presented and the competition which Professor Fischer emphasizes among the German states, led to a great effort within Germany, to try to catch up, and to use the scientific tool to do so. The resulting German supremacy in the chemical, pharmaceutical industries and in iron and steel, in optics, and in electrical machinery is well known.

But does this explanation of why Germany took the leadership from England in certain areas, also satisfy us with respect to what happened in the United States which we also heard about? The U.S. technology path is also clearly empirical. It is not one which is heavily founded in basic science, certainly not in the nineteenth century, as Professor Rosenberg points out. The U. S. took the lead in mechanical engineering. It borrowed freely from Europe with little inventive activity of a major kind within the United States. Thus a perhaps somewhat different, broader explanation may be more helpful to explain the U.K. loss of leadership to Germany in some industries to Germany but to the United States in other industries.

It may after all well be that the steam engine is not an isolated exception, as Professor Cardwell would have it. The technology choices that were made within England during Professor Cardwell's "tinkering period" may have been because the necessary scientific knowledge was "in the air". We do not have to have a direct causal link between a major innovation and the science which went before it, as long as some scientific information is known which can be utilized to spread the technology, and to have it accepted.

It may instead be necessary to differentiate between the major technology changes which may be very closely science related, and the somewhat more minor technology changes. For example, the so-called Green Revolution in contemporary times is clearly related to the Mendelian Laws of Genetics. Plastics are related to molecular chemistry. But it is also necessary to remember that in order to have the Green Revolution work, there must be the less glamorous kind of science-related technology which relates for example to the water-fertilizer combinations that make the Green Revolution work in a particular country context. And there must be industrial applications for the plastics before this becomes a workable technology change.

The causal order between science and technology also runs the opposite direction. For example, in the case of iron smelting cited by Professor Cardwell, it is also true that the very reason that the Bessemer process which worked in England did not work on the Continent, led to another breakthrough, i.e. the Thomas/Gilchrist steel process which was able to use high phosphorus content ore. Thus there are puzzles which come up in the process of tinkering, which in turn induce the next step in science. The Green Revolution is another example where breakthroughs in agricultural chemistry have resulted from the puzzlement about the apparent nontransferability of an international "miracle seed".

It might be preferable to talk, not in terms of technology as being either science dependent or engineering dependent, but to talk more in terms of the relative intensity of the technology with respect to science or engineering. I think it is more useful to differentiate between the major technology changes which may be more science intensive, and the less spectacular adaptive kinds of technology change which may be less science intensive. But indirectly or directly, an improvement of our understanding of the universe around us has to be part of the causal chain.

But then, to rephrase the basic question, why did England lose its lead in the so-called "science intensive" industries to Germany, and lose its lead in the "technology intensive" industries to the United States? I do think that the natural resources advantage which was cited as part of the reason for her initial lead, turned into a disadvantage, as was also suggested by Professor Cardwell. A certain smugness born of security was present in England, while the Continent, especially Germany, felt it had to scramble to make up for the lack of its good natural resources base. The attempt to economize on fuel in Germany, led to a greater efficiency and to a major breakthrough in scientific metallurgy in Germany. This synthetic thrust which we know Germany to have been so good at in recent years thus started early. They felt they had to make up for the absence of the bounties of nature. Especially in agriculture, we notice that the application of so-called biochemical kinds of changes to agricultural technology came early.

In the United States, on the other hand, we have a natural resources abundant country: abundant in land, abundant in wood. The abundance in wood led to a lighter, and, it turned out, superior, kind of machinery in the United States. The abundance of good land permitted an extensive kind of agriculture to start with and, as Professor Rosenberg points out, a turning to science only after the land frontier closed around 1890. In addition to differences in the natural resource endowment which provided signals for the reactions of both science and technology, the actions that governments did or did not take are part of the explanation. In Great Britain, the initial emphasis on laissez-faire became a handicap later on as the government did not support education, and research and development in scientific areas. Not until World War I was there a realization that England had become dependent on the United States for its engineering innovations and on Germany for its scientific education.

German science and industry, spurred on by the external threat of England, and by the internal competition that has been mentioned, also received government help; perhaps not as much as has usually been thought, but tariff protection, subsidies, expositions and awards played a substantial role, with various German princes vying with each other to be the patron of the scientist, not the technologist. General education, it is interesting to note, was emphasized and fairly widespread. During the middle of the nineteenth century, 97 percent of school age children were educated in Germany, as opposed to about 50 percent in Britain.

In the U. S. also there was widespread general education and widespread literacy at the intermediate levels of scientific knowledge. This indicates that the government may have played a larger role in the United States than most people will admit, and perhaps a lesser role in Germany than most people seem inclined to think. Particularly after the closing of the frontier, there was a very heavy government involvement in U. S. agriculture through the land grant colleges, i.e. in agriculture research and extension. Agriculture is a field of non-appropriable technology, (technology cannot be appropriated by private sector individuals) and therefore the government's role necessarily has to be greater. Only the government can absorb the high risk to return ratio.

Let us now turn to the countries examined which are among the late followers in industrial development. As is pointed out by the Hungarian National Academy of Sciences paper, feudalism, the effects of Turkish occupation, the absence of a major early agricultural revolution, and, finally, the role to which Hungary was assigned within the Austrio-Hungarian Empire, delayed Hungary's development. According to their paper, not until post-World War II, with heavy government involvement in research and development, was economic maturity achieved.

Japan is perhaps the most interesting historical case of late followers for our purposes. Its initial resource conditions are somewhat intermediate between those of Western Europe at the time of the Industrial Revolution, and those of the contemporary developing countries. It is interesting to note that in addition to the breakdown of the feudal social caste, which Professor Nakayama mentions, the period from 1868 to about 1890 witnessed large scale borrowing of foreign science and technology, without too much careful examination of what was being imported. Large numbers of Japanese went abroad and large numbers of foreign experts came in. The borrowing was generally indiscriminate. It is interesting to note that some of the agricultural techniques that were first tried in Japan were really intended for wheat in Germany, and especially in Prussia. Most inappropriate kinds of technology choices were made for a long period of time during this early phase.

But by the turn of the century a substantial shift to a much more careful selection of technology had taken place. In terms of the three kinds of technology available to any country-imported unadapted technology, imported adapted technology, and indigenously grown technology - the Japanese were really very selective and very eclectic about their choices. In some fields, especially armament, they began with their own indigenous innovations early in the twentieth century. In the majority of fields, they imported technology but did a lot of very substantial indigenous adaptations of those imports. For this they needed intermediate level scientific literacy, very much as in the German case. With government assistance veteran farmers traveled about and diffused agricultural technology. In the private industrial sector there similarly was a good deal of government assistance, for example to support the diffusion of technology in the textile industry. In the agriculturally related industries, such as fertilizer and food processing, there developed an increasing tendency to borrow from the science intensive industries of Germany and other western countries.

After World War I, basic science, universities, research and labor, came into their own in Japan for the first time. Simultaneously, and unrelated, the agricultural productivity increase from simply a diffusion of known technology, began to run out. Natural resource shortages began to impinge upon the Japanese conscience, public and private. The conclusion was drawn that science, especially agricultural science, had to be used much more heavily, along with the temporary palliative of food imports from Korea and Taiwan.

The contemporary developing countries in our sample are a good illustration of the difficulty of discussing "the" developing countries. Brazil and Ghana are indeed different in size, in resource endowment, and even in the time when they first became independent. However, some kind of phasing of development does seem to emerge from the papers. In the colonial period, both papers report, scientific effort was concentrated mainly in flora, fauna, and geological surveys. In the case of Brazil, development meant gold, cotton, sugar and coffee, in historical sequence. In the case of Ghana, it meant gold and cocoa. Scientific improvement of the primary food crops for home consumption was neglected. Export-oriented agriculture and health were the two fields which, because of the peculiarity of the conditions of particular geographic locations, did, in fact, receive much attention from mother country scientists.

When industrialization under an import substitution policy regime began in earnest, in the case of Brazil in the 1930's, and in the case of Ghana in the 1950's, there existed little indigenous science, but much imported science. Dr. Ayensu and I may disagree on the value of some of that imported science, but basically we agree that there was a good deal of "big science" imported during the Nkrumah regime. In the case of Brazil, Dr. Pastore points out there was much basic European-oriented science. There was in neither case, much indigenous application of science nor much adaptation of imported technology. This is, I think, closely related to the question of the absence of a middle level of scientific and technological capacity. The educational conditions for a domestic crop oriented science effort and for adaptive technological change in industry or agriculture generally, were not present. Little effort was made in either country to create it.

Professor Pastore says that you need a strong scientific establishment to understand what is on the international science and international technology shelves. I agree with that. But I would add that one of the important dimensions of that need is not necessarily to be strong in every scientific field, but the ability to choose well in science and to adapt well in technology across the board.

Now briefly to some conclusions: With respect to technology, we know that we have a choice among home-grown technology, imported technology and imported plus adaptive technology. The question that decision makers in less developed countries ask themselves is, how much of each, and what policy measures to use in order to get these. With respect to the choice of so-called appropriate technology, the prescriptions are not all that difficult. One of them is avoidance of undue bias in terms of the kind of economic environment created during import substitution. A measure of protectionism, price distortions, and so forth is probably inevitable and even desirable; but the question is how mild and how long the import substitution regime, how it is implemented and how, whether and when it is dismantled.

It is quite clear that if one neglected the demand for appropriate technology, and worried simply about the supply site, the results will be disappointing. If you do not have entrepreneurs -

large, medium and small scale - actively asking for technologies which would be in fact more appropriate to the endowment of the country, nothing will happen. Appropriate technology cannot be force fed. If the environment is not sufficiently competitive, if protection and distortion remain large, it will be difficult to avoid the appearance of large scale turn-key projects replete with the "latest" technology - which constitute a "luxury" only if the industrialist can count on unearned windfall profits without exerting himself unduly.

Over time, policies which permit changes in the endowment and human capacities of the country reflect themselves in the signals perceived by decision makers. Policies which tend to reduce the thickness of the veil between endowments and prices, is clearly part of this picture. There are other things which the government can do directly, such as provide information on markets, information on technology choices. Information is not costless and may be imperfectly distributed. We now know that there are many ways to produce a particular good that some of these are appropriate to some societies, and some to others. The question now is not some straight jacket of nature but, rather, do we have an environment in which the individual entrepreneur is really searching out and can find appropriate choices - or is he in such a comfortable situation that he does not care (or need) to take out paper and pencil and devise a better mouse-trap. Most of us, when not up against constraints, are likely to indulge our ever-present preferences for the shiniest, the latest, and the most prestigious.

The same kind of argument applies to the selection of goods, i.e., the output mix. There are such things as appropriate goods for a particular market, as well as appropriate technologies. Choices among goods such as between a sandal and a Western shoe, should be available, and the impact of international (prestige) taste diminished. I am not suggesting that some people should be told to buy bush shirts instead of drip-dry nylon - or a Green Spot instead of Coca-Cola; but I am saying that people should at least have and be aware of such alternatives and make their own choices on the basis of differences in prices and qualities desired.

With respect to science, I think that what we can learn from these studies is a little more difficult, just as the causal relationships mentioned above are a little more difficult. There are two extreme positions that can be found in the literature, as I am sure you are aware. One states that the less developed countries should sit back, let the rich countries do the basic science, and that they will then pick and choose what is needed. This is clearly much cheaper than attempting to plant expensive scientific flags in every field of human endeavor. The other extreme states that a developing country cannot afford to sit back, because there exist relationships which are so complicated, so indirect, but so important, that each society must keep itself abreast of the latest scientific knowledge in order not to lose out. In other words, they must contribute to basic science everywhere to avoid permanent second class status.

Which of these extreme positions should we subscribe to? It won't surprise you that I don't think we should subscribe to either one. However, I think we can say more than the customary "somewhere in between". Let us examine the lessons that can be learned from the agriculture and health examples we have looked at. I think most of us would agree that without indigenous scientific capacity in these fields, a country would be in serious trouble. Yet agriculture and health are not as special as we might think. There are other areas on a more or less continuous spectrum, in which human activity is affected by the special conditions in which the society lives. For example, fertilizer and other agricultural input depend on temperature, humidity, and soil conditions. Fiber quality affects the appropriate conditions for humidity, for the application of chemistry, and for the choice of technology in the textile industry. The type of pasture land available affects the choice of tanning process for hide, and the quality of shoes. I do not wish to take this too far, only to make the point that the boundaries between activities which are unrelated to particular geographic, temperature, and other environmental conditions, and those which differ across countries are not as firm, or narrow, as one might think.

But, then, what are the guidelines. How do we decide whether or not every developing country should or should not show the flag in every basic scientific field. Moreover, as was pointed out by President Handler last night, there is nothing quite as bad as mediocre science, which serves neither the purposes of science internationally, nor the purposes of technology nationally. Can a typical developing country afford non-mediocre science in every field of endeavor?

I think the burden of proof in answering this question really must lie with those who propose that advanced university training and basic research in a given field be initiated and supported at a quality level. I do not believe that scientists can escape some sort of cost/benefit analysis with respect to any such decisions. It can be flexible, long term and sophisticated but the analysis must be done. An Act of Faith is just not enough. The price of admission to the international college of science is just too high, a fact I know you are all aware of.

There are possibilities - as yet not sufficiently utilized - of intra- and also inter-developing country specializations in science which could serve to reduce wasteful duplication. Some of this has been done, as in the case of the rice and wheat international food-grain institutes. It has been accomplished in atomic energy research in Europe. It has been tried successfully in malaria and yellow fever control in Africa. In each case the scale and international character of the scientific activity made such a multi-national effort not only possible, but highly desirable. But there are still, as we all know, too many instances in which several universities within a poor country try to be preeminent in a certain scientific field, unwilling to agree on who should be best in what on a multi-country or regional basis.

I do not think that we can or should try to manipulate science in the narrow sense of the term; this would inevitably lead to mediocrity as I am sure scientists here would agree. The relationships and feedbacks are much too diffuse and much too complicated. But countries can spend more energy and resources in creating the necessary level of basic scientific literacy and capacity within each country so that these questions can be answered at the national level and negotiated intelligently internationally. To avoid the twin problems of mediocrity and irrelevance, countries can, once they have decided where to show the flag of science, make every effort to keep their best people at home (physically as well as psychologically) by creating the proper institutional structures and incentives. The concern is not so much with levels of pay as with the general environment, the facilities offered and the opportunities to maintain vital professional contacts.

If a society's scientific community remains a rather small elite island lobbying, sometimes effectively, sometimes not, for larger expenditures in every field, without real contact with, or understanding by, the country's decision makers, we are likely to continue to be beset by an inability to realize the potential of science on the one hand, and by a large-scale wastage of scarce physical and even scarcer human resources on the other. Neither the natural nor the social scientist can escape the need to face up to these tough issues of interdependence if science and technology are indeed to play their proper role as a resource for humankind.

SCIENTIFIC CAPACITY AND GLOBAL ENVIRONMENTAL PROBLEMS

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The early 1970's saw the confluence of two streams of events affecting the capacity of the world scientific community to deal with global environmental problems. For the first time there was widespread recognition of the existence and probable expansion of perturbations in world environmental systems. Concurrently, scientists, with the support of the inter-governmental specialized agencies, developed a capacity to deal with such problems. They did this by establishing a conceptual framework for identifying problems in a balanced perspective, and for linking the contributions of a wide variety of scientific disciplines. They also fostered working groups of scientists who would collaborate across disciplinary and national boundaries in seeking problem definition and solution.

The 1930's had seen a wave of concern for environmental deterioration as it influenced the capacity of the human race to sustain itself. There was acute distress at the rapid degradation of soil profiles and plant cover under shifting cultivation, monoculture agriculture, and over-grazing. These concerns were muted during World War II. The post-war period saw renewed anxiety as to the capacity of the earth to support rapidly growing population and as to possible effects of radiation on human health and ecosystems. Radiation hazard commanded a wider degree of collaboration among scientists around the world in identifying problems and analyzing solutions than any previous environmental perturbation.

During the 1960's and early 1970's attention turned to other interventions in the global environmental systems which seemed to promise widespread consequences for human welfare. These included the possible effects of releases of fluorocarbons and nitrous oxides in the stratosphere, the diffusion of toxic pesticides, and petroleum spills in ocean waters.

The Global Atmospheric Research Program of the World Meteorological Organization (WMO) and ICSU contained as one of its two major aims the modelling og global atmospheric systems with a view to estimating the possible consequences of alterations in atmospheric conditions. The organization of the International Biological Program, the International Hydrological Decade, and the UNESCO Man and Biosphere Program for the first time provided formal organizations within which environmental scientists from all countries could join in exchanging data and methodology. These and related activities came into focus at the Stockholm conference on the environment in 1972.

Recognition of the magnitude and possible significance of the human interventions made possible by new technology was not accompanied by equally prompt and incisive organization of non-governmental scientific resources to deal with them. Scientists seeking to examine global environmental systems were handicapped by the persistent tendency to look at each perturbation in the context of particular traditions of scientific work. Thus, toxic substances were examined in large measure in terms of the effect of those substances upon human health, a proper concern of the World Health Organization, but not one that led to a review of their implications for entire ecosystems.

Scientists were slow in finding ways to view the specific problems which they investigate in a global setting. Widened recognition of the concept of global biogeochemical cycles is the result of one such effort in many countries. It now can be arrayed alongside the concept of global atmospheric systems. Environmental toxicology places the earlier preoccupation with impacts on humans in a perspective that embraces other organisms. Similarly, the view of resource management as being a manipulation of natural terrestrial and aquatic processes helps provide a common scientific orientation for investigations of problems as diverse as ecosystem change or drainage design for an irrigated field.

As reported in the SCOPE analysis of Environmental Issues 1976, many of the newer studies of global disturbances share in problems of method of analysis. For example, simulation modelling of environmental systems in a variety of situations raises similar issues of technique and interpretation. Likewise, the process of hazard identification and evaluation as a part of the broad effort at risk assessment involves workers in fields as diverse as soils, epidemiology, meteorology, and agricultural engineering in roughly the same difficulties in their attempts to recognize and critically appraise the social consequences of altering natural conditions.

One result of looking at the whole array of environmental perturbations in a more unified framework is to see how methodology may be improved to the benefit of numerous investigators. Another is to gain balance in estimating the significance of particular changes. In terms of the welfare of the human race over a time horizon of decades it is important to consider the deterioration of irrigated land along with such challenges as the discharge of fluorocarbons or the extinction of species. Relatively undramatic and inconspicuous shifts in the cycling of nitrogen on the land masses may hold as great a threat to survival as does the more widely debated change in carbon dioxide in the atmosphere. We are beginning to see a bit more clearly how the many alterations may be related to each other, and to recognize that the diversity of world landscapes imposes caution as to generalizations about world changes.

In appraising these complex perturbations it is instructive to ask the circumstances in which they were first identified. We may thus learn lessons which will make it easier to identify new threats before they reach severe magnitudes. Judging from the record, we may expect some surprises, and may find that some accustomed human activities as well as new technologies will turn out to carry grave implications for global systems. A perennial aim will be to minimize the degree of surprise and the disruption which they will generate. To do so will call for more effective modes of collaborative action. These can be expected to develop most rapidly through a combination of inter-governmental and ICSU ventures.

In 1969 ICSU created a special committee to deal with environmental problems. That group, as reported by Martin Holdgate, concentrated upon a few issues of clearly global significance. In trying to bring to bear the best available thinking, it drew upon each of the interested scientific unions in the ICSU family, and invited participation from those national academies of science that are members of ICSU. Similar efforts had been launched on questions of the oceans (the Scientific Committee on Ocean Research) and of Antarctica (the Scientific Committee on Antarctic Research). Instruments for fostering joint work thus far are in the formative stage, but they provide a machinery worthy of development, and demonstrate a capacity for cooperation with the major intergovernmental bodies in the field, principally FAO, UNEP, WMO, WHO, and UNESCO. In turn, UNEP, UNESCO, the Ford Foundation and the Rockefeller Foundation have been generous in support of the scientific unions and committees, and have helped make possible a number of ventures reported in Environmental Issues 1976.

The challenge at this stage is to link the expanded understanding of environmental problems and methods with the activities of national science establishments where more than 95 percent of all environmental research is carried out. National groups understandably focus upon the basic issues that are raised by the multiplication of regulatory activity as described by Gordon MacDonald. Ideally, in dealing with their distinctive national problems the national academies would cultivate international networks to use the best of experience from other nations.

At present, the most effective networks are the informal communication systems among individual scientists who out of common curiosity and interest, and trusting the integrity of their fellows, share data and insights directly and in journals. Through correspondence and at meetings they develop these linkages on questions such as toxicity, nutrient cycling, and resource transformation. In practice there are severe obstacles to easy flow of information and to comparison of national experience. We have only just begun to experiment with a variety of devices which will strengthen the ability of scientists in one country dealing with a question of global significance to draw information and critical appraisal from other areas. And the fact remains that the difficulties of crossing a number of disciplinary lines are as formidable as those of crossing some international frontiers.

ENVIRONMENTAL ISSUES 1976

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In this report, the Scientific Committee on Problems of the Environment (SCOPE) accounts to the International Council of Scientific Unions (ICSU), its parent body, for its work over the past six years. Through the Unions and Committees of ICSU, and the national Academies in member countries, the report will also come into the hands of the leaders of the scientific community.

But it also seeks a wider audience, and hopes to reach it more directly because this report is about a subject that is all-embracing in its extent, and co-extensive in time with human history. It is about how man and environment interact, and about how we may learn from the scientific research of past and present in order to safeguard the future. The principal lesson in this document is that human power to disturb the environment has run ahead of the methods for recognising and controlling that disturbance. The scientists working in ICSU and in SCOPE must respond to this situation by putting their own house in order: by increasing their professional capacity to gather and evaluate the information upon which wise policies for the management of our common environment must be based. But they must not ponder this knowledge in the detached and rarified atmosphere of the intellectual ivory tower. They must be prepared to communicate it to those charged with the formulation of national, regional and global policies - in a fashion that permits it to be brought together with the other specialised knowledge of economists, social scientists and administrators to form a clear and cogent whole. This kind of science is not just addressed to scientists.

SCOPE was set up to improve knowledge of the influence of human activities upon the environment, and of the consequences of the resulting changes for human health and welfare. In the report much effort has been devoted to chronicling such changes, and evaluating how far they are proven, probable, or hypothetical. Seven main themes have been examined during the Mid-Term program of SCOPE, which provides the main scientific substance of the present Report. As is to be expected since the Report deals with a two-component interactive system - the natural and the man-made world - some of these themes (called "Environmental Concerns") focus on features of the environment, and on how they have been altered by man, while others, called "Environmental Management" investigate human responses. The environmental concerns explored in detail are the biogeochemical cycles of the elements fundamental to life, climate, as a dominant influence on the biological patterns and processes of the world; pollutants as chemical factors perturbed by man; and the processes of ecosystems, which integrate the dynamic responses of life to these variables. The themes grouped under the heading of environmental management are the processes by which we identify problems and monitor their changing scale; the methods of modelling, by which we describe and explore the properties of environmental systems; risk estimation, from which we endeavor to judge the seriousness for human society of various environmental constrints; standard setting, in which we formulate social codes or guidelines which we believe will guarantee an acceptable level of protection, and evaluation and communication, which binds and limits our societies.

SCOPE is especially concerned with the changes going on in the world, and with their implications for the future of life on earth, and human life in particular. Change needs to be measured against some kind of baseline. For this reason the first Chapter of SCOPE's report is a general essay on the environmental properties and processes of the world. This essay takes a long perspective, for we stand today at the latest - though assuredly not the last - phase of five thousand million years of physical, chemical and biological evolution on this planet. However proud we may be of our cultural creativity and of the way in which we have reduced our vulnerability to the vagaries of the natural world, mankind remains totally dependent upon that world. All life on earth depends on the sun, and most of it upon the production of plant matter, using and fixing solar energy. The natural cycling of elements like carbon, nitrogen, phosphorus, sulfur and many metals, depending on those microbes ecologists term "the decomposers", remains fundamental to our continued existence. The processes by which all living organisms pass through their life cycles, multiply, and adapt themselves by continuing evolution, are as vital now as they ever were, and hold the solution to survival in a world that will assuredly continue to change. But over the past ten or twenty milennia, human agriculture and medical science have gained an increasing capacity to modify the life cycles of man and other organisms and develop new strains capable of enhanced productivity, setting these crops within ecosystems that are themselves unlike those of the natural world. Linked to these developments in "environmental management", there has been a dramatic increase in man's capacity to acquire, analyze and present information, and this last development is thought by some to be the most potent of all. For it allows communities to blend the individual contributions of enormous numbers of individuals on an unprecedented scale, extends human intellectual capacity, and presents the potential for large numbers of people to respond as a collective intellectual entity.

Science teaches that while there may be simple unifying themes and forces in the world, they manifest themselves in the generation of complexity and diversity. The world is a highly variable place, and conditions for life can never be the same everywhere. Global pronouncements of gloom/doom or euphoria are all likely to miss the mark - except as sweeping generalizations to which there will be many exceptions. The world is of finite size: it may have an ultimate limit to the numbers of people it can support at even the most basic level. But the state of mankind is very different from place to place in today's world: some areas are too crowded for comfort, while others need more people. The SCOPE report is not one of those documents trying to solve all the problems of this varied world at a stroke. Its aim is rather to focus attention on some of the scientific issues that need to be considered in constructing the solutions appropriate for different areas and times.

After such an introduction, the Committee felt it necessary, in Chapter 2 of the Report, to address itself to the ways in which scientific finds could be incorporated in wider policies. Successful action on an environmental issue generally demands four conditions:

> that there is enough knowledge on which to base action;
>
> that the problem is recognised as important enough for action;
>
> that there is the social and technological capacity for effective action; and

> that there is enough determination and resources in the community to make the action succeed.

The role of the scientist is especially to define the problem, predict the outcome of various alternative sequences of events, and develop the technical methods by which the preferred option or goal may be achieved. The highest priority for further scientific investigation should clearly be given to those problems whose solution is being impeded by lack of scientific knowledge in contrast, it is wasteful to indulge in science as a "displacement activity" when there is already enough knowledge for action, but the limiting factor is the social or political will. A similar search for limiting factors is often needed along the pathway from problem recognition through the evaluation of the available information to the stage at which evaluations are available for communication to those concerned with developing overall policies and Chapter 2 of the Report analyses these stages in some detail.

The first environmental concern to be described in detail in Chapter 3 is that of biogeochemical cycles. The part describing the cycles of nitrogen, phosphorus and sulphur, was written (largely by E. Eriksson and T. Rosswall) after a special workshop in Sweden, and it contains new material that makes it probably the most up-to-date review of these topics available. It is clear that the cycles of all these elements have already been substantially altered by man, especially through the industrial fixation of nitrogen, the emission of nitrogen and sulphur oxides to the air, and the changes in the scale and rate of nitrogen and phosphorus cycles as a result of agriculture, and key areas for new research have been identified. The carbon cycle has been reviewed less thoroughly by SCOPE, and attention especially needs to be given to documenting the importance of living organisms in the cycle and their relationship to the trends of carbon dioxide in the air, with its possible effects on climate.

Climate is the subject of the second essay in Chapter 3, written for SCOPE by R. E. Munn. The spatial and temporal variability in climate is stressed, emphasising that man's activities are superimposed upon a complex and only partly understood natural system of variation. The need to understand such systems better is evident, both in order to forecast the likely agricultural and economic impact of pollution that may modify the radiation transmission properties of the atmosphere, and in order to guide development in an ecologically sound manner. It is becoming evident that climatic averages over short runs of years may be a misleading basis for planning. To cite one example in the Report, it is likely that much of the economic development and population expansion in parts of West Africa took place during a period of abnormally good rainfall between the 1920's and especially the 1940's and 1958 and may consequently have gone beyond what is sustainable under more "normal" conditions.

SCOPE's approach to pollution (led by G. Butler) differs from that in many recent general reviews. It has concentrated on the critical analysis of the parameters that must be measured if the quantitative relationship between the exposure of a 'target' plant, animal or person and the consequent effect on its physiology is to be determined. Such analysis depends on the determination of the kinds of material released to the environment; the transformations they may undergo there, the pathways they follow from source to target, the factors determining how long, and under what conditions the target is exposed, the extent to which a pollutant is actually taken into the tissues of the target (and then transformed, stored, or eliminated), and the biochemical processes by which the effect is actually mediated. A technical appendix to the Report shows, using methyl mercury as an example, how such calculations can be done: the point SCOPE would wish to make is that this kind of rigorous scientific analysis is vital if complex problems of pollution are to be evaluated in a meaningful, non-emotive, fashion.

Rather similarly, ecology today is increasingly drawing on mathematical concepts and methods, as an aid to the precise analysis and description of processes within ecosystems: the section of Chapter 3 drawn up under R. Slatyer's guidance illustrates this trend. The section concentrates on ways of modelling and predicting ecological succession, but has direct relevance to the prediction of patterns of ecological change that are likely to follow human activities. The work may ultimately lead to a 'Practitioner's Manual" which outlines the techniques available for modelling successional processes, the data requirements and limitations of each, and the methods by which they may be applied to the management of semi-natural communities - or in the longer term, more modified systems. The second part of the section on ecosystem processes, by Gilbert White and M. Kassas, stems from a SCOPE/COWAR workshop in Alexandria, analyses the problems of arid land irrigation and the ecological changes such improvement can bring, and could lead to the development of a different kind of "Practitioner's Manual": a practical check list of questions that need answering before any proposed irrigation venture is embarked upon.

Chapter 4, on Environmental Management, starts where Chapter 2 left off, with the evaluation of problem recognition. SCOPE's thinking in this area owes much to G. Butler and I. Burton. In environmental management, many decisions have to be made under conditions of uncertainty or risk. Sometimes this is because of inherent variability in the environment, sometimes through lack of scientific knowledge about the processes at work, and sometimes through absence of detailed knowledge of the locality in question. Monitoring is often instituted in order to measure how the environment is changing, so that the consequences of such uncertainties can be detected and if necessary, remedied by changes in policy before unacceptable risk or damage ensues.

Four main kinds of monitoring are described in the section of Chapter 4 provided by G. T. Goodman. The first type is concerned with measuring levels of potentially harmful (or beneficial) substances in air, water, sediment, soil or organisms. The second examines physical attributes of such media (like solar radiation or other major climatic variables). The third looks at the effects of such factors on living or non-living "targets". The fourth, really a kind of survey, compiles inventories of environmental patterns (including human land use) at particular times. Repeated surveys reveal and quantify broad patterns of change. Because so many things can in principle be monitored, it is essential to commence by a critical analysis of the system liable to display change, and the selection of parameters that are both readily measurable and likely to give real insight into changes in the functioning of the whole. Moreover, monitoring can never stand aside from human policies. It is undertaken in order to determine the state of an environmental resource or the degree to which human activities are leading to change, and needs to be designed so as to provide its answers in a form that can be injected into the process of policy review.

Much has been said and written about modelling in recent years. The simulation modelling project of SCOPE, led by F. N. Frenkiel, has emphasised that this tool is useful in three main ways. Simulation modelling helps in research because the need to build an adequate description of the structure and working of a complex system itself casts light on gaps in knowledge that might otherwise be ignored. Modelling is also useful as an educational tool, displaying the main features and chains of cause and effect in complex environmental systems. Thirdly, modelling can provide a sophisticated method of prediction, helping the environmental manager to evaluate the effects of alternative policy options. Modelling is not an end in itself, but a tool for management and an aid in decision making. Partly with this in mind the SCOPE report looks at the components in the model-building process, where gaps are likely, and how they may be bridged.

Standards are promulgated by authorities as one component of a broad spectrum of action to protect or enhance public health or well being. There are two main kinds of environmental standard: those prescribing the maximum tolerable levels of contaminants at a target, in the environment or in an emission to it, and those prescribing the minimal permissible quality of a construction like a building, bridge or a dam. The SCOPE section on pollution, with its annex on methyl mercury illustrates how the first type can be worked out. The final section of Chapter 4, by Akin Mabogunje and his colleagues, takes up the second, with special reference to buildings in developing countries. The study has revealed a significant fact about shelter provision in developing countries: the incompatibility of present policies with the maintenance of a desirable level of environmental quality. This has often arisen because of the uncritical export to those countries of standards developed elsewhere, and often not adapted to the resources, climate, traditions or true needs of the countries concerned.

Standards are no more than an element within a broad field of environmental policy. To that extent the discussion in Chapter 4 interlinks with the preceeding section of text concerned with risk estimation and communication. A risk is a statement of the probability of something happening (by implication, something undesirable). Risk estimation draws upon scientific understanding of the relationship between exposure and effect and makes statistical judgments about the frequency with which a certain level of event will happen. By itself, it is not a value judgment. The value judgment is a second step and is concerned, often intuitively rather than through any rigorous assessment of costs and benefits (however determined), with the risks that should be accepted. A process of evaluation and communication is (or should be) an integral part of the process. A standard is one possible outcome, embodying the judgment. The SCOPE study (led by Ian Burton) indicates some of the conceptual steps in this process, and points to the need for a more critical discussion of just what is involved, and how far the process can be made rigorous.

SCOPE does not pretend to act alone in these wide-ranging fields. Indeed, any multidisciplinary approach like this is likely to be no stronger than the component specialist disciplines on which it draws. As Chapter 5 of the Report points out, there are many ICSU Unions and Committees, and numerous other international organizations, with whom SCOPE has collaborated and through which the world's scientific community as a whole is advancing in its environmental understanding. This collaboration is fundamental to the future.

What of the future? Chapter 6 of the Report is a Forward Look. SCOPE turns to the future with cautious optimism. There are many success stories of the wise management of man and environment, to sustain landscapes that are productive, stable, beautiful and rich in a diversity of living things. More information is still needed about the factors that determine the patterns and processes of the living world and especially those parts of it that are exposed to fluctuating climates, or are now coming into intensive human use for the first time. Better communication between scientist and policy maker is also needed, if the one is to gain the knowledge and the other to respond to it, in a manner that benefits all. But there are examples to show that the knowledge can be both gained and applied.

Only recently in the long time scale history of this planet have the impacts of human activities become comparable in scale with those of the factors in the natural world. These impacts will certainly not all continue to grow at the exponential rate many have displayed in the recent past. Equally certainly, however, the proportionate influence of man and of natural factors will continue to change in the direction of human dominance, at least over the next century, when the urban populations in developing countries are certain to expand greatly and when technology will certainly increase human capacity to perturb the cycles and processes of the natural world.

In preparing for the future there are certain specific actions SCOPE feels should be pursued - not all through its own agency. They are set out on pages 165 to 188 of the Report. There are eleven of them. They cover a wide span. In summary, these suggested priorities are for:

1. More research on the natural cycles of vital elements in the biosphere;
2. more research on the relationships between the exposure of living things to potentially toxic substances, and the effects;
3. more critical research on patterns and processes in ecosystems;
4. studies on the adaptability, resilience and stability of species, population and ecosystems;
5. research and development in agriculture and genetics that will improve world food production and give people everywhere a reasonable standard of nutrition;
6. more thought about the design of human settlements that are stimulating to live in as well as sustain basic needs;
7. more thought about the balance of resource use and conservation in the world; and research that will guide wise development, including strategies that bring people in different regions into appropriate balance with the environment;
8. development of rigorous and objective methods for environmental impact and risk assessment;
9. continued study of man's impact on the climate of the world;

10. a more considered approach to environmental education;

11. an evaluation of the genetic diversity and ecological richness of the biosphere, and the development of strategies to conserve them.

In conclusion, two general points are emphasized. The first is that it is necessary to respond to diversity with diversity. The world is not a uniform environment and we could not make it so if we would. Human aspirations and talents differ. So do the things that make people creative and happy. We should beware of universal, sweeping generalizations and of too much preoccupation with averages, and endeavour to match regional or local environmental constraints and opportunities with policies truly adapted to them. This, after all, is what organic evolution has done over the milennia.

Second, scientists must continually remember that they are not alone in the world, and are only some of the specialists in a complex society. The problems of the environment demand the synthesis of the results of many sciences. They will be of little value unless they are communicated to people who are not scientific specialists in a fashion that can be understood. The future of the world is not being molded only - or even largely - by scientists, but by the ploughman, the woodcutter, and rice-planter, the worker in the factory, the administrator, the economist, and the policy maker at national level - among all those other occupations that make up a part of the diversity of man. It would be foolish to assume that the scientist could single handed revolutionize the thinking of all his fellow men. The scientists chief need is to do his special work effectively and communicate it effectively, in order to contribute as he should to the future.

CHANGING ROLE OF THE SCIENTIFIC COMMUNITY FOR ADVISING ON THE ENVIRONMENT

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Science advice in the mid-1970's differs in fundamental ways from what it was in the 1950's and 1960's, a period considered by some to be the golden era of such advice. The scientific issues at that time included ballistic missiles, nuclear weapons and nuclear energy, the space program, oceanography and high-energy physics. All required very substantial governmental expenditures. The industries involved were for the most part not labor intensive, rarely had large consumer markets and were closely wedded to governmental action since they and their employees were dependent on government contracts and subsidies. Scientists were often intensely involved in the formation of government policies affecting further developments of the space program, oceanography, high-energy physics and similar scientific and technical programs.

There was, in effect, a tightly knit community of common purpose. Its members came from several major industries, the scientific and technical world, various government agencies and Congressional units. All were interested in the furtherance of a variety of scientific and technical enterprises.

But these programs and the scientists who helped shaped them had little impact on the day-to-day activities of most Americans and directly affected relatively few. Even though billions of dollars were spent on highly visible technological enterprises, the only real involvement for most citizens was in the taxes they paid.

The regulatory environment of the 1970's changed that. The kind of cars we drive, the quality of our air and water, the efficacy of our medicines and drugs, the kind of pesticides sprayed on crops or the siting of an electrical power plant are all affected in some way by regulations which have come into force in the past several years.

Our lives are now influenced directly by decisions of the regulatory agencies and by explicit regulations in legislation. Correspondingly, scientific advice impinges more directly and more meaningfully on the citizen in the mid-1970's than it did in the 1950's and 1960's.

Of course, regulatory legislation is not a new phenomenon, nor is associated scientific advice. The Food and Drug Act was passed in 1906; the Insecticide Act, in 1910. In 1938 the Food, Drug and Cosmetic Act focused attention on the possible dangers to the public from the increasingly complex food industry. The Federal Insecticide, Fungicide and Rodenticide Act of 1947 furthered interaction between science and regulation. These laws, however, were only a prelude to the crescendo of regulations to come from legislation passed in the late 1960's and early 1970's.

That the new regulatory setting would provide new difficulties for science advising was foretold in 1953 by the highly publicized case of the AD-X2 battery additive which pitted scientific judgment and analysis against its acceptance in the marketplace. A vendor of a chemical which was supposed to extend the life of storage batteries was challenged by government agencies, including the Federal Trade Commission. The Federal Trade Commission argued that the product had no merit according to tests run at the National Bureau of Standards. The vendor provided testimonials from satisfied customers and was supported by the Secretary of Commerce and other political leaders in his opinion that customer acceptance was the real test of the value of a product. The regulatory agency felt that the law compelled it to use scientific evidence to protect the public by insuring the quality and the reliability of commercial products, but at that time political leaders felt that science should not be concerned with regulatory matters, and the vendor's position was temporarily upheld.

The complexity of today's regulatory decisions make the AD-X2 case a model of simplicity. For instance, regulations on permissible auto emission levels affect a very substantial fraction of the Nation's total economy and employment, and they have multiple international consequences involving not only balance of payments but overall international trade stability.

As the AD-X2 case implicitly warned us, technical questions are not always resolved on technical grounds. This remains true today. While scientific advice can be a useful guide to the decision-maker in promulgating regulations affecting a good part of the population, it is not invariably the final arbitrator.

To gain a better perspective on the regulatory arena in which science advice is now sought and given, it is helpful to examine briefly the genesis of environmental laws enacted within the decade.

Spurred by Rachel Carson's poignant Silent Spring and other works, political leaders in the Congressional and Executive branches in the 1960's intensified their interest in environmental problems. An example of this interest was the landmark study in 1965 by the President's Science Advisory Committee, PSAC, Restoring the Quality of the Environment. While clearly pointing to the need to increase the effectiveness of our regulatory base for environmental management, the study also strongly recommended a careful investigation of a tax system in which all polluters would be subjected to effluent charges in proportion to their contributions to pollution. While many of the recommendations in the PSAC study were acted upon, this particular one is still dormant with the net effect that today's management of the environment has been given over to the regulators. Rather than financial levies to dampen pollution levels, the tax is a regulatory one which specifies allowable pollution levels. Typically, ambient air quality standards are the basis for emission standards which in turn are ultimately enforceable by the federal government and the federal courts.

A major element in setting the nation's environmental posture and in spurring analyses of programs and policies affecting the environment was the National Environmental Policy Act (NEPA), passed by Congress in 1969 and signed into law by President Nixon on January 1, 1970. Section 102 (2) (C) of NEPA requires a comprehensive assessment of the wider and less easily measured environmental impacts of federal actions and policies.

NEPA was drafted as an administrative law in the sense that it requires federal agencies to take into account the wider and longer term consequences of the action. What was not clear from the legislative history of NEPA itself was whether "to take into account" was a procedural or substantive requirement. Subsequent court rulings have left this ruling open.

The NEPA experience has encouraged analysis both inside and outside government to devise new techniques for project evaluation and to embark on novel interdisciplinary decision-making processes. However, many of the advantages of impact analysis, both real and potential, have not yet been assimilated in the decision-making process in the regulatory environment. Because of so-called "non-substantive considerations," the regulatory process itself has been exempted from the requirements set forth in Section 102 (2) (C) of NEPA. As a result, many opportunities for science advice exist in a different forum and format than those provided by NEPA.

Moving in sympathy with the forces that created NEPA were intense pressures to remedy the serious weaknesses in environmental management that were described in the PSAC report and by various public and private groups. Congressional leaders wanted reforms. A presidential commission headed by Roy Ash, citing dispersion of environmental regulations among a large number of federal agencies, recommended the creation of a new agency with broad regulatory powers. In 1970 the Environmental Protection Agency (EPA) was created to take over the functions of a large number of regulatory units in the government.

Shortly thereafter, the president signed into law the Clean Air Act Amendments of 1970. Thus, the fledgling agency was faced with the immediate task of creating and then enforcing a vast variety of regulations to control air pollution at the same time it was organizing itself.

The coincidental creation of EPA and the passage of the Clean Air Act Amendments influenced in a major way the development of the agency's regulatory philosophy. For example, the Clean Air Act required that the primary air quality standards be set to fully protect the public health and that these standards contain an adequate margin of safety. In mandating these standards the law assumed a threshold concentration for air pollutants below which there are no adverse health effects. But the wisdom of that assumption has been questioned. For example, it may be that susceptible people exhibit adverse health effects at concentrations below primary ambient air standards and even down to natural background levels.

However, the legislative requirement to fully protect health and the assumption of threshold concentrations at an early stage closed down other approaches to setting standards. For example, given more leeway, the agency could have adopted a cost-benefit-risk approach to standard setting. Rather than setting specific levels, a continuum of probable health risks for various segments of the population and control costs could have been set accordingly. An attempt could have been made to balance costs against health risks.

Of course, while cost-benefit-risk approach is attractive, it is often very difficult to apply in practice. Basically, it is much easier to calculate control costs than to assess in some quantitative way the benefits of avoiding health risks. In spite of the difficulties and of the axiomatic point that one cannot measure environmental health solely in terms of dollars since one cannot price what is inherently priceless, cost-benefit-risk analysis does have the advantage of avoiding generalities. It focuses attention on dollar decisions. Since regulatory decisions can have vast economic consequences, this kind of quantitative analysis has the value of bringing together factors affecting cost and benefits in an organized way and thus facilitating debate on the adequacy or inadequacy of regulations.

Cost-benefit-risk analysis has the further value of making explicit fundamental underlying assumptions. Some have argued that where the health of the public is concerned, money is no object. "We must take every precaution; we cannot afford to compromise on the nation's health." However, costs are associated with every regulatory decision, and the most effective overall environmental program tries to put each dollar where it will add to the total effectiveness. The emphasis should not be on cost but on cost and effectiveness together.

The two sorts of cost-benefit-risk considerations have been de-emphasized by the evolution of the threshold concept, which in turn was essentially forced by the requirements of the Clean Air Act. Still these considerations are or should be important in assessing the overall benefits of regulatory programs. For example, the control of emissions from automobiles will involve national expenditures measured in billions of dollars a year. Relatively little of this will be spent by the federal government. While these costs do not show up in the federal budget in the same way as sewage treatment plants do, they are just as real. In considering such expenditures, we should examine whether an additional million dollars spent on controlling oxides of nitrogen from moving sources will be as effective in protecting human health as the same amount spent on controlling oxides of nitrogen from stationary sources. Or would such an expenditure be more valuable to the overall health of the nation if it were employed in controlling the dispersion of toxic materials in the environment.

An examination of the marginal costs and effectiveness of various alternatives may be even more important in the legislative process than in the regulatory process, since regulations codified into law are difficult to change. For example, as mentioned above the Clean Air Act requires the EPA Administrator to protect the health of the public with an adequate margin of safety, an implicit regulation. The same act also provides a 90 percent reduction in automobile emissions in a specified time, an explicit regulation.

These legislated timetables and goals have led to the promulgation of regulations to achieve short-term goals without concern for the longer term implications. The legislated, strict automobile standards with short deadlines influenced, if not actually forced the automobile industry to follow one particular technology, the catalytic converter, without paying sufficient attention to alternate technologies that perhaps offered greater promise for the long term. Short deadlines for municipalities in meeting a sewage treatment as required by the Water Pollution Control Act Amendments of 1972 led to replications of past technology and little or no incentive to find better methods. Legislated time pressures have kept EPA from preparing a multi-year plan that weighs regulatory programs and their marginal costs against various technological options.

Planning for the future will require the careful analysis of the concept of threshold for health effects, the examination of technological options to achieve health standards and the consideration of the long-term impacts of regulatory decisions. At a more fundamental level the whole issue of whether regulation is the most appropriate tool to manage the environment should be seriously questioned. Other management tools such as the use of effluent charges need to be critically assessed. Otherwise, we may be frozen into an unmanageable system with an ever-growing regulatory bureaucracy.

Whatever the process for making regulatory decisions affecting the environment, it should be done within the broadest context as possible. This is where science advice could perhaps be most helpful. In most cases decisions involve elements that are part of a larger system, and good decisions recognize the fact. For example, regulatory decisions on effluent limitations of sulfur oxides from power plants should take into account the need to dispose of the solid waste generated by the stack-gas scrubbers. The interaction of sulfur oxides with other components of the atmosphere could result in the forming of secondary pollutants whose adverse effects might be even greater than those of the sulfur oxides. The cost involved, the availability of the technology and the implications for economic health of the affected regions are also elements that require analysis. The electrical power generating plants emitting sulfur oxides are but one part of that large interrelated system. Rational regulatory decisions cannot be made without an understanding of the overall system. The kind of environmental analysis required is not found in a single discipline. The analysis is not physics, engineering, mathematics, biology, medicine, economics or political science. Yet, it will involve elements of all these disciplines. Environmental analysis requires much more a frame of mind than a specific body of knowledge. Like any good analyst, an environmental analyst must be a relentless inquirer, asking fundamental questions about the problem at hand.

Environmental analysis is not a panacea for problems of environmental management. Most environmental issues are highly complex with variables of unknown and uncertain magnitude. No study can account for all the variables or all the factors involved, but good environmental analysis can be an aid to judgment by clearly defining issues and alternatives, by indicating uncertainties in the data when uncertainties exist, by clarifying underlying assumptions and by further indicating the probable cost of hedging against major uncertainties. A good analysis is characterized by openness, explicitness, objectivity, the use of empirical data, quantification and a self-correcting character. At the same time it should be recognized that many of the underlying assumptions are either not rigorously verifiable or else cannot be verified at all. Many of them involve value judgments to be made by policymakers as to what an uncertain future is likely to be or should be. The point of environmental analysis is not to give the answer but rather to show how an answer depends on the various assumptions and judgments. For example, the analysis of the costs and benefits of automobile pollution control strategies is not scientific in the same sense as physics or engineering. In important ways this kind of an analysis draws upon the scientific method using that term in its broadest sense. However, this fact does not make it scientific.

As in other fields of analysis, the assumptions drive the conclusions. There can be no doubt about the fact that there is not a single right set of assumptions, only a variety of relative assumptions each more or less equally defensible. Ultimately, all environmental policies and regulations are made on the basis of judgment. There is no other way. The real issue is whether judgments have to be made in the fog of inaccurate data, unclear and undefined issues, conflicting personal opinions and hunches, or whether they can be made in the clear atmosphere of relevant analysis and experience, accurate information and well-defined issues.

Quantitative environmental analysis is possible even if there are uncertainties. And rather than conceding uncertainties, a good analysis will help bring them out and clarify them. There is an obvious tendency to ignore important, non-quantifiable factors, but this failing is less likely if a systematic approach is used in the analysis. The analysis must lay out clearly the assumptions, uncertainties and calculations, so that both the decisionmaker and the critics can see what was done and whether the analysis over-emphasized quantitative factors. Good documentation of the analysis is essential if the regulators are to know what factors were used and which were neglected. A good example of an analysis in which there were large uncertainties but which still clarified the basic issues was the 1974 National Research Council study, "The Cost and Benefits of Automobile Emissions Control." Despite the lack of hard data, the study did derive a ballpark estimate of damages associated with automobile emissions and did provide guidance on the most economical strategy for controlling emissions.

A sound environmental analysis also contains the recognition of the built-in institutional biases of various organizations that have a say in regulatory decisions. The Environmental Protection Agency has a legal responsibility to protect the environment and in so doing will have an institutional slant towards environmental protection. The Department of Commerce in commenting on regulations will have a different slant, one protective of business and industry. The Treasury Department will be less concerned with the aesthetic benefits of emission control but will emphasize international trade impacts. The Office of Management and Budget and its coordinating function will bring still a different view with concern about the macro-economic consequences of a particular regulation and the impact of that regulation on employment and overall economic well-being. Others will examine regulations from a political point of view. Agencies can call on outside consultants. These consultants, however, are more likely to reflect an agency's biases. In light of this it is important that regulatory decision-makers have independent analysis available to them.

Clearly, no group is completely free from bias. Freedom from bias in institutional settings can help. This does not mean that analysis proceeds without consulting with experts associated with various institutional points of view, but it does mean that the final analysis should be done in a setting as free from institutional biases as possible. The National Research Council with its stringent selection of committees and personnel, its review procedures and sensitivity toward potential sources of bias, provides an institutional base that is as independent and free from imbalance as is realistically possible.

Over the years the National Research Council has presented to decision-makers and to the Executive and Congressional branches rigorous analyses pertinent to regulatory decisions. Some of the perils of that process are illustrated by the report of the May 1975 Conference on Air Quality and Automobile Emissions. This report, which drew on four years of efforts by various groups within the National Research Council, gave conclusions distasteful both to the regulator, the Environmental Protection Agency, and to the regulated industry. The analysis, which was open and documented, included many conflicting points such as the state of development of the three-way catalyst, savings associated with implementing a two-car strategy and the health benefits of reduced carbon monoxide and hydrocarbon emissions. Although perhaps predictable, it was still surprising that, since the report essentially reaffirmed judgments given in previous National Research Council studies, there was considerable criticism principally from the senior officials of the automobile industry. These criticisms were carefully examined and answered in a supplementary statement issued in late July 1975. None of the judgments in the initial conference report was changed.

Finally in considering the role of scientific advice and analysis, in environmental decision-making, it is well to recall that laws and regulations are not always drafted with sole concern for scientific facts and realities. These decisions are often highly political and therefore subject to intense political pressures. They can, in fact, affect a large fraction of the population and as a result, the decision-makers are buffeted by the attention of the public media. These pressures often result in decisions that may appear to be intended to anticipate public reaction rather than flowing from rational analysis. The public may not be well informed and the anticipated reaction may or may not conform with the analysis provided by either independent or governmental groups. This may not appear to be the most rational approach, but it is a reality of the decision-making process.

It is commonly held that most environmental issues are too complex to be understood. The fact is that every effort must be made to understand them. This requires both analysis and judgment. Analysis by itself cannot answer many questions that turn out to be the most important factors in any decision. There are also questions that cannot be answered by judgment and experience alone. A mix of judgment and analysis is essential if we are to have better regulatory decisions. The development of the methodologies and analysis of the kind described above can help restore public confidence in the wise use of the scientific method for dealing with issues affecting a large segment of the public.

AN INTERNATIONAL PERSPECTIVE OF THE GLOBAL ENVIRONMENT

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Mr. Chairman, it is a formidable task to produce a comprehensive perspective on such an important and complicated field as the problems of the environment. Three years ago in Indianapolis, Indiana, the outline of today's report was accepted by the Executive Committee of SCOPE. As the President of SCOPE, I was involved in the drafting of the tentative outline of the report summarized this afternoon so brilliantly by Dr. Holdgate. The editors, Gilbert White and Martin Holdgate, are to be congratulated on achieving such a scholarly document. Of course, they were assisted by many scientists from different countries. In particular, I think we all are in debt to our Swedish colleagues, to British scientists, to American researchers, to Soviet Russian investigators, to Egyptians, Japanese, French, Canadian and to many others. An endless list of countries, scientists, and material was involved.

Why did we decide to do this? It was in response to a Resolution of ICSU at its 14th General Assembly "to define clearly those environmental problems toward which ICSU can make a unique contribution." Without tentative marshalling of existing information and extraction of the most important conclusions, it is impossible to produce a real, important, creative program of future international research, useful for the United Nations family and for the international scientific community. I, as a former president of SCOPE, was impressed with the magnitude of the problem: interdisciplinary, international, global, cosmopolitan, involving the fate of mankind. All those tremendous problems must be understood, must be formulated. I think it is a great success that this task - this tentative integration of existing knowledge and problems of the environment - is now complete.

Simultaneously, scientists of every country were doing similar work on a national basis. These works were very much influenced by the program of SCOPE. For instance, at Moscow State University and with the Academy of Sciences of the U.S.S.R., we recently produced a review concerning biogeochemical cycles and the destruction and perturbation of these cycles by the activities of man. It has been translated into English and we hope it will soon be available. A short review of my personal understanding is being published now in English in the autumn issue of a popular scientific magazine, Environmental Conservation, in Geneva.

I think the most important result of our three-year international effort is that we all now understand much better that the biosphere is a universal, multi-component system of living matter. The interaction of living matter and mineral matter is a unique aspect of the biosphere as it exists now. This complicated system including atmosphere, hydrosphere, upper crust of our planet, soil cover, and living organisms, is driven by solar energy in addition to volcanic and tectonic sources.

The second point which we understand better now than we did before our study is that this universal supersystem is, in spite of complications, self-regulating, self-proving, and self-guiding. It has developed over several billion years. Mankind, by technology and economic growth, has interfered with this self-regulating mechanism. In the past, when our knowledge was quite primitive, the interference of the powerful forces of modern civilization into the self-regulating machinery of the biosphere sometimes provoked very complicated, even catastrophic, consequences. I think this is the most important lesson we are learning.

Since mankind has become an important force in the biosphere, the self-regulating system is even more complicated. From one point of view, the influence of man is positive. The historical, natural frontiers of the biosphere just before our eyes are expanding. For example, satellites now have penetrated far into the cosmos and forced our present into the future. Our drilling technology has permitted us to penetrate many kilometers inside of the earth's crust. So we see the general frontiers of the biosphere as being much broader than it was before the interference of man.

Nevertheless, the price for this is very expensive. We estimate that approximately 25 percent of the global biomass (mostly phyto biomass) has been lost due to man's interference. Approximately 15 percent of the soil has been covered by concrete or transformed into urban areas and is lost for the natural cycling of carbon, nitrogen, oxygen, calcium, potassium and minor trace elements in the biosphere.

Why did this happen? I tried to listen for the most general reasons. Some were given yesterday afternoon. Some were mentioned by Dr. Holdgate and Dr. White this afternoon. The important lesson is that we did not even suspect how profound the consequences could be. It is a brilliant achievement of modern science that we can now understand the thesis which was formulated by an internationally known Russian scientist, Vladimir Vernadsky who, in his lectures in the Sorbonne in Paris as well as in Leningrad and Moscow, formulated the concept of the biosphere in the early twenties. Later, in the early forties, he formulated the idea of the noosphere, the idea of the ripening of the intellectuality of mankind, the possibility of reasonable ruling and guiding the processes of the biosphere by man.

Alas, it is only beginning and the reality is relatively sombre. Illiteracy, ignorance, anarchy, short-sighted approach to the utilization of resources, colonial exploitation, predatorial utilization of resources, tendencies to obtain other profit, tendencies to obtain immediate results with minimum cautions and minimum of allocations, wars, conflicts: they are responsible for this. All these factors are mostly social, as they are inherent of man. These factors, these limitations, must be excluded in the future. We have only to understand their role. Of course every nation and every region will decide its own destiny in given time and in the way which is preferred for each nation.

Let me give you a short list of the most general changes as differentiated by the previous three or four groups of factors which I just outlined. The natural ecosystems are endless in number and in variability. They are receiving more and more pressure from man-made ecosystems. Does this pressure reduce the forces driving the cycles of oxygen, carbon, nitrogen, sulphur and the rest?

The ancient natural geography of the paleontological period has fully changed. The original soil life has been destroyed in many areas. Inside of the soil, climatic and bionatural zones are now myriads of local, small and weak, artificial and foreign ecosystems produced by man.

The heterogeneity of man is much broader, much deeper, much stronger than it was, for instance, three hundred years ago. This heterogeneity, this diversity, is typical not only for space, not only for distance, but in time. The usual, traditional cycles related to soil activities and the cycles related to global changes of climate are now complicated by unexpected phenomena. Local, subregional and sometimes global changes in weather, in climate, in soil, in productivity, in yield, hamper the effectiveness of our work. These are the forces which changed global and local cycles of man, brilliantly described in the Holdgate report.

Probably destruction of the water cycle is the most tragic of the consequences. I am a soil scientist and so I will put as the second most tragic consequence the destruction of the soil. Even as pleasant a country with as pleasant a climate as England or Scandinavia in the last two or three years has felt the impact of deficit of water. The frequency of droughts is growing with alarming speed. This century is not yet finished but we already have had fifteen 20-week droughts.

The quality of water has been lowered by wastes from cities and industry. The rivers of the northern and southern continent of America, of Africa, of Europe, and of Asia now carry waters salted due to irrigation projects. The normal concentration of soluable salts in river water is almost one gram per liter. Sixty or seventy years ago, it was 0.2. The same can be said about our land. A most important resource, land, is now fast disappearing due to erosion. The four countries, United States, India, Soviet Union, and Pakistan, together have lost almost a half billion hectares of land under erosion and salinization. The same is true for many other countries and areas.

What is required? Action is required -- action, action, and action! Research as has been outlined is needed -- biological, ecological, and medical. In the best sense ecological propaganda - scientific ecological propaganda is action. But still it is not enough. Legislation is required and concerted national policies in environmental problems. Some examples in

European and American countries exist, but still in the majority of countries an appropriate infrastructure responsible for the formulation and implementation of environmental policy and services is nonexistent. In countries just beginning their phase of development this infrastructure is crucial.

I am as optimistic as my predecessors, but my optimism is based on science. It rests on beneficial allocation of scientific research by governments. It rests on the creation of social opinion in favor of financial guarantees for a comprehensive network of monitoring stations research, modeling, and deliberation of a program of practical action. If social factors will be improved, if national intellectual forces will be created in developing countries, if the principle of equality and democracy will be really factual, I think the task of creation of the noosphere and the task of preventing disaster and the task of guiding and ruling the environment will be solved.

Thank you.

A PROSPECTIVE LOOK AT SCIENCE, TECHNOLOGY AND SOCIETY

THE BELLAGIO REPORT

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In the previous papers, you have seen the ghost of technology past and technology present. Now we visit the ghost of technology future. Let us hope it turns out as well as it did in the Dickens' story. The analogy is a little forced, but people do associate with technology some Scrooge-like properties: insensitivity to human values, greedy consumption of resources and creating wealth for some, leaving others in poverty. Scrooge's deceased partner, Marley, showed him how hiw power and wealth might be better used. We want to share with you a similar vision.

I do not want to press the analogy too far -- for although science is appropriately technology's partner and in the future science must increasingly illuminate decisions on uses of technology, I do not want to admit that science is dead, or must die, as a result of its emerging role in societal decision-making.

I would ask you to think this afternoon about three questions which call for serious thought and action:

(1) Do science and the technologies it gives us offer a realistic hope for a better future for humankind?

(2) If so, what are the key challenges that science and technology must meet? What factors will determine whether or not scientists and engineers are able to make the positive contribution that is required of them?

(3) Finally, can these commitments be fulfilled in a manner consistent with the further development of science itself? Are conditions for science and these expectations from science mutually exclusive?

Indeed the capability of science and technology to meet human needs may be limited by the threat -- both real and perceived -- to the integrity and further progress of science as we know it that this involvement implies.

Let me summarize by saying that we answer the first question with guarded optimism. While we believe the hope is realistic, we have no illusions about the likelihood of rapid changes in human values or political institutions. Some countries will certainly cope with adversity and opportunity more creatively than others, and the determinants of their success may relate only weakly to their wealth, size, technical sophistication, or even political system. In particular, we do not see any shortcut to the replacement of the narrow, selfish, and short-term view associated with excesses of nationalism by a more global, long-range view associated with the pooling of sovereignty into an effectively self-governing world society. But within the constraints of the world, more or less as it is, we perceive additional effort in science and technology as not only useful but essential for meeting human needs - for food, energy, materials and health. We recognize that the benefits of technology will not flow without strenuous effort and at the same time we do not consider technology to be an unmitigated blessing.

We do not see any obstacles <u>in nature</u> that will prevent the attainment of reasonable goals for the future; we see no scientific "show stoppers."

Our report concerns itself primarily with the new circumstances that will most likely determine whether scientific and technical efforts can or will be effective in providing humankind with options for solving its more serious problems.

We will illustrate our concerns this afternoon by reference to three pairs of problems: food and population, climate and environment, materials and energy, and with an underlying common denominator -- the role of technology as a source of productivity and economic development.

Most of what we have to say can be drawn down to two quite general assertions:

(1) Many uses of science and technology that contribute to short-term benefits do so at the expense of the future resiliency of human society and of nature. A glaring example is the nuclear arms race, which threatens to spread from a bilateral to a global threat of catastrophe. The very idea of reliance on mutually assured destruction as a means for producing military stability in the short-term is a threat to the resiliency of human society.

Other examples such as those involving the interrelationship of agriculture and climate equally challenge society's ability to manage risk. Risk is aggregated so many suffer a little rather than an unfortunate few suffering a lot. Often it is done in a manner that threatens the future ability of societies to adjust to unforeseen events that jeopardize the viability of complex human arrangements. The very necessity of relying more heavily on science and technology itself represents an aggregation of risk to the extent that the technological systems on which humankind depends for basic necessities become more vulnerable to inadequacies in the social, political, or economic fabric of world society. A brighter future for all humankind is a Faustian bargain and we must not forget it.

This brings me to our second concern, the decision-making structure at the local, national, and, most importantly, the international level. Threats to resiliency need not be doomsday weapons; there are sensible and prudent ways to go about gathering the facts and making decisions about technology strategies. But we clearly must achieve a more future-oriented decision making structure which at the same time is more self-correcting in its development over time. If I can be pardoned a personal view of the efficacy of different political systems, there is much to be said for the long-range planning approach and for the pragmatic, day-by-day approach if they are properly combined with one another. Farsightedness and flexibility are the keys.

Central to a better decision process is the management of risk and uncertainty in terms that permit public decisions that will carry popular support. The public must understand the alternatives before it is asked to forego a near-term benefit in the quest for a viable situation for their children. In the past the scientific community has sometimes taken an elitist view of its role, and not without justification as the anthropologist in our conference will tell you. They have -- should I say -- we have responded to the opportunity and obligation to advise the leaders of government and industry about technical matters that have important bearing on the future. This must continue, but it is not enough. We must share with the world public our views of how a better world can be achieved -- not because the public should appreciate science -- but because public perceptions will limit the ability of leaders to employ the tools that science and technology can contribute. This public tends to be skeptical and conservative on this matter, and I for one, welcome this view, for I think a cautious attitude is consistent with a proper instinct for survival.

It may not be the task of science to save the world. As Dr. Handler said on Sunday, saving the world is not a task that scientists are qualified to accomplish in any case. But that does not mean that scientists and engineers do not have a serious duty to their fellow humans to live their lives in such a way that they leave the world a better place than they found it. It is our assertion that the opportunities to do this are growing and are increasingly compelling. In the process of responding, scientists will find that the neat distinctions we like to make between applied and pure science, engineering, medicine, and the like will increasingly give way to a distinction between those who are part of the problem and those who are a part of the solution. Our challenge to ICSU is to insure that viewed over the perspective of decades and centuries, the world scientific community is judged by history to be squarely in the second category.

ROLE OF THE SCIENTIFIC COMMUNITY

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Our message is basically an optimistic one, or perhaps I should say one of optimism about our potential for dealing with the problems that face us. Our present situation justifies neither complacency nor despair. But what we do believe is that scientific and technological progress can place in our hands the tools for a far better human future. For the first time in man's history we can see that world development does not have to be a zero-sum game, a game in which one group's gain is another's loss. We are entering the era of a truly global society, in which the incentives for mutuality and cooperation should far outweigh the incentives for competition and unilateral advantage of one human subgroup at the expense of others.

Scientists and engineers are not passive technicians, providing tools for the achievement of goals set by others. For much of the twentieth century they have been the initiators of social change, and the creators of new social institutions -- whether for good or ill, whether consciously, as in the role of scientists in World War II, or unconsciously and indirectly, as in the computer and communications revolution of recent times, and the revolution of rising expectations which in many ways is the most important product of this revolution. It is no accident that Harvard's chemist President, James Bryant Conant, subtitled his autobiography, "Memoirs of a Social Inventor."

The difficulty, of course, is that science and technology, like every other human construct, are mixed blessings. We have to learn how to avoid the twin pitfalls of, on the one hand, excessive optimism and exaggerated claims for our favorite intellectual tools, and on the other, of prophecies of doom and warnings of apocalypse if the rest of humanity does not heed our advice and mend its profligate ways. Indeed both the technological optimists and the technological pessimists are guilty of different forms of intellectual hubris.

In the Bellagio paper we list seven conclusions or pieces of advice to the international technical community. They are most easily characterized by single words as follows: diversity, anticipation, communication, rigor, diffusion, cooperation, responsibility. Let me consider each in turn.

Diversity. This means we must avoid the temptation to buy final technical solutions to problems, and keep open a greater variety of options for longer than has been customary in the past. A good recent example is our wholesale adoption of chemical pesticides following the discovery of DDT during World War II. It is not that they were inherently bad, but that we in effect phased out many of the operational skills and almost all of the research which could have led to a more balanced approach to pest control, while we embraced the new technology with uncritical enthusiasm. Even in the case of malaria control, I was recently interested in hearing public health experts complain that the effect of the introduction of DDT had been to denigrate other relevant skills and experience in the control of insect borne diseases.

In energy it is estimated that during the next 30 years the U.S. alone will have to invest something like a trillion (10^{12}) dollars in energy systems -- a combination of new supplies and more energy efficient utilization technologies. By contrast the development and technical demonstration of a single supply option might cost between 20 and 40 billions (10^9), or of a suboption within a principal type of option 1-2 billions. This is well under 5% of the ultimate investment required. We certainly should be able to afford the R & D investment to keep more than one option open; in fact, we can scarcely afford not to.

Recently I introduced the concept of a "technological monoculture", the tendency of a new and apparently successful technological option to drive out alternatives. This was obviously true in the case of chemical pesticides. To a large extent, it has been true of the automobile and the airplane. It was true of the dependence of the industrialized world on cheap petroleum, the most convenient but least abundant primary energy source. The last quarter century has taught us something of the high price that can be exacted by overdependence on a single technological alternative. Thus our future strategy, both for the industrialized world and for development in the poor countries, should give greater attention to a diversity of options.

Anticipation. How do we introduce new technologies and anticipate the problems down the road which may result from their large scale deployment? Here we must steer a difficult course between the Scylla of overassessment at a premature stage, and underassessment which leads to painting ourselves into a technological corner. It is unrealistic to expect a completely certain assessment of all aspects of a new technology before there is substantial design and operating experience accumulated in the course of its deployment. Yet we must not rush blindly into a major commitment without a major effort to narrow the uncertainties, especially with respect to secondary and unintended consequences. The technical community must be deeply involved in the early warning function, more so than in the past. But we must recognize that technology assessment is an evolutionary learning process, not a once-and-for-all decision. By the same token the evolutionary nature of technology assessment provides an additional argument for the maintenance of a diversity of options, for a valid technology assessment requires comparisons among several alternatives, and we must know enough about the alternatives for this comparison to be reasonably soundly based. Otherwise we may simply jump from the technology we know, whose problems are well identified, to some other technology that looks superficially more attractive simply because we have not investigated it well enough to be aware of all its potential problems.

Communication. This topic includes communication between scientists and the public, and between specialists and generalist decision makers. Such communication must become much more a recognized function of the technical community. It must also become truly a two-way process. Scientists are often excessively naive when dealing with the political process. If society would only behave according to our rational and eminently logical prescriptions its problems could be solved so easily. However, "society" consists of multiple intereacting and partially conflicting interests; it is not an engineering system which can be "optimized" with respect to any single "objective function." The socio-political interface of science and technology requires a social learning process which is not unlike the progress of science itself. There is a great need for institutional settings in which this learning process can occur more continuously and with greater organizational memory than has been true in the past. Ironically enough such a socio-political interface with science has occurred systematically only in the military sphere where it has been highly successful in relation to its defined purposes -- only too successful in the minds of many. The Consultative Group on International Agricultural Research (CGIAR) may be an example of a similar successful pattern in the field of world agricultural development, but it would certainly be premature to proclaim its success.

In any case, one generalization can be made: skill in interpreting scientific and technical considerations to a broad public outside of science will command much greater recognition and reward in the scientific community in the future than in the past if science is to make its potential contribution to solution of the world's problems.

Rigor. The communication of science with the socio-political process is inevitably interdisciplinary, since it is social problem oriented rather than scientific problem oriented. The problem of communication is the difficulty of getting public attention and the attention of decision makers without sacrificing the intellectual standards that are so important to the future health of science and technology. This is especially so since the public policy arena we are almost always in a situation where technical evidence is incomplete and ambiguous, and yet where some kind of action may have to be taken. This provides an ideal setting for the proposal of oversimplified solutions and for using the social authority of science to legitimize essentially political goals. The question of preserving intellectual standards in the present socio-political millieu of science is a new problem for the scientific community and one which will be the increasing topic of debate and soul searching both within the community and between the community and the larger society. There is no simple prescription or code of ethics which can be formalized to govern the interaction between scientists and politicians, and yet the need for self-discipline and self-restraint on both sides of this interaction is only too apparent.

Diffusion. There is a need for the diffusion of scientific and technological skills much more widely in the world, and indeed, within our own societies. Whether we are talking about science and technology for development in the LDC's or about the use of technology to improve the management of our cities, we have learned that it is not enough simply to transfer technology packages. The recipients of technology must be in a position to choose wisely, and usually to adapt the technology which they receive to a particular end-use which only they understand, or which fits their own social and political realities. Thus technology transfer is a two-way process, an iterative dialogue between the needs of the recipient and the technical opportunities at the disposal of the supplier. Only when the supplier and the recipient are in a position to learn from each other on a more or less equal basis will technology transfer be truly successful. Here again the model of the CGIAR and our own agricultural extension programs may be suggestive. The other important point is that in the diffusion of technology more than mere communication is involved; over and over again studies have shown that technology moves most successfully when it moves inside people.

Cooperation. Most of us are dimly aware that science and technology have made nationalism and national sovereignty obsolete, and yet we cannot abolish these institutions and attitudes overnight. Indeed, sovereignty and autonomy are at issue even inside each of the national societies of the developed countries in their management of technology. In the international sphere, we face a long hard row to hoe of institution building and adaptation. Most of this has to be achieved by negotiation and by cooperation among equals because that is the reality of our world. In the kind of interdependence which science and technology have created, the mutual advantage to be gained from cooperation far exceeds the unilateral gain to be achieved at the expense of others. The problem is that the gain from mutuality and cooperation tends to be a much longer term advantage than the gain from unilateral action. Thus the whole question of cooperation ties in very closely with the issue of resiliency versus stability, which is a theme of the Bellagio paper. National sovereignty and advantage appears to enhance stability, but only cooperation can achieve resiliency.

In the area of transnational institutions and international cooperation, I believe it is scientists who are going to have to take much of the initiative in institution building, in cooperation with others, much as they have in the last quarter century within their own national societies.

Responsibility. In carrying out the agenda we have outlined, ICSU is faced with a difficult dilemma. One of the biggest contributions of science to international relations has been its use as a neutral form which can bridge national boundaries and differences in culture and socio-political systems. It has often achieved this by sticking rather strictly to scientific problems, i.e. problems defined internally by science. On the other hand, the more leadership that ICSU and other international scientific bodies try to exert in helping science to contribute to the solution of the great problems facing the world in the next half century, the more it is likely to find itself involved with the divisive political and distributional issues of our time. So there is a conflict inherent in ICSU's communications role and its potential contribution to the constructive use of science in the world. How ICSU succeeds in resolving this dilemma will determine its influence and importance in the future, but it is the thesis of the Bellagio Conference that it cannot resolve it by ignoring it.

THE BELLAGIO REPORT - A RESPONSE

John H. Knowles
President
The Rockefeller Foundation
New York, New York

I would make the rather abrupt statement that we have enough knowledge and technology at the present time to improve markedly the quality of life by controlling the inexorable expansion of population, improving nutrition, decreasing fertility rates, and bringing equity to the 4 billion people of the world IF we only had more knowledge about human needs and human behavior from cultural anthropology, sociology, political science, government and economics. That is not to say that the acquisition of that knowledge will result in a sudden purification of human behavior. Let us remember that he who hates sin hates humanity. After all, bizarre and frequently irrational behavior is what makes life interesting.

Now, having opened up with that, there was something about the Branscomb presentation that disturbed me. We all say that we are basically optimistic, and that we are serious and not pessimistic. I agree, but I think that a sense of urgency was lacking in his paper. The time frame has constricted itself markedly in recent times. It is only in the last ten years, really, that the average person in the street, or indeed even the highly educated person here or abroad or any place in the world, has come to know the words "population," "Malthus," "geometric expansion versus arithmetic," the problems of food and nutrition, of health globally and nationally. We have found suddenly that there will be one future for the world. There will be no two futures. There will be one, or none at all. And the turbulence increases as we enter the last quarter of this century. We face the most complex global issues in the history of man -- or woman. We face the problems of money, markets and inflation; defense, deterrents and detente; resources, raw materials and energy; pollution, ecology, weather modification; population and urban congestion -- Mexico City, Ibadan, the great cities of the world are growing at 10, 15, 20 per cent a year! far outstripping any other growth of any part of the world; inequality, unemployment, and increasing disparities in the distribution of income and wealth;

famine prevention, poverty, food production; genocide, discriminatory violence, human degradation; drugs and terrorism; and finally, nuclear power, the oceans, and outer space. The eight-year-old son of one of the vice presidents of The Rockefeller Foundation woke up this morning, broke into tears because he was worried about "nuclear bombs." Now he may have been scared about something else, but nonetheless nuclear bombs were on his mind. The world's annual arms expenditure is now at a level of greater than $250 billion a year; whereas all the money that goes to the less developed countries of the world for economic development and the melioration of human misery is around $15 billion. And with the inflationary trebling of oil prices and food prices in the last three to four years, it is my understanding that inflation has soaked up about half of the annual expenditures that go to stimulate food production, population controls, development of educational institutions, and so on.

We have learned in recent times that humanitarianism is fine in the short run, but can be oppressively bad in the long run. Some of our politicians in the United States have yet to learn this. It is all very well and good under PL-480 to send food supplies endlessly to less developed countries. But just like the family, and dependent children, the will to develop one's own independence simply is not given the chance to flower. Don't throw a man a fish; teach him to fish! The whole business of transferring technologies remains a very difficult subject. Many of our efforts in the Rockefeller Foundation today are to try to develop labor intensive technologies which will reduce urban migration and help keep the major part of the world's population, which is still rural, in rural areas.

When I was in England about 15 years ago, a friend of mine, knowing that I am a bibliophile, gave me a book by Aldous Huxley called <u>The Humanist Frame</u>. It is a fine collection of essays and brings humanistic scholarship together with hard science and, as you say, soft science. It was Huxley's contention in his lead essay that the world had evolved to a wonderful degree of scientific and technical capacity, but the evolution of human institutions and social and political and economic arrangements was just beginning. And he was optimistic, with the feeling that the next major advances in the world will and in fact <u>have</u> to come from social, economic and political re-arrangements. As this occurs, there is no reason necessarily to staunch the flow of hard scientific knowledge. Now when I use the word science, I don't think just of biology.

I think of the true meaning of the word and that is knowledge. And I think we have just barely scratched the surface in terms of the social and behavioral sciences, while hard science and technological developments have proceeded in an accelerating fashion. Bertrand Russell noted that as scientific and technical skill increase, wisdom tends to fade!

There is a certain anti-intellectual and anti-science tone that besets the United States periodically; the Good Lord knows it came back into office during the late 1960's and early 1970's. It was not the first time in the history of the country. People began to be disenchanted and disaffected with science and technology. They didn't see how it finally came to benefit them as individuals or they chose to forget how their lives had been improved. Problems of equity, cost, and quality came to the fore. Those of us who study the subject know that science and technology have done much to narrow the gaps between the haves and have-nots. As we all know, science and technological developments have caused lots of problems, but ignorance has and always will cause many more. And we seem now to be in a race between technological fixes and more and more attention and more and more social pressures to learn more about social, political and economic arrangements. It is only in the last ten years, as far as I can tell, that the world has developed international institutions, whether they be the World Bank, the Inter-American Bank, the multiplicity of United Nations' organizations, or the transnational and truly global free-standing associations of well-intentioned, knowledgeable people. Certainly the International Council of Scientific Unions is one fine example. Another is the International Institute of Applied Systems Analysis, which gets many people from different cultures to share scientific programs. I also have to say that when I was in China for four weeks, the people I felt most comfortable with, and the people who were most open and friendly, happened to be the scientists, whether they were biologists, botanists, or physicists. There was a much freer interchange through the common language and interests of science and technology, which transcends ideological barriers, and I still am of the carefully considered opinion that these aggregates of international scientists of good will and knowledge can do much to transcend ideological barriers and to stem the rising tide of destructive conflict.

The reason I feel we need more urgency and more sophistication on this subject is that if you list the number of wars that have broken out, and the number of people killed or injured in these wars over the past 35 years, there is scarcely cause for optimism. If you then look at the population figures, and reckon with the stark reality of doubling times and geometric expansion of numbers, and then couple this with the marked instability of governments, you have to be worried! If one looks at the question of energy, human energy in the form of food, industrial and agricultural energy in the form of oil, fertilizer and water and the subjects that we heard discussed here, you have to be very concerned. And yet we in Western civilization, no matter what, still enjoy and worship at the altar of the metaphor of progress through inexorable growth. We are just beginning to deal with that subject in the United States. It is complex and the report doesn't really deal with it thoroughly or with a sense or urgency.

The interdependency of ecological variables is interesting and complex. We know that as agricultural systems develop (it was interesting to me that in China 30 per cent of the land is irrigated; in the United States, the amount of agricultural land irrigated is only 10 per cent) we also spread disease through the replacement of human settlements to areas of endemic disease previously uninhabited or sparsely inhabited, and through the spread of vectors. Increasing vigilance and anticipatory planning must be developed to insure that the technological solution does not create a problem greater than the ones solved. We have not been in the habit in the United States, or as far as I can tell, in almost any country of the world, of trying to anticipate the social and economic and cultural effects of the introduction of new technologies. Now I say that with great feeling, having spent a large part of my life pursuing one of the prime examples of technological development in the United States - medicine. We had the tools to detect sickle cell anemia. So we went around and detected it, without the faintest notion of what we were going to do after we detected it! That led to a great rash of literature, and kept a number of social and behavioral and political scientists busy for the next year or two, telling us what we should have done before we introduced that particular technology. In medicine in the United States, we are loaded with halfway technologies such as renal dialysis, and divert more and more of our attention to the technological fix, life at any cost, any solution, even halfway, no matter what it costs; as contrasted with putting more effort into fundamental knowledge, or at least trying to anticipate, in this case, the medical, ethical, social, economic and cultural effects of the introduction of a new technology.

The ethical questions and moral imperatives and dilemmas they create now occupy many of us and have resulted in one of the most rapidly expanding fields of new knowledge in the United States, as complex as the issues are. In order for decision makers to make decisions, they have to have scientifically and technically valid information. They also have to have some frame of reference to the culture, and some knowledge of the social and economic costs to a country, as contrasted with the benefits, <u>before</u> technologies and the changes they produce are introduced.

I would like to comment on the general degeneration of clarity of thought as manifested by the spoken as well as the written word. If one cannot say what he thinks, or understand what he hears, and allows the language to degenerate (and this certainly is true of scientists and technologists, who use so much jargon and so many code words that they are virtually unintelligible to other educated people), then I fear me for the political process and the rapid evolution of sound rational public policy. Simplify your language. The highest power of the intellect is exercised when the expert conveys understanding to the non-expert.

As you pointed out, the per capita protein consumption over about the last twenty years kept pace with the expansion of population, largely due to the Green Revolution, including the development of strains of grain like the big, bushy-headed wheat with the thick stalk that wouldn't lodge when it rained or blew, and which is dependent on great quantities of water and nitrogen. Even though the Green Revolution started in Mexico, today the corn productivity per hectare there is still one-quarter of what it is in the United States. Norman Borlaug of our staff got the Nobel Peace Price because clearly, if food could be grown and distributed equitably to the world's population, one of the major causes for conflict would certainly be reduced. But also, as the report notes, if the population expands from 4 to 8 billion people, and over 6 billion are in the less developed countries of the world, leaving 1.7 or 2 billion in the developed countries, we are in an almost impossible race. Over the last thirty years, only Canada and the United States remain the major food exporters, whereas twenty to thirty years ago many European countries were exporters. Argentina and Australia are marginal exporters. And with estimates of up to 500 million starving, malnourished people now in the world and with the population expanding as it is, we will need at least a four per cent increase in food production annually and indefinitely in order to not only keep pace with the skyrocketing population, but to actually improve the nutrition of the people around the world. And the FAO estimates that we will need a 270 per cent increase in water supplies. Roger Revelle wrote a very interesting position paper stating that if the arable lands were fully utilized, the world could support as many as 40 billion people. And I think that's fair enough, Roger, because in my travels around the world I began to understand what you meant. If we had the political will, the social and institutional arrangements, and the necessary inputs -- and potentially we do -- we could do these things. I think that is an optimistic note, and should charge us on urgently to do these things.

You mentioned that list of ten or twelve countries in the demographic transition where increasing standards of living, in fact, seem to result in reduction of fertility rates. However, even in the United States, when we approach a growth rate of 0.8 per cent and the fertility rate is at replacement level, we will add 70 million people over the next 60 years. I say that only to make a point. Don't think that when you get to replacement levels that you don't still have that pig going through the python. And we are not anywhere near that when we talk about growth rates in the less developed countries of 2.5 per cent.

Finally, let me say that in the Rockefeller Foundation we have elected to focus most of our efforts on the problems of food production, population controls, and health and education in the less developed countries. In addition we have focused on the reduction of conflict through everything from fellowships to the support of new or existing international institutions whose job it is to study the complexities and anticipate needed change to bring about a better world. And we do this through trying to integrate the interests in our various disciplinary divisions of agriculture and the health sciences, natural and environmental sciences, social sciences, and the arts and humanities -- which play a very important part. May I say, we have had more meetings on the transnational issues surrounding humanistic concern, the humanities and social sciences at Bellagio than we have on directly scientific and technical subjects. We do not think they are antagonistic in any way; but we think it is time to get rid of the two-culture approach to the world's problems. The gap between scientific and humanistic concern must be narrowed, and it can be with the help of the social and behavioral sciences.

APPENDIX A

STEERING COMMITTEE FOR THE SYMPOSIUM

Chairman: Thomas F. Malone, Director
Holcomb Research Institute
Butler University

Lewis M. Branscomb	Vice President and Chief Scientist, IBM Corporation
Harvey Brooks	Dean, Division of Engineering and Applied Physics, Harvard University
Donald G. Fink	Executive Consultant, Institute of Electrical and Electronics Engineers Inc.
George S. Hammond	Foreign Secretary, National Academy of Sciences, Merrill College, University of California at Santa Cruz
Franklin A. Long	Director, Program on Science, Society and Technology, Cornell University
Gordon J. F. MacDonald	Chairman, Commission on Natural Resources, National Research Council
Gustav Ranis	Professor of Economics, Economic Growth Center, Yale University
Walter A. Rosenblith	Provost, Massachusetts Institute of Technology
Gilbert F. White	Director, Institute of Behavioral Sciences, University of Colorado

Staff Officer
for
Symposium: William Beranek, Jr., Research Fellow
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Indianapolis, Indiana 46208 Telephone: 317/283/9551

APPENDIX B

Participants in the Historical Role of Science and Technology in Economic Growth

Chairman:	Gustav Ranis Professor of Economics Economic Growth Center Yale University	
Authors:	Brazil	
	Jose Pastore	Professor, Institute of Economic Research, University of Sao Paulo
	Ghana	
	Edward Ayensu	Chairman, Department of Botany, Smithsonian Institute
	Great Britain	
	D. S. L. Cardwell	Professor, Institute of Technology, University of Manchester
	Hungary	
	Peter Vas-Zolton	Institute for Science Organization, Hungarian Academy of Sciences
	Lajos Szanto	Director, Institute for Science Organization, Hungarian Academy of Sciences
	Japan	
	Shigeru Nakayama	Professor, Department of History, University of Tokyo
	United States	
	Nathan Rosenberg	Department of Economics, Program of Values, Technology and Society, Stanford University
	West Germany	
	Wolfram Fischer	Department of History, Freie Universitat
Advisors:	Julian Engel	Deputy Director, Board on Science, Technology for International Development, National Academy of Sciences
	Melvin Kranzberg	Department of History of Science, Georgia Institute of Technology
	Richard Nelson	Department of Economics, Yale University
	Derek de Solla Price	Department of History of Science, Yale University
	Eugene Skolnikoff	Department of Political Science, Massachusetts Institute of Technology
	E. Nancy Stepan	Department of History of Science, University of Massachusetts

APPENDIX C

Participants in the Environmental Issues 1976

Chairman: Gilbert White, Director
Institute of Behavioral Sciences
University of Colorado

Ian Burton	International Development Research Center, University of Toronto Canada
Gordon C. Butler	Division of Biology, National Research Council of Canada, Canada
Francois Frenkiel	Naval Ship Research and Development Center, Computation and Mathematics Department
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Martin Holdgate	Director, The Institute of Terrestrial Ecology, United Kingdom
V. Landa	Czechoslavakia Academy, Ced., Narodini, Tr. 3, Czechoslavakia
Akin Mabogunje	Department of Geography, University of Ibadan, Nigeria
R. E. Munn	Atmospheric Environment Service, Canada
Ralph O. Slayter	Department of Environmental Biology, Australian National University, Australia
Victor A. Kovda	President of SCOPE, Moscow State University, Faculty of Social Science, U.S.S.R.
M. Kassas	Vice President of SCOPE, Arab League of Education, Cultural and Scientific Organization, Egypt
Thomas F. Malone	Secretary of SCOPE, Holcomb Research Institute, Butler University

Participants in the Prospective Look at Science, Technology and Society - The Bellagio Report

Chairman: Lewis M. Branscomb
Chief Scientist & Vice President
IBM Corporation

William Beranek, Jr.	Holcomb Research Institute Butler University
Harvey Brooks	Division of Engineering and Applied Sciences, Harvard University
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Wolf Haefele	Deputy Director, International Institute for Applied Systems Analysis, Austria
N. Bruce Hannay	Vice President, Research & Patents Bell Laboratories
Gunnar Hambraeus	Director, Royal Swedish Academy of Engineering Sciences, Sweden
Yoichi Kaya	Engineering Research Institute, University of Tokyo, Japan
Thomas F. Malone	Director, Holcomb Research Institute Butler University
H. Charles Pereira	Ministry of Agriculture, Fisheries and Food, Great Britain
Eugene Pusic	University of Zagreb, Yugoslavia
Moeen A. Qureshi	Vice President, International Finance Corporation
Roger Revelle	School of Public Health, Harvard University
Stephen Schneider	National Center for Atmospheric Research
Herbert F. York	University of California at San Diego

APPENDIX E

SCIENCE, TECHNOLOGY, AND SOCIETY
-- A PROSPECTIVE LOOK --

Summary and Conclusions of

THE BELLAGIO CONFERENCE

Organized by the

U.S. NATIONAL ACADEMY OF SCIENCES

June 20 -- 27, 1976

Bellagio, Italy

PREFACE

On June 20, 1976, seventeen scientists convened at the Rockefeller Study and Conference Center in Bellagio, Italy, under the chairmanship of Dr. Lewis Branscomb, to discuss the role that science and technology could play to help solve some of the major world problems. The seventeen scientists came from eight countries around the world, and represented not only an unusually wide range of expertise in physical, mathematical, and social sciences, but also deep personal involvement in the study of societal problems.

The Bellagio conference was one of a series of scientific gatherings preliminary to a symposium of the U.S. National Academy of Sciences to be held in October 1976, in conjunction with the general assembly of the International Council of Scientific Unions. This symposium is in three parts, with the general theme; "Science: a Resource for Humankind". The first part consists of a retrospective examination of the role of science and technology in the social and economical development of seven selected countries. The second part deals with the adequacy of our knowledge base for the successful worldwide management of the quality of the human environment and our natural resources. The third topic is a prospective examination of the role of science and technology in addressing world problems for the next 25 years.

No one doubts the pervasive interactions of science and technology with society, although opinions differ as to the magnitude of good and evil that has come from these interactions. The U.S. National Academy of Sciences felt that in this Bicentennial year of the United States it was appropriate to take stock of the influence that science has had on our lives, and contemplate how best we can ensure that science can be an agent for future progress for all humankind. To the Bellagio participants fell the task of developing exactly this latter topic, the best deployment of science and technology in the service of humankind.

The Bellagio participants came to the conference with an open mind about the extent to which science and technology could or could not address societal problems. It may be argued that as scientists they were biased toward scientific activism. This, of course, cannot be denied. Neither can it be denied however, that many of the Bellagio participants have the best insight into the possible abuses of science and technology, and have even personally championed the prudent use of these tools rather than their deployment for their own sake.

I believe that the Bellagio message is at the same time an affirmation of faith in the fundamental goodness of humankind, and a sobering assessment of the dangers that must be avoided in order to attain a better future for everyone. It is also a moving appeal to all scientists to join forces with engineers, ordinary citizens, and decision makers, in order to address the world problems in a spirit of international cooperation.

It is with great honor and personal pleasure that I introduce the Bellagio call to action to the participants of the National Academy Symposium and the General Assembly of ICSU. It is my sincere hope that scientists worldwide will give it the attention it deserves.

I would like to thank Dr. Branscomb for his leadership in structuring and chairing this conference. I would also like to take this opportunity to express my deep appreciation to the management of the Rockefeller Foundation for offering their facilities to the U.S. National Academy of Sciences for this conference.

Thomas F. Malone
Chairman of the Steering Committee
NAS Bicentennial Symposium

FOREWORD

"Science, in its pure form, is not concerned with where discoveries may lead; its disciples are interested only in discovering the truth." This view, expressed in 1962 by Alan T. Waterman, Director of the U.S. National Science Foundation, is still held by many scientists. But others demand of science not only subjugation to social values but even pursuit of social goals that science alone cannot reach.

Those who appreciate the beauty and fascination of science are particularly eager to sustain the insulation of scientific activity from excessively utilitarian goals. This desire has been good for scientific progress -- some insulation is essential for the flowering of the most advanced and speculative investigations. Few people outside the scientific community realize what extraordinary scientific progress the last quarter century has produced under exactly this regime of relatively uncircumscribed exploration. The unlocking of the molecular basis for biology is as significant for understanding life processes as was the discovery of the atomic basis for the structure and behavior of inanimate matter. Dramatic discoveries are also being made in other fields such as cosmology, space exploration, high energy physics, and the earth sciences. We have no doubt that such fundamental discoveries viewed from the perspective of history will eventually be recognized as the most important contributions science can make for humanity. Thus, to be true to its own principles and promise, the world scientific community must sustain its commitment to the fullest possible understanding of man and nature.

This conclusion, however, in no way frees the scientist from an obligation to participate appropriately in the process through which this understanding is -- or should be -- applied. The popular view of this process is that science leads, in a more or less serial fashion, to technologies whose introduction is the agent of social change. But the relationship of scientific knowledge to technology is much more intimate than this concept suggests. Technology is as much an agent of scientific progress as science is a generator of new technological possibilities. The two progress in parallel. Moreover, scientific understanding can illuminate the utility, cost and consequences of technological change. This may be a contribution of science even more important than that as a source of technology.

The success with which human affairs are managed will therefore depend strongly on the involvement of scientists and engineers with the social and political institutions that determine the use of technology. We believe that the readiness, indeed eagerness of most scientists and engineers to meet this obligation is a basis of optimism for the future prospects for humanity.

Lewis M. Branscomb
Armonk, New York
October 1, 1976

I. INTRODUCTION

Do science and the technologies it gives us offer a realistic hope for a better future for humankind?

Yes, we are confident they do.

Humanity is, for the first time in its history, within reach of managing its fate toward a better life for all. This new condition has been reached through a period of two centuries of intensive applications of science and technology to the satisfaction of human wants. But the benefits of technology have not been shared equally by all nations. A thirst for these benefits is the focus of rising expectations for a better life in many parts of the world still in the grip of poverty and uncertainty about the future.

While much of the scientific knowledge, and many of the technological tools for improving living conditions worldwide are already available, political, economic, and social constraints often frustrate our efforts to apply them constructively. In addition, application of these tools on the large scale that is required poses a threat to the environment, which has been viewed with apprehension, and even pessimism, by many people, scientists and laymen alike. What makes this concern justifiable is not only the magnitude of human activity, which is beginning to compare with that of natural phenomena, but also the lack of full knowledge concerning it, and the fact that environmental impact often crosses national boundaries and must be dealt with in a spirit of cooperation among nations which we have not as yet achieved.

Nevertheless, we believe that science and technology need not be a menace, and can be a blessing in humanity's quest for a better future. We are also convinced that the outcome of this quest will not be determined by a single dramatic effort, or by any single institutional invention, but by the continuous, dedicated effort of people everywhere to use what is known and proven and to take proper account of uncertainty and risk for that which is not. As John von Neumann wrote* in 1955, the proper use of technology in the future depends on "a long sequence of small, correct decisions".

Thus, fulfillment of humanity's hope for a better future requires improved anticipation of long range problems so that they can be dealt with early rather than treated later by hasty repair. It requires increased vigilance to ensure that the technological solution does not create a problem greater than the ones it solves. It also requires the recognition by all that, while expanded scientific and technological input into many social decisions is crucial, it is often just one among many necessary components for these decisions.

Societal decisions involve scientific fact and understanding, but more and more people with varying access to such knowledge want to participate in decisions which affect them. If popular participation is not to lead to disaster, people must have a good understanding of what science has to say about changing global conditions. New knowledge must be disseminated in a form such that its relevance to the social choices which have to be made is as clear as possible. Clearly, the "small correct decisions", of nations as well as individuals, will produce the most constructive results if each decision-maker has the best scientific knowledge of the implications of his decisions, together with a wide selection of alternate technological options.

In the following pages we offer our thoughts on contributions that science and technology can make toward a better future for all. We make no assumptions about major changes in world institutions and attitudes, however much such changes might be welcome. We do see the need for scientists and technologists to rethink their roles and the roles of scientific institutions. We

*Can We Survive Technology? May 1955, FORTUNE Magazine.

think that their role is not only to contribute new knowledge, but also to participate in the creation, evaluation, and application of the right technologies for societal use. We regard the scientific and technological activities as an integral part of society, not the private preoccupation of a technological elite. Indeed, we regard these activities as but one of the major elements of the infrastructure of contemporary societies, embracing discoverers, designers, makers and deciders and, together with users, forming the family of man that shares a common destiny.

II. SOME MAJOR PROBLEMS AND POTENTIALS FOR SOLUTIONS

The world faces serious problems today, which require concerted effort by all nations for their solution. Much has been written about these problems, and the limitations within which solutions can be found. But the limitations are not those frequently assumed. Nature offers us many opportunities to readjust our technologies to solve problems. Nevertheless, some physical limitations, particularly those imposed by the ecological balance of which man is part, are real and must be respected.

We must learn to live with a naturally dynamic ecosystem and not make unreasonable demands for short term stability. Rather, those long term trends that are more likely to determine the survivability of human society must be identified and properly managed. In ecological terms, we urge that greater need be given to *resilience** rather than *stability*. How much freedom of action does this leave mankind? It will take a great deal of research and careful exploration of technologies to find out.

To illustrate the potential role of science and technology, we now discuss four of the major global problems for the next quarter century -- food, environment, natural resources, and arms control. These problems are not selected to set global priorities, but rather to discuss by example some opportunities for the scientific and technical communities, some constraints on their contributions, and some requirements for new decision-making structures.

* ***Resilience*** (after C. S. Holling) is the ability of a system to absorb, and even benefit by unexpected finite changes in system variables and parameters, without deteriorating irreversibly. In contrast, *stability* describes the ability of a system to absorb very small perturbations about a state of equilibrium.

In each case, we illustrate the need for resilience, the difficulty of accurate predictions, and the importance of social, political and economic factors. Showing through the discussion of each problem are reasons for our guarded optimism toward the future.

Food and Health

Providing the basic needs of the poor, even at the inadequate levels of today, will require much greater effort twenty-five years from now simply because there will be so many more people. The dramatic drop in the death rate in the poor countries since World War II, a result of the introduction of improved sanitation, public health care programs and, most importantly, improved nutrition, has not yet been followed by a corresponding drop in the birth rate (still at 40 per 1,000).

Consequently, while the rich countries are approaching population stability with a growth rate of 0.8% and a fertility rate corresponding to ultimate zero population growth, the poor countries are growing at an annual rate of 2.5%. About 80% of the world population growth is among the poor. In twenty-five years, the 2,800 million people in poor countries will have expanded to at least 4,800 million while the population of rich countries increases from 1,200 million to 1,700 million. To feed the world, the world food-grain production must increase from its present level of 1,200 million metric tons/year to about 2,000 million metric tons/year. If allowance is made for increased incomes resulting in increased meat consumption, or simply for a more nutritious diet for the poor, then the food grain production will have to reach about 3,000 million tons/year by the turn of the century.

Over the last tweny-five years, food-grain production has kept pace with the rising world population. There have been year-to-year fluctuations of course, but the maximum annual fluctuation from the mean never exceeded 60 million tons, about 5%.

This record of increasing food production has been due largely to continuous increases in the agricultural efficiency of the food exporting countries. Smaller increases must be expected in the future because the major inputs, the hybrid grains introduced in the 1930's, the fertilizers and the pesticides are all now approaching optimum general use. Furthermore, most of the high quality farmland is now in use. Yields will continue to increase in the food exporting countries, but logistic, economic and social effects combine to dictate that most of the doubling of food-grain production which will be needed in the next twenty-five years must be obtained from crops grown in the poor countries. It is of crucial importance that a global effort be made to apply and adapt the best existing agricultural science and technology to increase food production in the countries in which the major population increases will occur.

Let us take a closer look at the anatomy of the food problem.

A major factor in food production is the climate. Unfortunately, we can only predict weather about two days in advance. But we can also look at the past climatic record to determine what is "normal" behavior. This record seems to indicate that in recent years we have had unusually favorable climatic conditions for growing. Any return to normal conditions will be a turn for the worse.

Moreover, if an apparent long-term cycle continues we may be at the start of a period of especially bad growing conditions. The severe drought conditions around the world in the 1930's occurred at a similar point in this cycle. Perhaps the recent Sahelian and Ethiopian disasters were warnings. In any case, recent droughts have brought the world's cereal grain reserves to an uncomfortably low level.

If we could predict the climate several growing seasons in advance, it would greatly aid the choice of land use, of strain of crop planted, of fertilizer transportation networks, and of food storage plans. However, prospects for predicting even one season in advance are small, and certainly not realizable within a decade. In the absence of such predictive capability, systems must be designed to be able to produce food under greatly variable conditions. As a first step, international attention must be given to an analysis of the temporal and spatial variations of climate in relation to food production. We feel that clarification of the issues and alleviation of the hazards are well within the bounds of present and prospective technology.

But even without the unpredictable hazards of climatic changes, the fact of the expected geographical redistribution of the world's human population presents us with a grim handicap in the task of doubling the world's food production in the next twenty-five years. Two-thirds of the additional people will be born in countries which are not only the poorest but are also located in the Inter-Tropical Convergence Zone. Rainfall in that region has a seasonal instability far greater than that of the rest of the world. Thus we face an inescapable shift of human population distribution into the areas where, even without any adverse climatic change, crop failures are likely to be frequent.

The magnitude of the task of doubling food production in areas of subsistence agriculture under an unstable rainfall regime becomes more apparent when contrasted with the advantages which have enabled the food exporting countries of the temperate latitudes to achieve continuous increases in food production. These advantages have included a land tenure system which encourages innovation and investment; competent extension services conveying the use of improved crop varieties, hybrids, fertilizers and pesticides; an efficient distribution system stabilized by government price support and storage operations; development of new arable land; and half a century of favorable climate. This powerful productive system will provide yet larger crops, but there is no prospect of overcoming the financial, transport, and sociological difficulties of feeding the increasing tropical populations from the temperate zones.

Technology does provide means for improving agricultural production where it is needed. New high yielding tropical varieties, proven irrigation technologies, faster-growing crops which reduce weather hazards, and major yield responses to fertilizers are examples. The obstacles to their application are mainly political, social and economic. Until both the poor countries and the countries which provide aid give genuine top priority to developing rural areas and improving transport, water supply and amenities for the villages, it will be impossible to feed the growing population and we cannot foresee other than a food crisis of major proportions in many areas.

The continuing rapid population increase in the poor countries is a major handicap. Because of the current age distribution, a major increase in the world's population is inevitable for the remaining part of this century. In order to reach a long-term food-population balance it is critically important to create the policy and institutional framework necessary to contain the rate of population growth in poor countries. We do see hope for accomplishing this, from the following observation. In ten to twelve of the smaller developing countries, there has been a steady and pronounced decline in the birthrate, with a progresive slowdown in the rate of population growth. (Korea, Singapore, Taiwan, Sri Lanka, Mauritius, Hong Kong, Trinidad and Tobago, Costa Rica, Chile, Puerto Rico, and probably also Egypt, Tunisia and Guyana). These countries appear to have a number of characteristics in common -- a relatively high life expectancy and literacy rate, relatively high incomes, a fairly high status of women, a comparatively equitable income distribution, a good communication system, and a fairly effective family planning program. The case of Sri Lanka in this group is of particular interest because, despite a relatively low per-capita income, it shares in most of the other listed characteristics. The results achieved in these poor countries are persuasive evidence that the pursuit of appropriate economic and social policies, and not just programs of family planning, can make an effective contribution to reduction of population growth.

Since population stability and food self-sufficiency seem to be dependent on balanced social and economic development, access to scientific and technological skills in health care may be more than just a humane requirement. The well-being of people around the world is still strongly limited by sickness and poor nutrition. As many as half the people of the poor countries are sick much of the time. Proper nourishment would prevent much of this disease. The malnourished young children of the poor countries are much more vulnerable to childhood diseases than the children of the rich countries. Older children and adults suffer from bacterial and virus infections, from parasitic diseases, and from the effects of nutritional deficiency. These illnesses greatly lessen their ability to work, but also increase their physiological food requirements.

Considerable improvements in health and lowering of mortality could be accomplished with presently known techniques given the proper socioeconomic conditions. For example, trachoma could be reduced by increasing the quantity of domestic water supply available for washing and bathing in rural areas. Delivery of health services in the rural areas of poor countries would be greatly enhanced by a systems approach as well as by a more widespread appreciation of the problem.

It is clear from the above discussion that feeding and caring for the world's population is not a problem that either requires or can be solved solely by a dramatic new invention. It does call for some new scientific and technological development. But, even more importantly, it calls for concerted action by the technical community and the society at large to apply many available technological tools with the sense of urgency that the problem deserves.

Environment

Over the past decade, the danger of altering crucial natural cycles in the environment has been receiving increasing attention. This attention is motivated both by the advances in measurement technology and by the growing scale of human activities. Unfortunately, however, major decisions concerning the environment must still be made using best guesses based on only sketchy knowledge.

By and large, we lack the understanding necessary to estimate whether or not a given natural system is resilient, before the threshold is reached beyond which the system irreversibly deteriorates. On a regional level, there have been many instances in which this threshold has been passed. An example is *desertification* resulting from improper agricultural practices. On the other hand, there are also counter-examples in which removal of the stress allowed a return to an acceptable, if somewhat different, state.

In theory no environmental change is absolutely irreversible. The environment can be restored with sufficient effort, money, and technical skill. But in practice a distinction must be made between changes which are effectively irreversible and unacceptable, such as desertification, and those in which it is reasonable for society to weigh the benefits from a temporary environmental change against the cost of correcting for it or reversing it later. The 19th century economist, David Ricardo, viewed environment as a national capital and advocated caution against its destruction. One can make the valid argument that there are instances when this capital can be used to create new wealth, part of which can be subsequently used to restore the original environmental capital.

Irreversible, or possibly irreversible, perturbations are causes for great concern, particularly when they occur on a global scale. For example, concentrations of certain compounds related to human activity have increased noticeably above their natural levels in recent years. Nitrogen fertilizer manufacture, for instance, is beginning to compete in magnitude with global processes in fixing nitrogen. Its effect is in dispute, but what is not in dispute is the fact that we are altering the natural system in what *can* be an irreversible manner. A much better understanding of the dynamics of the natural system is needed to predict the effect of these perturbations.

Another example concerns the carbon dioxide concentration in the atmosphere, which has been steadily increasing in recent years, paralleling the increased combustion of fossil fuels. The implication of this increase for climatic modification is unknown, but a persuasive case can be made that it could become a major problem.

To wait for definitive detection of climatic effects before taking corrective action may be dangerous, particularly since man-made effects will be superposed on often longer natural fluctuations. Rather, such effects have to be anticipated on the basis of scientific understanding of underlying mechanisms. This in turn requires the development of refined models of the atmospheric system on which artificial perturbations can be tested. It was on the basis of such models, admittedly still crude, that the effects of fluorocarbons and SST exhaust on the ozone layer were estimated, though the precise magnitudes of the effects are still a matter of debate.

Meanwhile, technological options should be developed for correcting harmful consequences of environmental interventions. For example, should the increasing concentration of carbon dioxide be found to be a major problem, a contingency plan might be developed for carbon dioxide removal, or deep ocean disposal. Conversion to non-fossil energy sources such as breeder reactors or solar energy might be accelerated. In any case since CO_2 concentrations are globally dispersed, they must be controlled by global agreements which may involve significant compromises of national sovereignty.

The introduction into the environmental of synthetic compounds, while easier to monitor than the introduction of natural compounds, leads to effects just as difficult to predict. In this case the major concern is that of an unknown chemical reaction somewhere in the environment which could alter a natural system. The methylation of mercury is one example, fluorocarbons another.

Unfortunately, the work required to identify new reactions and establish their significance must often be done with minimal understanding of natural systems. Traditional scientific institutions are not very well equipped to deal with preliminary and tentative information regarding such reactions.Because of the interdisciplinary nature of the problem and the need for preliminary alerting of decision makers, the release of even tentative evidence and conclusions is desirable. Yet such release outside the self-correcting arena of the scientific communication system runs the risk of creating unnecessary economic dislocations and is often inconsistent with scientific rigor.

Complicating the search for compounds hazardous to humans and to natural systems is the fact that two or more may act synergistically -- that is, their combined effect when acting together is greater than the sum of their individual effects. For example, the carcinogenic effect of cigarette smoking and of airborn asbestos acting together is greater than might be expected from simply combining the carcinogenicity of the two. Such effects broaden the scope of risk assessment even further.

Even when a clear understanding of the hazard is available, a trade-off must often be made which involves economic, political and social considerations. Over the next twenty-five years, such decisions will increasingly have international implications, because of both the economic and the environmental interdependence of nations.

The role of the technical community is clear -- to monitor, to assess risk, to pursue leads energetically, to develop options for decision makers, to communicate new evidence and interpret its implications responsibly and with proper attention to uncertainties, so as to assist decision makers in arriving at the best possible anticipatory actions.

Materials Resources and Energy

Neither the basic needs of a growing population nor control of insults to our environment can be accomplished without an adequate supply of natural resources and energy for the future. There are serious questions about the adequacy of existing resources of raw materials and energy fuels. Such resources are, in fact, extensive but must be seen as functions of price, geological assurance, and environmental implications.

It is important to understand that because a shortage of a certain resource raises its price, great intensity may be brought to the search for a new source or a substitute. Thus, the adequacy of a resource is a function of the availability of technological alternatives. Sufficiently assured resources, with production costs below acceptable thresholds, are considered reserves. Figures for reserves, therefore, refer to a given economical and technological situation.

Thus, the recently popularized view of our habitat as "Spaceship Earth", with mankind steadily consuming a finite stock of resources, may be misleading . Very little is really lost from the earth; it is mostly put in less accessible form, from which it can eventually be recovered at a price, given the appropriate technology. Thus, the extent of raw materials resources effectively depends on the acceptability of higher prices or new technology to cover extraction, processing, substitution, and environmental impact. This is especially so when energy consumption for the production of such raw materials is not a constraint. Thus, *energy is very much the basic resource.*

For more than a century the situation in developed countries has been characterized by declining raw materials costs, in general, and declining energy fuel costs in particular. This has been due to a combination of technological advances and economies of scale. For example, since 1945 the cost of electricity has declined by more than a factor of 3 relative to the consumer price index, while the relative cost of a barrel of oil is less than half. The present talk of scarcity of raw materials and fossil fuels is made in reference to departures from this long-term declining trend. There is now general awareness that such a trend could not continue forever. We cannot escape an eventual exhaustion of cheap reserves in a few decades, at most fifty years. In particular, the inexpensive sources of oil and gas in the Middle East are probably a one time gift of nature. Future petroleum discoveries, if any, are likely to be off continental shelves in increasingly deep waters, in hostile areas such as the Canadian arctic, or in remote areas such as the interior of Siberia or China.

Oil and natural gas offer unique advantages for uses other than as fuel for electric power plants. Both serve as fuel for transportation vehicles. Oil is a feedstock for chemicals, especially plastics, and natural gas is especially useful in industrial processes requiring careful temperature control, and in the nitrogen-fixation process for fertilizer.. Thus, the future value of oil and gas as raw materials may be much higher than their current value as energy resources.

On a larger time scale of fifty to seventy-five years, several options exist for a very large, or even practically unlimited, supply of energy: nuclear fission with breeder technology, several alternative solar technologies, nuclear fusion, and coal with new technology. Since it is not obvious which of these options will be successful, it is imperative that a stockpile of energy technology options be developed. Any one of these options, or combinations, would allow the use of low-grade ores for the production of raw materials, but each is expensive. It is expensive first in a monetary sense, particularly in capital investment requirement which will probably be significantly higher than that for oil and gas. Each is also expensive in terms of societal and environmental impact. Moreover, very large uncertainties presently surround estimates of the magnitudes of costs and environmental risks.

Special care has to be taken in exercising any of the above options in order to minimize residual risks and impact on the environment. In particular, exercising the nuclear fission option on a global scale entails not only a potential environmental impact from possible accidents, but also the danger of proliferation of nuclear weapons. International cooperation in managing the production of nuclear fuel, and the disposal of nuclear wastes, is imperative in order to minimize this danger.

In any case, future systems for the production, handling, and use of energy, and the production of raw materials from low-grade ores, will require extensive changes of the existing infrastructure (transportation, storage, labor usage and industrial processes). Among the most important constraints for such an adaptation are the following:

- The requirement of gradual transition. (In the past, transition to a new fuel or raw material source has usually required 25-50 years.)

- Geographical distribution of facilities and other elements(which differ for each energy technology, and have implications for land use planning and power transmission facilities).

- Evolution of environmental and safety standards and regulations.

- Requirements for capital and skilled labor.

Energy conservation and materials recycling have to be part of both the new infrastructure, and a transition policy toward this infrastructure. Of course, energy conservation and materials recycling must be seen in the context of their economic implications; namely, conservation opportunities must be weighted against their capital, labor, and energy requirements. If it is indeed true that we face a rising cost trend for energy in the future, then the historical trade-off between investment in increased energy supply and investments in efficiency of energy end-use will change. With higher prices, and especially if environmental costs of new supply are fully internalized, the savings from a dollar investment in end-use efficiency may exceed the return from a dollar investment in energy supply. In other words, in a rising cost environment conservation will make more economic sense than increase in supplies, in many more instances than has been true in the past.

Since the cost of raw materials in usable form is closely tied to the price of energy, the economics of materials will also tend to shift in favor of materials recycling, materials thrift in design, and substitution of materials based on more abundant raw material sources. To the extent that materials recycling is both economically and technologically feasible, materials are a renewable resource. But products must be designed with ease of recycling in mind. To some degree, such recycling design will be market-driven in the coming years. To the degree that is it not, because of market imperfections, institutional arrangements must be made to ensure that it is given proper attention.

Science and technology can lessen the impact of materials shortages by increasing our options of substitution of one material, possibly a synthetic one, for another. This capability can reduce the requirements for stockpiling, and consequent depletion of world resources. On the other hand, international agreements may be required to prevent or correct disruptive effects of material substitutions. For example, a high commodity price may stimulate R & D leading to displacement of the expensive commodity, which in turn may have a serious effect on the economy of a country critically dependent on exports of that commodity. Ultimately, stability in prices and availability of resources will be best assured when the countries of origin share in the creation of the added value that contemporary technology brings to raw materials through manufactured products.

Arms Control and Nuclear Proliferation

One of the most ominous developments of the last thirty years is the worldwide technological arms race. The East-West component of this arms race has already led to the creation of both the hardware and the software for killing some five hundred million people, almost entirely from among the populations of the technologically most advanced countries, in less than one day. This component of the race seems to be past its most dynamic phase, and the prospect for marked changes in either direction are not great.Because of what is somewhat loosely called the "overkill" capacity of the nuclear weapons systems, neither fractional changes in numbers nor evolutionary changes in doctrine can really change the situation very much. In addition, at the moment there are in sight no qualitative developments which are likely to change the situation appreciably.

The North-South and intra-South components of the technological arms race are in their earliest stages, but all signs point toward rapid worsening of the situation.

Within the developing world, the dissemination of nuclear technology accompanying the spread of nuclear energy, is generating a new potential for the proliferation of nuclear weapons. This promises to have deep and not entirely foreseeable political consequences, including the risks of triggering a large-scale use of nuclear weapons.

The arms race, both conventional and nuclear, is obviously a major concern of mankind. The character and level of the threat from nuclear war to human survival is the direct result of the highly sophisticated technology involved. To produce this technology, many governments have engaged significant fractions of the scientific and technical capabilities of their countries. Thus, the role of science and engineering has not been a passive one in this instance, but rather a very leading one. It may even serve as a model of mobilization of technologists for the attainment of national or transnational goals of a more benevolent nature.

In all the nuclear weapons states, the designers and builders of these weapons built them in order to achieve a number of widely endorsed political objectives: getting them before some enemy did so; accelerating the end of a long and terrible war; or redressing the local or regional military balance. Certainly, some of these objectives were achieved. In the net, however, the result can be described as achieving stability in the short term at the risk of catastrophe in the long term. Indeed, a world with gigantic overkill in place is the ultimate example of the sacrifice of resilience to stability. If the deterrent should ever be used, civilization as we know it probably could not recover from the shock.

The main problems posed by the East-West arms race are the enormous potential for death and destruction inherent in the systems now in place and the bad example it sets for the rest of the world. Our efforts should, therefore, be directed towards preventing the use of these weapons in the short run, and eliminating them in the long run. This can probably best be done by insistently focusing attention on the dangers inherent in the present situation, and by promoting detente and all related policies toward increasing communications and relieving tensions. Mutual deterrence is probably not a viable posture for the world in the long term, and becomes less so as the deterrence becomes multilateral rather than bilateral.

The North-South and intra-South arms races pose a somewhat different problem. They consume human energies and physical resources badly needed elsewhere: they make nuclear war more likely simply by placing the power of decision in more hands; and they threaten in the long run to become one of the tools through which some of the have-nots may seek to acquire what they consider a just share of the world's goods. The efforts of the North, therefore, should be directed towards correcting the bad example these states currently provide, towards slowing the diffusion of the most dangerous elements of nuclear hardware and software, and towards providing assistance for meeting the critical needs of the South.

The issues related to arms control, disarmament, and the proliferation of nuclear weapons capability are not only of vital importance to the future of society but turn on the interplay between complex political issues and highly technical questions. Despite the security restrictions that conceal much of the information from public view, there are opportunities for scientists and engineers to inform themselves on the major issues, and participate in the search for progress in this field. Indeed, the technical and policy aspects of arms control are deserving of international research effort, in the same way such efforts are helpful in the solution of other major problems of society involving substantial technical questions with global applicability.

Notwithstanding any technical contributions to the resolution of the arms race problem, ultimately this resolution must be made in the political arena. In this respect, scientists and engineers can make two important contributions: they can increase the awareness of the disarmament issues by scientists all over the world; and they can strive to slow down the arms race, through involvement in the political process. The objective must be to slow down the current dangerous course to the point where the evolving political institutions of the world can cope with it.

Finally, it is clear from the rest of this report that the past and present products of science and technology will form an essential element of the means for meeting the critical needs of the world's people, especially those in the so-called *third* and *fourth worlds*. A larger part of the efforts of scientists and engineers generally must be devoted to meeting these needs. The main reason for doing so is simply because it is right; but an important secondary reason is to avoid the development of the kind of chaotic and rapacious world in which recourse to nuclear weapons may some day somewhere seem the only promising way to escape misery.

III. SOME BASIC REQUIREMENTS AND PERVASIVE CONSTRAINTS

The solution of the global problems we have discussed involves not only specific difficulties in each area, but also some general requirements and constraints. Prominent among them are: availability of capital; opportunities and difficulties in increasing productivity; equitable sharing of the fruits of productivity increases, reflected in the growing movement for improved *Quality of Work*; and cultural constraints. Let us consider them briefly in turn.

Capital Constraints

While it is possible to envision with some confidence that, within the next quarter century, scientific and technological approaches to the solution of the global problems discussed above will be well within reach, there is no doubt that massive new investment will be required to realize the benefits of technological advances, especially in the developing countries.

The issue of capital availability to meet these new challenges has a somewhat different connotation and significance in the industrialized societies as compared to developing societies. In the industrialized countries, with a gross domestic product of $3,000,000 million equivalent, and a current investment rate of as much as one-fifth of this gross domestic product, the main problem will be to create the necessary mechanism and financial incentives to mobilize and exploit the new, capital intensive, high technology areas. Without a deliberate and organized effort to create the necessary conditions for attracting resources into these areas, there is a serious danger that the financial marketplace will not adequately take into account the technological opportunities which are opening up, particularly in view of the time that is sometimes required before such opportunities can come to fruition.

The developing countries, with a population of close to three million, a gross domestic product of only about $600,000 million (excluding the oil producing countries), and domestic investments perhaps only about one tenth of their GDP, will have to continue to depend on a large and growing net transfer of capital from the industrialized countries. Currently, the total net capital flow from the industrialized to the developing countries is in the range of $30,000 million, which is 1% of the gross domestic product of the industrialized countries. The resolution of the food-population crisis, and the implementation in the developing countries of development programs in other important fields, such as materials and energy, will require a substantial increase in the present levels of this resource transfer to the developing world. However, we do not see these requirements as becoming a significant and unbearable burden on the present economic situation or prospects of the industrialized world. In addition, more effective application of science and technology toward better utilization of human and material resources in the developing countries should itself generate additional capital to sustain and strengthen the growth of the world economy as a whole.

Productivity and Economic Development

None of our hopes for mankind can be realized without continued economic development. Striving for the solution of world's problems will inevitably exert inflationary pressures worldwide. In order to raise the living standards of the developing nations without substantially reducing those of the developed ones, steady increases in capacity of existing capital, facilities, and human resources to satisfy the general needs of society must be made. We have specifically pointed out that the materials and energy needs of all nations can be met, but only with technological progress that will involve major investments. These costs must be offset as much as possible through efficiency improvements. For all these reasons research and development is needed to improve productivity.

In a capital-short world, the most powerful sources of productivity increases are new technologies, and the effective engagement of well trained people. Research, education and engineering are major sources of these productivity enhancing capabilities.

Productivity increases are most effectively achieved when an innovation produces a significant reduction in the materials, labor, or capital consumed to accomplish a given task. Whether or not such an innovation takes place depends particularly heavily on the rewards for successful innovations, and on the existing stock of basic and applied scientific knowledge. Such innovations often bring with them not only the potential to perform old jobs better and more efficiently, but totally new functions as well. This stimulation to the economy may of course be offset to some extent by costs associated with the requisite social change, or other indirect effects, all of which must be properly managed.

More frequently, productivity gains come about through incremental engineering improvements in efficiency, and in particular through reduction in cost or in materials consumption. In this way, tolerances and design margins are reduced and industrial efficiency is increased. Thus industrial societies deliberately strive to reduce margins as a reduction of waste. Obviously, this otherwise desirable strategy is increasingly vulnerable to unanticipated dislocations in the material supply and costs, or changes in the regulatory environment.

The present high productivity levels in the industrialized countries were achieved through a number of innovations in the production process, such as application of power sources, assembly line production process, component interchangeability, automation, etc. The potential of some of these techniques appears to be nearly exhausted. For example, little additional productivity can be expected from further application of power, or from piece parts assembly. On the other hand, we have just begun to realize the benefits from some other innovations, such as the use of computers for design automation, improved man-machine interaction, and process and assembly automation.

Thus, productivity increases are likely to continue in those industrial countries that are committed to continued investments in industrial R & D. One possible area of concern is the increase of productivity in parts of the service sector, which has generally lagged far behind that of the industrial sector. In this connection, the rapidly developing information technologies offer a major opportunity for substantial productivity improvements.

The situation is substantially different in the developing countries. There, productivity increases are urgently needed in all sectors of the economies, and they can be obtained either through application of available technologies, or through advanced technologies that are particularly appropriate for the local conditions and constraints (for example, solar energy technology for sun-drenched countries with inadequate distribution facilities). Since developing countries must avoid simple emulation of R & D activities of advanced countries, which are often unsuited to local needs and conditions and may absorb unwisely scarce scientific skills of the poor nations, special care is required for appropriate development of these indigenous technical capabilities. International groups such as CGIAR*, can play a very important role developing and adapting technology as needed to foster a rapid increase in the productivity of developing nations.

*Consultative Group for International Agricultural Research, an international but non-governmental organization for coordinating financial support and research strategy for a group of highly effective international research centers around the world.

Technology and Quality of Work

The benefits of increased productivity in industrialized countries, have been shared by capital, labor, and the consumer. In particular, work conditions in production have been improved, and the concept of *quality of work* has begun to emerge as a focus of attention by labor. To the extent that labor's desire for further improvements of the quality of work impacts the rate of productivity increase, it competes with other objectives of many countries. While today this is a subject of concern largely in the industrialized countries, it will undoubtedly become the concern of more and more countries, as they manage to satisfy the basic needs of their populations and their labor forces.

The thrust of the quality of work effort goes beyond mere increases of wages, or reduction of working time. Discussion of working time does not only involve the number of hours per week, but also paid vacation, gradual retirement (with pension), less shift work, flexible working hours in the day (or in the week or month), plus the right to take time off not only for reasons of health but also for personal business or family care.

In many countries, organizations of workers seek more active roles in decisions which impact the work environment, even to the planning of research and development. In this way they seek to internalize the benefits of the productivity contribution of R & D in order to improve the quality of their own lives. We must recognize that this very understandable desire exerts additional pressures on the need to steadily increase productivity and at the same time make the production process more congenial to workers.

Cultural Constraints

Fundamental to addressing all of the above issues are questions of human motivation and values. Scientists must, of course, avoid falling into the trap of imposing their own values on all those who are expected to benefit from scientific progress. Frustration of our hopes from science and technology may result from a failure to assess correctly the needs and aspirations of people. It may also result from tendencies of the scientific community to set themselves apart, and thus fail to communicate effectively their understanding of technical realities and possibilities.

In the context of the present discussion, the main goal we are addressing is to find a way for all countries to solve their collective and individual problems and share the benefits of the scientific and technological revolution in accordance with their own aspirations. People in industrialized countries are often, quite properly, concerned with the danger of upsetting the culture of a less developed country through introduction of modern technology. In this connection, however, they often show more concern than the countries in question themselves.

The technological revolution is a revolution in innovative power. Sharing in the technological revolution involves sharing in this power, which in turn requires a transfer of technology to less developed countries. But this transfer is not a simple matter of transfer of technological operations, or know-how. It is very difficult for a developing country to absorb any technology more complex than the level at which the country has the power to contribute to, as well as to scrutinize and control the innovative process. Simply stated, the level of technical literacy in the developing countries must be raised if they are to share in the fruits of the technological revolution.

More often than not, the technological revolution increases uncertainty, as each new stage perturbs existing knowledge, existing price structures and distribution of power, and as increased choices relieve the existing constraints on human unpredictability. Recognition that increasing uncertainty may accompany technological development should give the technologist a realistic perception of his role, and also help establish a rational public assessment of the power of technology.

The technological revolution means that a high price will increasingly be commanded by technological knowledge. Developing countries are well aware of the cost of knowledge, as they compare the prices of their raw materials with the prices of goods manufactured from them. The world will be knowledge intensive in specialized areas linked by the common language of mathematics. The trend in a knowledge intensive world is for the lay public to have more knowledge of science, while at the same time scientists have increasingly extensive knowledge of social, economic and political matters. In this world, scientists and engineers are likely to experience the problems and temptations of a priviledged (but not necessarily powerful) elite.

One major problem is that society in a knowledge intensive world often tends to become stratified and compartmentalized, making common understanding rather difficult. In such a situation, there may be a temptation for the scientists to draw a boundary around themselves limiting communication with outsiders. Thus, scientists run the danger of excluding exactly those people with whom they must share their knowledge if they are to make a contribution toward the solution of world's problems.

Perhaps it would be helpful for scientists and engineers to draw some lessons from a model of culture that applies to all societies. According to this model, an elite class generally supposes that the apparent irrationality of the surrounding population, its slowness to learn, or its lack of motivation are fixed either by innate capabilities or by a rigid cultural background. But neither theory can be justified. A good reason for rejecting such explanations is that they inhibit the search for variables relevant to the attainment of goals. The main message of contemporary anthropology on cultural constraints is that they are not rigid, but culture is more flexible than has been popularly supposed. Seemingly irrational behavior in decision making should not be dismissed as mystical, or primitive, or due to cultural bias, until a thorough examination of the cost structure involved in decision making, and the local distribution of power, have been made.

IV. CONCLUDING REMARKS

We have given a view of the world today -- its problems, and prospects for their solution -- from the perspective of concerned scientists. It is not a view of impending doom, but neither is it a view that justifies complacency or procrastination. Rather, it is a sobering view of a great challenge, together with an assertion that the world *can* reach the goal of a better life for all humankind, if it can charter a prudent course through troubled times, and if a lot of people make their share of correct small decisions. We assert that science and technology are not obstacles to the attainment of this goal, but rather necessary agents, both for making those decisions and for carrying them out.

Fulfilling people's expectations will not be easy. The magnitude and complexity of the needed activities challenges capabilities for making and implementing wise decisions, and even competes with natural environmental forces. Science may provide technological options to relieve the constraints of environmental effects, raw materials supply, and even energy resources -- but it may also have to provide large productivity improvements to pay for these options. To successfully address some global problems, scientific and technical skills must be much better distributed globally than they are today. And we are faced with the fact that many of the technological contributions to human progress today are aimed at short-term benefits at the potential expense of long-term resilience -- leaving an ominous legacy for future generations.

But, on the positive side, we have never had, in the long history of humankind, so many tools available for constructive effort, or even so much awareness of the need to act in a spirit of international cooperation. The power to ensure that science and technology have the opportunity to make their full contribution to satisfying human aspirations does not lie in the hands of scientists and engineers alone. But the failure of the world's technical community to commit itself to this end and insist on the development of needed policies, institutions, and cooperative activities could make the pessimistic view of doomsayers a self-fulfilling prophecy. So, it is appropriate that we end this discussion with a call for mobilization of this spirit of commitment on the part of scientists and engineers.

To our colleagues and fellow citizens of the world we address the following appeal:

1. Improve the Process for Generating and Managing the Introduction and Evolution of Technology

The fruits of fundamental research are only identified in retrospect, but applied research and engineering can and must be purposefully directed to human needs. It is naive to assume that needed technologies will become available just because the necessary science exists. Technology must be effectively encouraged. In making technological choices it is difficult, and possibly unwise to suppress attractive but potentially harmful technologies before the benefits and risks are evaluated. But it is also dangerous to wait until irreversible harm is threatened before technology assessments are made.

Assessment must be an on-going process, accompanying the evolution of technology. Processes must be developed that will permit a greater variety of technologies to be experimentally introduced and thereafter closely monitored so that appropriate choices and adjustments can be made at several stages. Laymen and professionals, hard and soft scientists, academic, industrial, and governmental sectors all need to participate. Much greater flexibility than we now have for readjusting technological strategies to new findings will be needed in the future; more imaginative engineering will be needed to develop better options; more scientific understanding will be needed to support wise choices among them. In this process, it is as much the responsibility of the engineer to be alert to consequences of his technological contributions as it is for the scientist to help create healthy foundations for useful technological alternatives.

2. Create the Institutions, and Provide the Facts and Analysis for Anticipatory Decisions

Political leaders and decision makers generally understand the need to anticipate future consequences of present decisions. Too often, however, they do not understand the time scales over which the consequences may fall, the potential cost of reversing adverse effects once they become apparent, or the range of technical alternatives or contingency plans which might be possible. Better ways than presently available are needed to bring early warnings to public attention, but they are not enough. Scientists must work to create new problem-oriented institutions for both scientific and policy research, experienced and credible enough to deal with problems so riddled with uncertainties that hypothetical situations must be modelled as the basis for public decisions.

The needed institutions must have a degree of stability, continuity and breadth of expertise beyond that available in comparable institutions today. The new circumstances facing humanity require a serious and permanent commitment for coping with technical complexity in decisions affecting the future. Thus, these institutions must take account of long-term threats to the resilience of the systems on which people depend. This may require the sacrifice of some measure of short-term stability or benefit to protect against very large, long-term risks. Scientists and engineers must also get involved in efforts to improve society's ability to provide contingency planning for the corrective action necessary when a suspected technological risk materializes.

3. Share with the Public a Sufficient Understanding of Risks and Technical Alternatives to Support Wise Public Policies

Those scientists concerned about the contribution of science to world affairs have long recognized the need to inform and advise public leaders. In the coming decades, it will be increasingly necessary to also inform the general public on scientific conclusions relevant to policy making, because the public's sense of priorities and values limits the decision options of its leaders. Frequently, society must forego immediate benefits for the sake of long-term safety or gain. Unless the public understands the reasons for such decisions, it is difficult for the political leadership, however enlightened, to provide the technical community with the opportunity to make the best technical choices.

Expert judgments will always be needed -- which can be evaluated and used by other experts. But the public measures scientific credibility by a standard unfamiliar to many scientists -- the ability to communicate outside the group of recognized experts in one's field. This situation poses opportunities, but also temptations which can lead to corruption of the integrity of the scientific process.

Finally, a great deal of work must be done to understand and help clarify public perceptions of risk. Great difficulties are encountered in public policy today with respect to those risks which are very small, but which involve unacceptable consequences.

4. Evolve and Sustain New Standards of Scientific Rigor Appropriate to Research in Support of Early Warnings and Policy Decisions

Public issues are multidisciplinary, crossing the boundaries of both social and natural sciences. The traditional standards of rigor in a discipline, and of criteria for professional career advancement, are not always applicable to interdisciplinary efforts. What constitutes convincing evidence is not always the same in science, engineering and economics. The information a decision maker wants often is the best answer given the present state of knowledge. But bringing to the attention of society a potential long-range danger often requires divulging tentative observations. Nevertheless, the accuracy of the estimates and the underlying assumptions must be rigorously and explicitly stated. In the absence of standards, we recognize this struggle for rigor is difficult -- but it is necessary.

The values by which scientists judge one another must, therefore, undergo an evolution which elevates the incentives for responsible professional performance and high-quality research applied to problems of public importance, and communicated in a timely manner. This task must be undertaken by professional societies, international unions and scholarly institutions; it cannot be left to either legal or political institutions.

5. Promote the Diffusion of Scientific Capability and Information Throughout the World, Especially With and Among the Developing Regions

We are convinced that the opportunity for technology to expand the effective resources of food, materials, and energy requires a rapid improvement in the indigenous professional and technical capabilities of every region of the globe. The ability of the poor countries to absorb technology -- native and imported -- is limited by the professional and technical strength of their human resources and their institutions. Even if much of the technology needed by poorer countries is to be imported, those countries must be able to make their own evaluations and choices. This will be an increasingly technical task as the technology strategies of industrialized countries change to meet their own needs.

The world's scientists should, therefore, commit themselves to new and more effective approaches to technical assistance and cooperation. This is worthy of emphasis, not only because of the urgency of unmet human needs, but also because of the rising threat of technological protectionism and the persistence of impediments to free interchange of science and scientists among the various parts of the world.

6. Strengthen International Frameworks of Decision-Making for Global Issues

The common feature of every major world problem that we have discussed is that solutions require concerted action by people of many nations. But nationalism is too strong and, with few exceptions, today's international institutions are too frail to provide the proper framework for mobilizing science and engineering on a global scale to solve these problems. However, the exceptions are encouraging and the existence of a worldwide scientific and technical community whose common bond of understanding and mutual respect transcends national boundaries is a great asset. Through this community, national as well as international research centers can be linked to provide a common basis for global decision making on transnational issues. But above all, increased harmonization of national policies is essential to avoid a *tragedy of the commons* on an international scale.

7. Explore How the International Scientific Unions Can Enhance the Contribution of Science to the Solution of World Problems

Our appeal to scientists is addressed not only to each individual scientist, but also to our professional associations, academies, and unions. The stresses we anticipate concerning personal career choices, and standards for scientific rigor, are reflected in similar questions for these scientific institutions. The dependence of the people of the world on enlightened and imaginative application of scientific skills to fulfilling human hopes and needs presents these institutions with a difficult challenge. The scientific unions must preserve and extend their effectiveness in behalf of scientific progress and the diffusion of knowledge. But science and technology are powerful agents for change, and it is important that this change be in concert with people's aspirations and values. Scientists -- at least most scientists -- must not view themselves only as the custodians of knowledge, aloof from world affairs, nor should engineers ignore the broad significance of technological alternatives they conceive and create. In the next quarter century, the institutions, goals and values of scientists and engineers will not be immune from the forces of change, but must also evolve. Properly guided -- with the participation of scientists and engineers themselves -- this evolution could not only facilitate effective answers to the world's most pressing needs but ensure the continued vitality and progress of science itself.