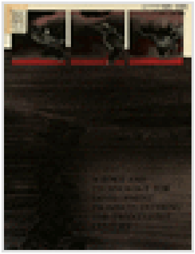

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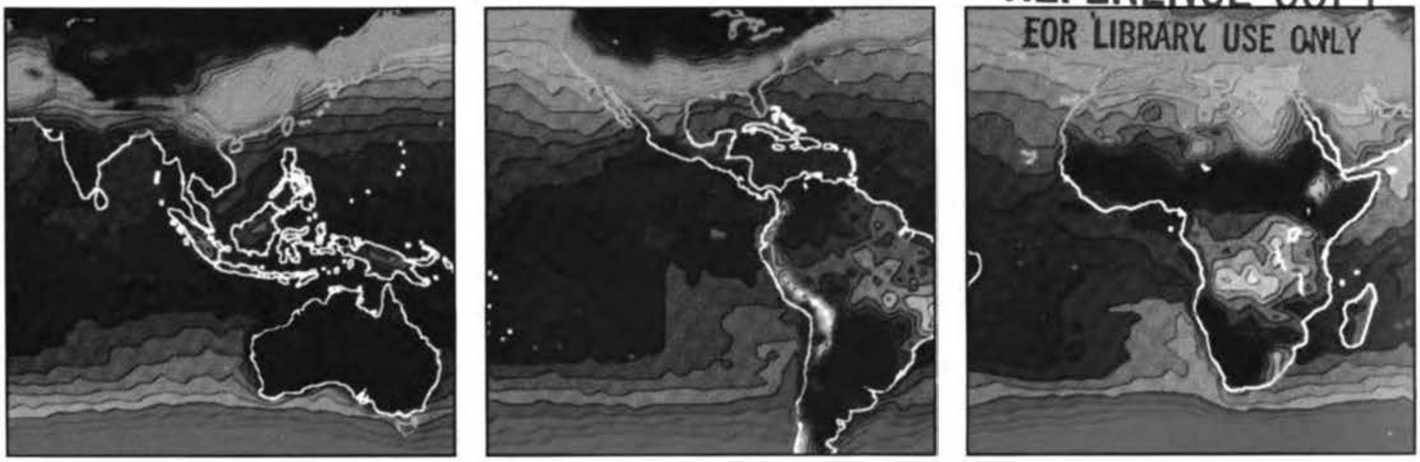

SCIENCE AND TECHNOLOGY FOR DEVELOPMENT: PROSPECTS ENTERING THE TWENTY-FIRST CENTURY

A Symposium in Commemoration of the Twenty-fifth Anniversary of the U.S. Agency for International Development

Washington, D.C.
June 22-23, 1987

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PREFACE

"Science and Technology for Development: Prospects Entering the Twenty-first Century," a public symposium, was held in Washington, D.C., June 22–23, 1987, to commemorate the twenty-fifth anniversary of the U.S. Agency for International Development (USAID). The anniversary of the Agency was thought to be a suitable occasion for describing and assessing the contributions of science and technology in selected areas to the development of Third World countries, and to focus attention on what science and technology are likely to accomplish in the decades to come. The symposium was cosponsored by the Agency for International Development and the National Research Council (NRC), two institutions that have long worked as partners in examining the role of science and technology in the development process through the programs of the Council's Board on Science and Technology for International Development (BOSTID).

Dr. Nyle C. Brady, USAID senior assistant administrator, opened the symposium by describing briefly the history of U.S. technical assistance. Twenty-five years ago most development experts believed that the technology needed by developing countries was available and waiting for the appropriate applications. They also believed that the primary responsibility of the United States was the transfer of technological products and methods to those countries. This short-term vision of development needs limited the role that research, which is by nature long term, could play in the process.

The experience of the last three decades has shown that the transfer of available technology is a necessary but insufficient condition for development. Progress in most sectors has required continuous advances in science and technology. Increasingly, successes have been achieved by generating the specific technologies needed to overcome Third World problems. This has meant a surge in the growth of (1) indigenous scientific capacities, (2) national and regional institutions using the newly acquired skills of developing country scientists, and (3) scientific networks sharing research findings. Through these cooperative efforts, for example:

- Social scientists have improved project success rates by introducing the concepts of local participation and the need for adjustment to local socioeconomic conditions. They have also developed methodologies and processes that enable development agencies to create better strategies for achieving their basic objectives.

- Agricultural scientists have developed higher-yielding, hardier plants to feed the earth's growing population.

- Health scientists have extended the life expectancy of inhabitants of the developing world.

- Biological scientists and population experts have expanded the range of contraceptive methods as well as the modes for delivering family planning services to parents wishing to control the number and spacing of their children.

- Communications scientists have learned to use the new telecommunications and information technologies to provide crucial information in health and agriculture and to improve dramatically the teaching of the three Rs.

The first part of this report, "The Past 25 Years," describes more fully the vast contributions made by these disciplines to development over the last three decades. This description is based on presentations made at the symposium by four authorities who have broad experience in developing countries (see the Appendix for a list of all speakers and presentations).

The second half of the report, "Entering the Twenty-first Century," examines advances in specific technologies and asks how these advances might benefit the Third World. This examination is based on presentations made by 19 scientists who are pursuing cutting edge technologies in national laboratories, universities, research centers, and private industry. The technologies addressed seem certain to have major impacts in both industrialized and Third World countries, although the development-related applications of some are not yet as clear as for others.

The final section of this report is based on the summation delivered by University of Houston Professor Thomas R. DeGregori, who has published extensively on the role of technology in today's rapidly changing world.

AWARDS

In conjunction with this symposium, the Agency for International Development and the National Research Council jointly honored nine organizations for their substantial contributions to science and technology in developing countries over the past 25 years. They are the Asian Institute of Technology, International Centre for Maize and Wheat Improvement (CIMMYT), International Rice Research Institute, International Centre for Diarrhoeal Disease Research, International Executive Service Corps, Johns Hopkins University School of Hygiene and Public Health, National Association of State Universities and Land Grant Colleges, Rockefeller Foundation, and Population Council. The citations that accompanied the awards for these organizations are found on p. 30 of this report.

ACKNOWLEDGMENT

The Agency for International Development and the National Research Council would like to acknowledge the generous support given for this symposium by the Carnegie Corporation of New York, the Rockefeller Foundation, and the Alfred P. Sloan Foundation.

On behalf of USAID, Bradshaw Langmaid, Jr., and Norma Ayers played key roles in the planning of this symposium, while John Hurley and Patricia Tsuchitani were their counterparts for the National Research Council. Rose Bannigan and Griffin Shay of the NRC staff also assisted with the organization of the meeting. This report of the symposium was written by Sabra Bissett Ledent and its publication was supervised by Wendy D. White.

CREDITS

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OPENING REMARKS

Frank Press
President, National Academy of Sciences
Chairman, National Research Council

This symposium helps to mark the twenty-fifth anniversary of the U.S. Agency for International Development, an agency that reflects not only the concern of the American people for their fellow human beings, but also this country's realistic appraisal that we are inevitably tied to the global community, the global economy, and the global ecosystem. Our own self-interest is directly affected by the prosperity and well-being of the rest of the world.

As we think of these global issues, we need to remind ourselves that 141 of the world's 171 nations are classified as developing countries. Such classifications tend to be simplistic, of course, and to obscure the great differences that exist among and within these countries. Yet the fact remains that three-quarters of the world's 4.7 billion people live in the developing countries, and they will account for four-fifths of the inhabitants of the planet Earth by the year 2000. It should be no surprise, then, to note that developing countries buy more U.S. goods than Japan and the European Economic Community combined.

We can take encouragement from the fact that during the past quarter century the progress achieved by the Third World as a whole has been striking in many respects, and the Agency for International Development can be justly proud of the important role it has played in these advances. Great strides have been made in overcoming food shortages. Life expectancy in the Third World has increased in two decades by as much as it increased in the industrialized nations in a century, and a number of major diseases have been controlled or, in the case of smallpox, eradicated. The economic growth rate of many developing countries over the past 15 years has exceeded that of the industrialized countries. The percentage of populations that receive education is on the rise.

Yet despite these impressive accomplishments, the challenges are still great as the developing countries move toward the twenty-first century.

Before the end of this century 1.5 billion people will be added to the world, more than half in countries with a per capita gross national product of $400 or less. Although the per capita GNP of some developing countries has grown, over 300 million people—many of them in Africa—live in countries where per capita income has actually fallen during the past decade. Almost a tenth of the world's population lives in countries where life expectancy is less than 50 years. Hundreds of millions of people still have inadequate incomes, are malnourished, have no safe water, and lack access to schools and minimally adequate housing.

It is also vital to realize that a world with a growing population and an expanding human settlement is being severely stressed. The continued accessibility of resources that once seemed infinite can, in some cases, be counted in decades. Our living resources are especially important to us, and it is urgent that we find ways to maintain the biological diversity that is the heritage of our planet and that sustains and nurtures life itself.

In facing these complex challenges, science and technology lie right at the heart of the development effort. This symposium will review some of the important contributions that science and technology have made, but it will also look at exciting progress in selected areas that promise to have a major impact on developing countries in the future.

I think it is accurate to say that over the past six years USAID has supported science and technology more than ever before. Very substantial resources are going into research and the application of knowledge in agriculture, employment and income generation, health, diversity of plants and animals, and other critical problems related to development needs. Important advances are being made. The agency, and in particular M. Peter McPherson and Nyle Brady, deserve great credit for these initiatives.

But we should also recognize that USAID has outstanding predecessors and partners in this effort. American universities, private and voluntary organizations, companies, and other government agencies have played key roles in sponsoring and conducting research; devising technologies; training scientists, engineers, and managers; and building institutions that have helped to focus science and technology on the needs of developing countries. Increasingly, international organizations and institutions in the developing countries themselves are contributing greatly to these efforts.

I am glad to note that the National Research Council has long been active in examining how science and technology can contribute to development needs, especially through the work of the Board on Science and Technology for International Development. Through its studies, overseas activities, and innovative research program for institutions in developing countries, BOSTID has helped focus the voluntary service of the American scientific and engineering communities on the kinds of issues that will be discussed during the next two days.

As the symposium moves along, I hope that we will all gain new perspectives on the issues that will be examined here and be heartened by the realization that continued efforts to use science and technology to serve development needs have had important impacts and will continue to provide useful benefits in the future. ■

Jay Morris
Acting Administrator
U.S. Agency for International Development

On behalf of the Agency for International Development, I want to join Frank Press in welcoming you to this symposium and in noting the scientific and technological accomplishments in developing countries during the last 25 years.

The achievements we build upon today began more than a decade before USAID was established. In his 1949 inaugural address, President Harry S. Truman set in motion a new era in foreign assistance. Through Point IV, training skills and technology for improvement and growth were made available to developing nations. In a subsequent address, about three years later, President Truman emphasized that the secret of our own national success was inextricably connected with 'the magic of science and technology,' and that through Point IV we could share that secret with less-developed countries. Indeed it was during the 1950s that we really began to comprehend the potential of modern technology generation.

In keeping with this realization, development research programs were among the new elements introduced into overseas aid by the Foreign Assistance Act of 1961. Research and development programs have since played an increasingly critical role in international assistance:

- Using medical knowledge generated during and after World War II, scientists eliminated smallpox and developed miracle drugs that successfully fought many global diseases.

- With increased understanding of how successful institutions function, less-developed countries began building and operating their own universities and research facilities.

- Through advances in agricultural science, improved seeds and management practices produced a much-needed "green revolution".

- Because of research efforts led by the United States, couples in many countries have greater access to family planning services and are increasingly able to determine the size and spacing of their families with safe and effective contraceptives.

- Through work in the social sciences, we have gained a better understanding of how different socioeconomic conditions can distort the outcome of even the best-intentioned programs. For example, we have demonstrated how subsidized credit interest for needy targeted groups can be diverted and actually limit overall access to credit, and how apparent improvements in production technologies for one group may only shift the burden to another—such as from men to women.

These are a few of the prominent gains; the list goes on.

USAID's twenty-fifth birthday is a most suitable occasion on which to enumerate and assess the contributions of science and technology to development. It is an even more appropriate time to focus attention on what science and technology are likely to accomplish in the decades ahead. Thus, I hope that all present benefit from the presentations to follow. ■

THE PAST 25 YEARS

While few people doubt that social factors condition the application of science and technology to development, some may doubt that the social sciences can improve the prospects for such applications. The natural sciences advance by discovering new, simplifying explanations for things, but progress in the social sciences is often marked by the introduction of increasing complexities.

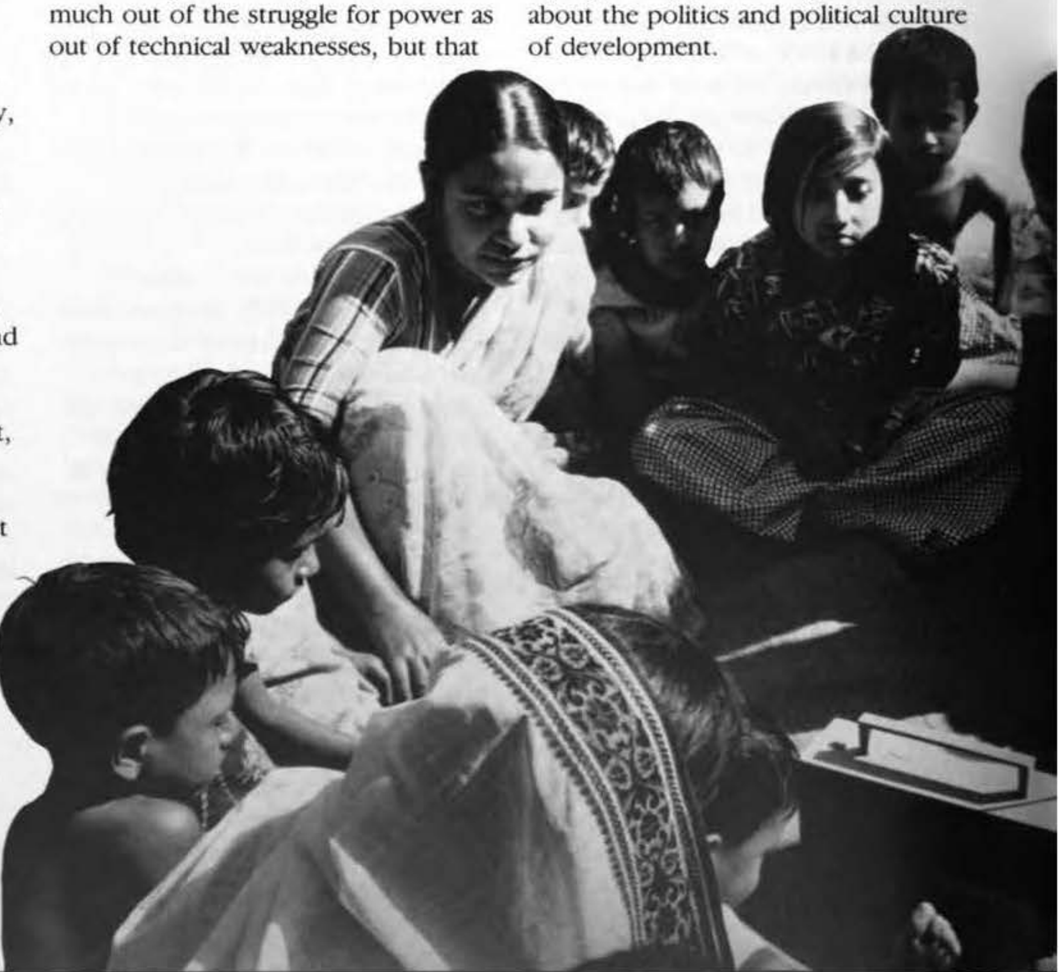
With these opening comments, Dr. John D. Montgomery, Ford Foundation Professor of International Studies at Harvard University, set the scene for his presentation on the contributions of the social sciences to development over the past 25 years. He prefaced his description of these successes with mention of two kinds of disappointments—intellectual and operational—suffered by social scientists in the recent past.

The intellectual disappointments have been caused by hubris or intellectual arrogance. For example, costly, but in the end ineffective, mathematical models were developed for such operational decisions as agricultural policies. Twenty-five years ago econometricians were eager to test their theories, especially by applying their techniques to current policy, and many saw the Third World as the natural laboratory for these efforts. The models, which generated elegant, logical, and consistent information, were then printed out in computer centers, but in the end they were not of great use to decision makers.

The second kind of disappointment—related to the acceptability of social science as a source of policy—usually arises when decision makers decline to apply existing knowledge, even when it is useful. For example, it has been known for years, through successful pilot projects in Latin America, Asia, and Africa, that radio and television can augment learning in primary schools, and even replace teachers in areas where they are unavailable. Social scientists, however, have found it difficult to convince policymakers to move from pilot demonstrations of the teaching effectiveness of communications media to a nation's classrooms. The reasons for these operational disappointments are only now becoming apparent, and they are adding to social scientists' knowledge about government.

"In the light of experience, we have to admit that sometimes, at least, the politicians have shown that they knew more about government than the political economists did," observed Montgomery. For example, national leaders were justifiably skeptical about centralized planning. "Their skepticism may have arisen as much out of the struggle for power as out of technical weaknesses, but that struggle turned out to be more important than the technical weaknesses were." Consistent planning cannot do much for governments that are effectively unable to execute any policies at all. But, while such unexecuted plans may not have hastened the course of development, they have sometimes called political attention to areas where government action was needed, such as correction of failures in the market system, where relations between governments and markets are always troublesome.

Montgomery then described four areas in which social scientists can point to triumphs over the past 25 years: (1) building an infrastructure of social science information, (2) understanding the nature of growth, (3) creating theories about achieving equity, and (4) increasing knowledge about the politics and political culture of development.



CONTRIBUTIONS OF THE SOCIAL SCIENCES

Infrastructure of Knowledge

Over the past 25 years social scientists have been able to test basic theory and the search for policy applications against reliable economic and social data. In the 1960s, for example, per capita GNP figures were rarely available for developing countries. With their recent availability, however, much of the guesswork has been eliminated about events in remote parts of the world, and even inexperienced governments can now appraise their present conditions and their progress in standard, quantitative terms.

Unobtrusive ways to generate fairly accurate estimates of population sizes, locations, and trends are also now available. With continued support from USAID, the World Fertility Survey has been completed. It provides information about demography, health, fertility, family planning, and many other features of life in 40 developing countries (see box).

The details of income distribution, which were the subject only of speculation a generation ago, can be estimated using the data banks created in most developing countries. With such data, social scientists can identify the long-term consequences of policy alternatives in terms of their distributive effects.

World Fertility Survey

The World Fertility Survey (WFS) was established in 1972 to help countries acquire the scientific information needed to describe and interpret the fertility of their populations. It was also designed to increase the capability of each participating country, especially developing countries, to undertake fertility and other demographic research and to collect and analyze internationally comparable data on fertility. According to the U.S. Agency for International Development, one of its supporters, the World Fertility Survey is the largest social science endeavor ever undertaken.

The International Statistical Institute (the Netherlands), with the collaboration of the United Nations and in cooperation with the International Union for the Scientific Study of Population, undertook the survey. Major funding was contributed by the United Nations Fund for Population Activities and USAID. Additional funding was received from, among others, the governments of the United Kingdom, France, Japan, and the Netherlands.

By the time this study was concluded in 1984, fertility surveys had been carried out in 42 developing and 20 developed countries with the participation of hundreds of scholars and experts. Its major contribution—along with the high-quality data produced which has already been widely discussed, assessed, and interpreted by social scientists, policymakers, and others—is the wealth of new and innovative survey methodologies and techniques for data analysis that were developed and tested in the course of the survey.

The results of this survey indicated that the increased availability of family planning supplies and services in turn increases their use. The data gathered also revealed that fertility rates are falling in much of the world and demonstrated the importance of birth spacing and the substantial role that breast-feeding plays in birth spacing and subsequent child survival.

[redacted]

As scientists have learned more about the determinants of fertility, they have also increased their understanding of demographic transition. Montgomery noted that former expectations that technology alone, especially improvements in contraception, would reduce family size, have yielded to new notions about the importance of the costs and benefits of additional children as a basis for making predictions. The economic, social, and cultural factors that produce large or small families do not follow a standard mathematical process.

An increased understanding of population movements, particularly rural-to-urban migration, has helped explain why slum dwellers reject public housing and why bulldozers fail to remove shanty towns. Armed with such knowledge, social scientists are even learning what policies to pursue in dealing with these problems.

A final example of the value of the social science information infrastructure is the emerging knowledge about the relationships of employment among the agricultural, manufacturing, and service sectors. Through projections of occupational trends, scientists can estimate future needs and potential problems and seek a redress of the sector imbalance caused by premature concentration on protected industrialization.

Montgomery then summarized these developments by saying, "I am not claiming that the infrastructure of knowledge now in place is sufficient in itself to produce coherent theories. . . . What I am claiming . . . is that it is now possible to use an extensive empirical base in generating and testing theories about development."

Economic Growth

It was once convenient to think that economic growth occurred in stages and that prescriptions existed for application of the appropriate doctrines to each period in the march toward modernization. Unfortunately, said Montgomery, the decline of this approach has led some skeptics to doubt that a field of "development economics" exists at all. The area specialists have, however, reminded social scientists that applications of standard economic remedies do little to help the development needs of either the newly industrialized countries or the African states. Thus, there is still a role for development economists.

Our understanding of economic growth has moved beyond developing indicators of wealth to a recognition of subtle relationships among technology, management and growth, which, in turn, we have begun to measure and to influence as well.

Montgomery

After throwing out many of the favorite terms from the early days of development theory—"big push," "low-level equilibrium trap," and "two-gap model," for example—and rejecting the notion that capital accumulation will automatically produce self-sustaining growth, economists have come to realize how complicated growth is, and they are learning how social factors affect technological choices. They long ago discarded the idea that "easy fixes" of technology alone will produce development. But, Montgomery explained, they may have gone too far in repudiating the historic contributions of technology transfer, especially if one includes the massive industrial and agricultural changes that have occurred without official assistance.

In searching for new technologies, natural and social scientists learned to combine their efforts. For example, in the health field, discoveries such as oral rehydration therapy became useful only after anthropologists and other social scientists working with public health scientists discovered how to develop community-based efforts aimed at the dissemination of information and behavioral change.

Montgomery also observed that an improved knowledge of incentive and delivery factors is associated with technological advances. He recalled that social science joined with agricultural technology to make the "green revolution" work. The availability of better, cheaper, and more abundant crops did not automatically solve the food and farmer problem. Pricing systems, especially those that distinguished between "sales" and "purchases," enabled farmers to afford new technologies and the urban poor to buy their products.

Finally, Montgomery noted that "we have learned something about maximizing human contributions to development. Our knowledge has gone far beyond calculations about how many specialists might be needed to achieve what we once called 'manpower balance,' as we begin to relate individual talents to social needs." He offered as an example the changed perception of how farmers contribute to development. Anthropologists and rural sociologists have worked tenaciously to destroy the stereotype that peasants cannot be motivated by economic incentives. General realization that the profit motive is not confined to the industrialized societies after all brought economics and the behavioral sciences into new areas of collaboration.

Equity

The few things discovered over the past 25 years about the relationship between growth and equity, observed Montgomery, are enough to dispel some early theories that were unnecessarily tolerant of extreme trickle-down policies and pathologies. "Economic growth, we now know, does not explain or predict the emergence of pluralistic, equity-seeking democracies." And few would argue today that the savings of the rich are more productive of developmental investments than are expenditures of the poor.

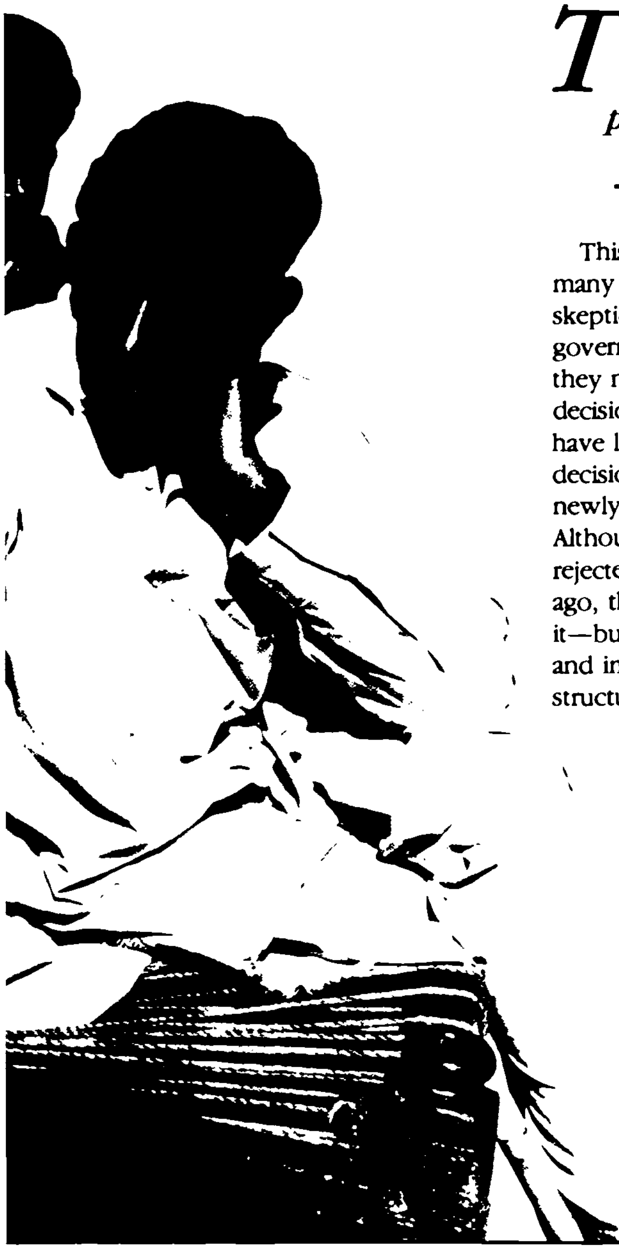
> ***Our greater knowledge of the role of equity in development: not only do we know that they go together, but we have extensive knowledge of institutional means of promoting that marriage.***
>
> *Montgomery*

One of the policy insights provided by these discoveries is that institutional devices can be installed to protect the interests of small farmers and even urban migrants, two groups whose capacity to produce wealth was often overlooked in the trickle-down era. Once it was fashionable to argue that the "green revolution" did little for the poor farmers, but current research shows that direct benefits came to them as well as to the more prosperous farmers.

Politics of Development

According to Montgomery, people still seem surprised to hear that democracy is not necessarily served by development, and that its institutions are fragile even when they appear to be firmly in place. Social scientists have found, however, that although democracy is difficult to acquire, under the right conditions it can be more durable than a dictatorship. "Nowadays political scientists rarely justify support to authoritarian regimes on the ground that they are more stable or last longer. . . . We now know something about the political preconditions of development, even though we no longer think of 'political development' as a linear progression from traditional societies."

Montgomery then cited two preconditions for the survival of democracy: (1) institutions for resolving conflicts must be in place before mass participation is feasible, and (2) while certain levels of economic development may help democracy thrive, new governments need the support of elements that used to be ignored, such as armies and rural populations, just as they need that of merchants and urban dwellers.



In place of "political development," a "political economy of development" seems to be emerging. This change has led political scientists to focus on comparing internal variables, and in doing so they have discovered that national decision-making capacities must be studied in their own historical and cultural contexts as sources of change and development.

> ***There is no political development, only political developments.***
>
> ***Montgomery***

This new focus has in turn led many political scientists to be skeptical of external explanations for government shortcomings. Instead, they now look at important policy decisions made internally, and they have learned much about these decisions from the experience of the newly industrialized countries. Although most political scientists rejected the dependency theory long ago, they have also learned from it—but with greater emphasis on tariff and import policies than on internal structural conditions.

Some of the valuable things recently learned about the relationships between culture and development have produced policy insights that are beginning to reach policymakers. Montgomery cited the example of the U.S. government which, like the banks, is beginning to prepare "social-institutional profiles" of countries receiving grants and loans in an attempt to predict whether local organizations and national parties will thrive in a given context.

He also noted that when it comes to using institutions to change people, factories are not necessarily the best way to modernize. "Factories do not always flourish even when there is a local market for their products. Some countries do not want to abandon their cultural heritage in order to adopt modern technologies, but prefer to find ways—slower, perhaps—to preserve their cultures while gaining the advantages of modern technology."

In the same vein, social scientists have discovered that there are systemic limitations on any government's capacity to bring about social change. Because governments quite often have interests of their own that are quite distinct from those of their constituents, certain government functions must devolve to local participants to keep public functions public-serving.

In summing up the contributions of the social sciences to development, Montgomery emphasized that the most encouraging progress has been the growing partnership between natural and social scientists. "Few among us now doubt that understanding the relationship between technology and institutions requires the expertise of both groups."

CONTRIBUTIONS OF

Robert D. Havener, president of the Winrock International Institute for Agricultural Development, focused his presentation on formal efforts to assist agricultural development over the past 25 years that have been funded by the U.S. government, U.S.-supported intergovernmental agencies, U.S. universities, and large philanthropic foundations. He reminded his audience that the agricultural sciences have significantly affected socio-economic development in the Third World during the past quarter century. They have, for example, increased the productivity of farmers, increased incomes in agriculture, spurred national economic development, and enhanced the socio-economic status of millions of people around the world.

After pointing out that formal U.S. government development assistance programs had their origins in the United Nations and its specialized agencies in 1945–1946, in the post-World War II Marshall Plan, and in the Point IV Program promulgated by President Harry S. Truman in 1949, Havener explained that during the 1950s and early 1960s the U.S. Agency for International Development and its predecessors established American-style extension systems throughout the developing world. It quickly became apparent, however, that U.S. technology was simply not immediately useful to many tropical and semitropical developing nations.

THE AGRICULTURAL SCIENCES

"Adaptation was necessary, requiring an indigenous research capacity—a realization that came slowly and unevenly, and is not comprehended by many nonagriculturalists to this day." By the early 1970s, USAID had turned to more focused extension initiatives, especially geographically-targeted rural development and agricultural projects.

> ***Early in the 1950s, U.S. foreign assistance agencies contracted with a number of U.S. agricultural colleges to help establish comparable institutions throughout Asia, Africa, and Latin America. . . . These activities. . . later contributed heavily to research work in those countries.***
>
> ***Havener***

Establishment of CIMMYT and IRRI

Other significant developments were occurring at the same time, resulting in the establishment of the International Centre for Maize and Wheat Improvement (CIMMYT) in Mexico and the International Rice Research Institute (IRRI) in the Philippines.

The Rockefeller Foundation has had a long history of development assistance, beginning in the early 1940s when it sent a small team of prominent agricultural scientists to Mexico to determine how that country might increase its agricultural production. The many subsequent programs undertaken by the Foundation have emphasized research on basic indigenous food crops and livestock, and on training promising young scientists. In 1959 Dr. Norman Borlaug became head of Rockefeller's International Wheat Improvement Project, which merged with a comparable corn improvement program in 1963 to form the International Centre for Maize and Wheat Improvement. CIMMYT was then upgraded significantly in 1966.

Although rice was not the centerpiece of any of the Rockefeller country programs in the 1950s, staff travel to the rice-growing countries, visits to scientific and educational institutions, and talks with government officials by Foundation officials confirmed that an international rice research center was badly needed in Asia. IRRI was not established until 1960, however, when in an unprecedented move the Ford and Rockefeller Foundations joined forces to sponsor the institute. USAID began to support IRRI in 1966 with a three-year grant for research on farm and equipment power requirements in Asia.

Although it had been recognized from the outset that the U.S. foreign assistance program must have a sound research component, it was not until 1964 that a conference on rural international development concluded that USAID should give greater support to the research component of its own programs and within its contracts with U.S. agricultural universities. There were constraints, however. One was a congressionally imposed lid on how much could be spent on all types of research (which continued until the mid-1970s), and another was the prohibition of support for research on commodities in which surpluses were appearing—such as wheat and rice.

Change in Attitude

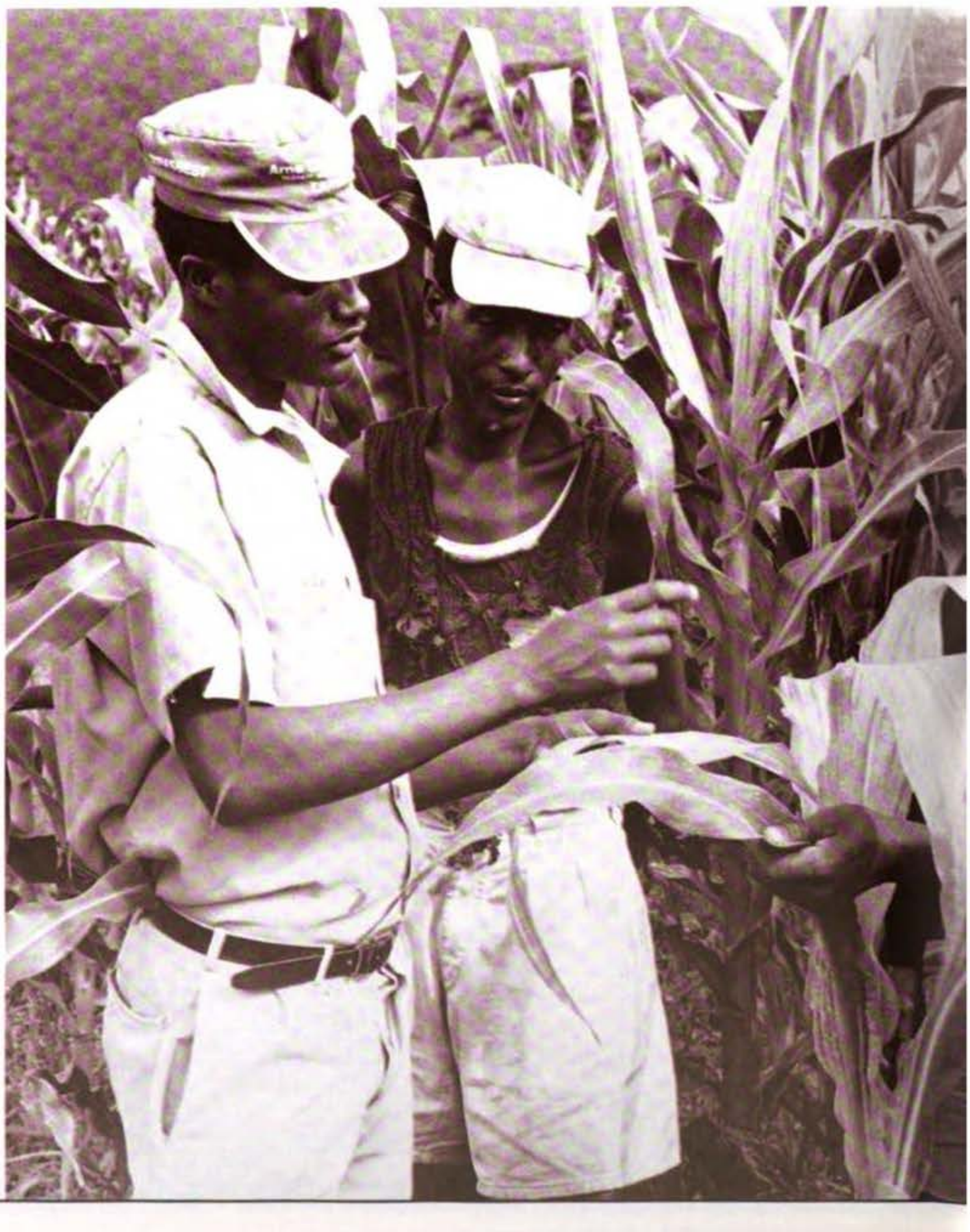
Fortunately, this attitude toward research on food crops began to change in 1966 with the initiation of President Lyndon Johnson's "War on Hunger." In recognition of the Administration's new emphasis on the need to help developing countries balance agricultural productivity with population growth, USAID issued an order in 1968 that liberalized the commodity focus, making it possible to support a broader range of research activities. Among these activities was the International Centre for Maize and Wheat Improvement.

Since 1966, observed Havener, CIMMYT has developed the world's largest wheat and corn improvement program. In fact, "the success of IRRI and CIMMYT in developing new varieties of rice and wheat. . . is frequently cited as proof of the efficacy of agricultural science in contributing to development."

The new wheat varieties also had a major impact on American farmers, both through direct use and through use in breeding programs. For example, Orville Vogel, a U.S. Department of Agriculture scientist stationed at Washington State University, first recognized the worth of Norin 10 (not suitable for direct use) in a breeding program. It was crossed with Brevor to produce the variety Gaines, which was quickly adopted in the Pacific Northwest in the early 1960s. By 1968 the U.S. wheat industry began to see the increased release of varieties developed from hybridization in the United States and, to a lesser degree, the release of selections from crosses originally made by CIMMYT. Varieties developed in Mexico were also being introduced. In 1984, Havener explained, an estimated 60 percent of the total land cultivated with wheat in the United States was sown in semi-dwarf or short varieties that had their origins in developing countries.

Somewhat later IRRI achieved similar results in improving rice varieties, and today modern varieties of wheat and rice compose half of the total plantings in the developing world. Each year the new varieties yield about 50 million more tons than the old varieties could have produced, or enough additional grain to provide a cereal diet for perhaps a billion people.

But this does not mean that the past levels of concentration on and financial contribution to agricultural research and economic development are no longer needed. Even though



the 1960s predictions of famine in 1975 were proven wrong—thanks to the dedicated accomplishments of agricultural scientists—it must be recognized, Havener warned, that despite the great initial yield breakthroughs attributed to the high-yielding varieties of rice and wheat, progress since that time in increasing potential yield has been relatively slow.

What agricultural science has accomplished through genetic improvement in recent years is to increase wheat and rice plant resistance to diseases and pests, make possible their adaptation to a wider range of soil, climate, and other environmental conditions, and thus increase the range of usefulness of different varieties.

Havener

There is now relatively little underutilized technology waiting to be transferred to developing country farmers, and there are no apparent major breakthroughs just over the horizon. "This is no time to rest on our research oars," stressed Havener. "Maize, sorghum, and millet varieties that would be substantial improvements over what exists will take time to develop. Biotechnology's promise is somewhat uncertain, but it is clear that time will be required before that promise is at hand."

A faster, not a slower, rate of technological change will be needed in the future to enable developing countries to keep food production growing at an adequate enough rate to stay close to meeting consumption needs and to provide the basis for economic growth.

Havener

In concluding, Havener gave two compelling reasons for the United States to increase, not decrease, its international collaboration in agricultural research. First, varieties that incorporate desirable characteristics are often identifiable only through collaborative research, and the genes for further improvement often exist only in Third World plant populations. For example, Kenya is the genetic source of modern resistance to rust in U.S. wheat varieties, while Peru is the genetic source of golden nematode resistance in U.S. potatoes.

A second reason to increase international collaboration is that countries may be willing to give us access to valuable native varieties only if they are identified through research that is also beneficial to those countries. Developing countries well recognize that they are the origin of most commercial crops and that the industrial nations have reaped the greatest benefit from their genetic reservoirs. Understandably then, developing countries wish to control the export of their genetic material. "If they are to give up something valuable, they want to get something valuable in return," said Havener.

In closing his presentation Havener called for an increased emphasis on sustainable agricultural production, warned against agronomic practices that abuse fragile lands, resulting in erosion and environmental degradation, and suggested giving higher priority to agroforestry. These areas, too, are subjects for agricultural research.

CONTRIBUTIONS OF THE HEALTH SCIENCES

Changes in mortality and morbidity tell much of the story of how the health sciences have contributed to development over the past 25 years. Infant mortality data for 130 of the world's largest countries, containing more than 99 percent of the world's population, show that 47 countries recorded more than 150 deaths per 1,000 births in 1960 *(see Table 1)*. As of 1985, however, only seven countries had rates of this magnitude. Other data reveal that in 1960 one-third of all children in eight countries died before their fifth birthday and one in four children died in a total of 42 countries *(see Table 2)*. Twenty-five years later only eight countries fell into the latter category.

Life expectancies have also improved over the past 25 years. Life expectancy at birth was under 40 years in only two countries in 1985, in contrast to 24 countries just 25 years ago. Indeed, the median life expectancy among 129 countries has risen from 49 to 61 years, a gain of 12 years achieved in only 25 years.

"Many factors beyond specific health interventions have contributed to these remarkable changes," said Dr. D. A. Henderson, dean of the Johns Hopkins School of Hygiene and Public Health. "But dramatic changes have occurred in the nature of health interventions and, unquestionably, these have played a role." The U.S. Agency for International Development, he noted, has played a central supporting role in the development and application of these interventions.

TABLE 1

MORTALITY RATES FOR INFANTS UNDER ONE YEAR, 130 COUNTRIES

	Number of countries	
Number of deaths per 1,000 births	***1960***	***1985****
≥200	11	0
150–199	36	7
100–149	31	32
50–99	26	32
25–49	17	21
< 25	9	37

*The figures for Iran are not known.
Source: UNICEF. 1987. *State of the World's Children.* New York: Oxford University Press.

TABLE 2

PERCENT OF CHILDREN BORN WHO REACH FIVE YEARS OF AGE, 129 COUNTRIES

	Number of countries	
Percent reaching five years of age	***1960***	***1985***
<65	8	0
65–74.9	34	8
75–84.9	33	33
85–94.9	32	38
95–97.9	21	24
98+	1	26

Source: UNICEF. 1987. *State of the World's Children.* New York: Oxford University Press.

Characteristics of Health in Development in the 1960s

Henderson then described three characteristics of development-related health efforts in the 1960s that set the stage for the changes that followed.

First, because development theory in the early 1960s held that improved health follows economic development, it was generally accepted that economic development, not specific health initiatives, should have priority. Thus, the health sector was assigned comparatively few resources for either programs or research.

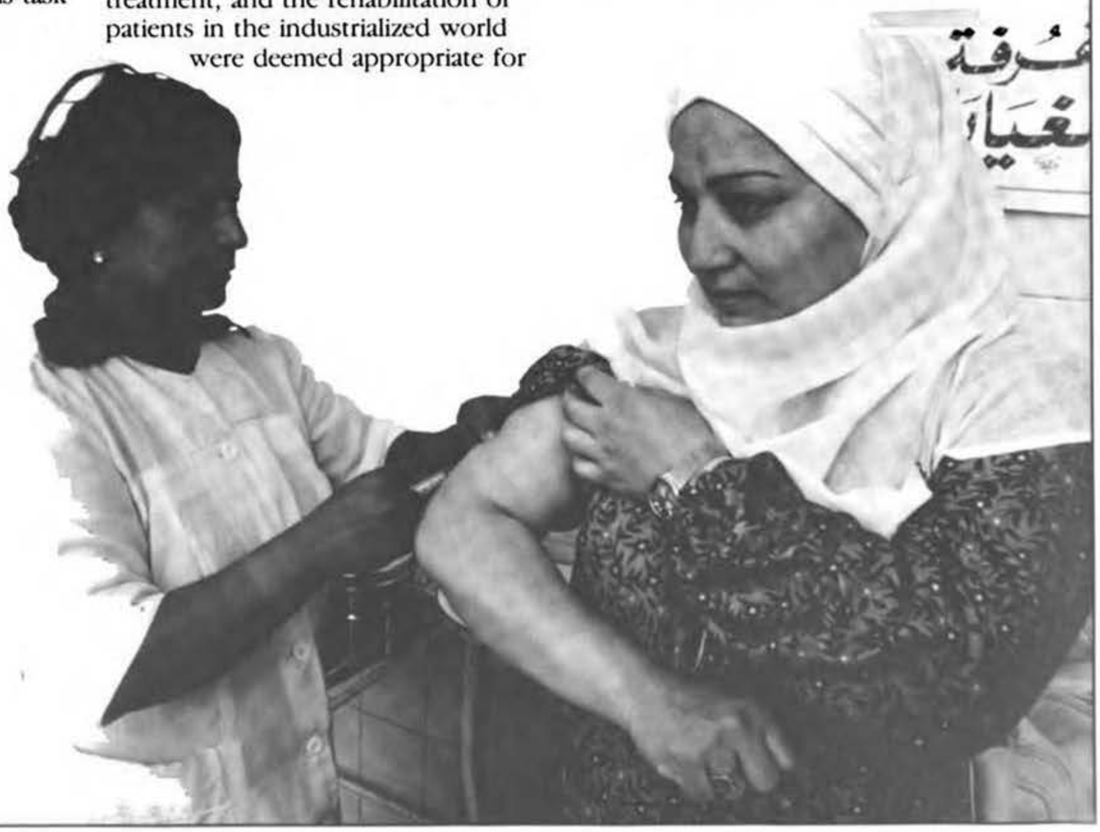
Second, malaria eradication was the principal health program in the early 1960s, and it consumed most of the resources. This program was based almost wholly on the systematic application of residual DDT to the walls of houses, so that mosquitoes resting on walls after taking a blood meal would die soon after contact with the insecticide. Because this task was viewed primarily as one of meticulous management and administration, few resources were assigned to research. By the early 1970s vector resistance to insecticides and parasite resistance to drugs pointed to the need for new approaches to malaria control. Unfortunately, no suitable research infrastructure existed.

As wryly observed by the British malariologist Sir Ian Macgregor, 'The program failed to eradicate malaria, but it eradicated the malariologists.'

Henderson

The way in which other health services were delivered was a third characteristic—and a problem—of the 1960s. The advances beginning to be made in the diagnosis of disease, its treatment, and the rehabilitation of patients in the industrialized world were deemed appropriate for developing countries. Thus, substantial national and international resources were used to develop curative care networks of hospitals and health centers and to train personnel to staff them. The other contributing factors to the health and well-being of the developed countries—safe water, pasteurization, nutrition, and immunization, for example—were forgotten. The small number of pilot projects actually undertaken demonstrated that community-based primary care programs could be cost effective and have a significant impact. They were never extended to large populations, however.

Family planning services were all but unknown in the early 1960s, and apart from the sporadic use of frequently impotent smallpox vaccine, immunization was not common. Research dealing with diseases known only to the tropics was almost nonexistent, as was research in nutrition and sanitary engineering.



Significant Events of the Past 25 Years

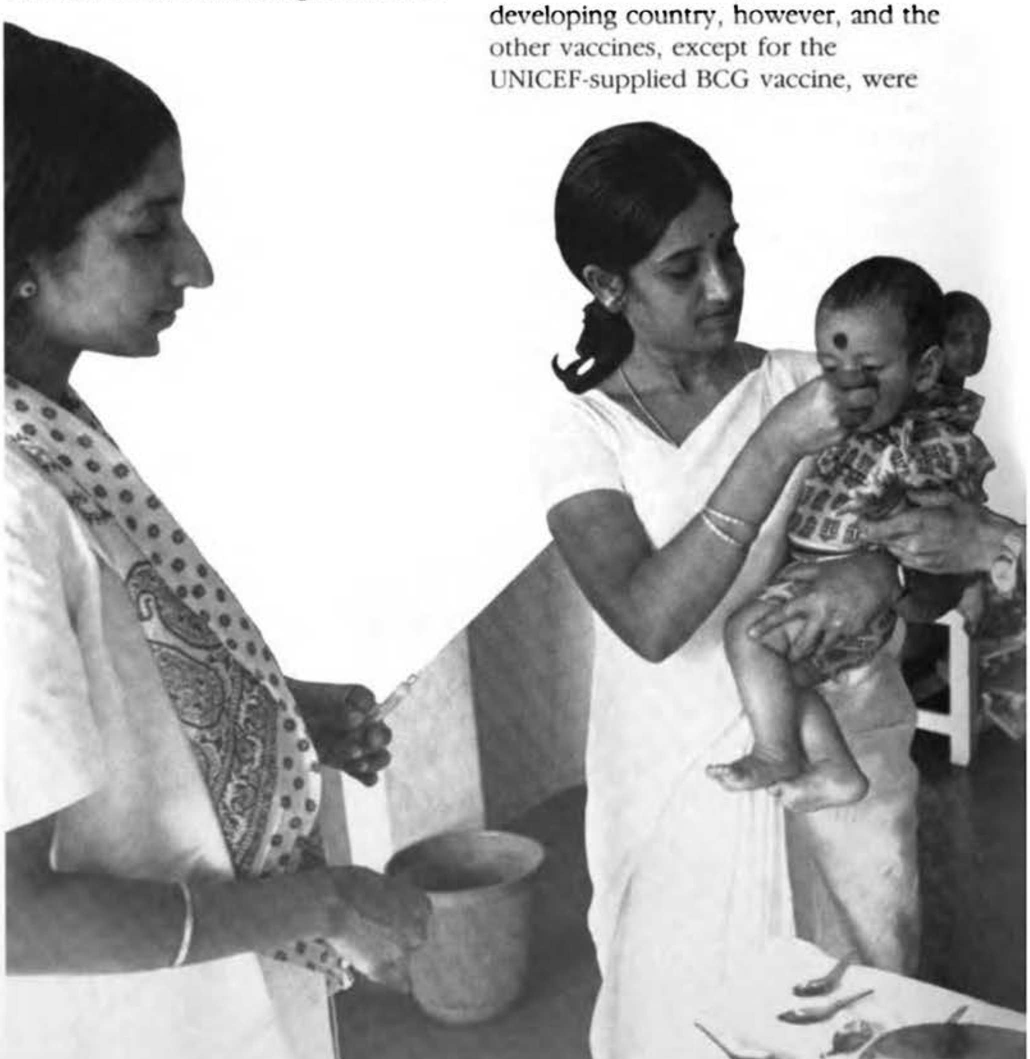
According to Henderson, perhaps the most significant action taken by the newly constituted U.S. Agency for International Development in 1962, was its investment in a new research enterprise, then called the Pakistan-SEATO Cholera Research Laboratory, and located in what is now Dacca, Bangladesh. In the health field, the International Centre for Diarrhoeal Disease Research (as it is now known) is the world's only disease-oriented international research center that can be compared to the large international agricultural research centers.

Henderson then described the threat presented by cholera in the 1960s. In 1962 cholera was a major problem in Asia, and it was just beginning its seventh pandemic spread. Frequently, more than 60 percent of those hospitalized died. In 1958 physiologist Robert Phillips, then at the Naval Medical Research Unit in Taiwan, showed that mortality rates could be reduced to less than 1 percent through the generous use of intravenous solutions—50 or more liters for some patients. This extraordinary advance was of limited practical use, however, because of the tremendous quantities of fluids required, the shortage of such fluids and the facilities needed to administer them, and the epidemic proportions of the disease.

After the Dacca laboratory opened, Phillips—soon to become its director—discovered that oral, as opposed to intravenous, hydration was feasible. Oral replacement of the tremendous loss of fluids had not been possible previously, even when the proper amounts of sodium, potassium, and chloride had been added to the water. But Phillips found that the addition of a small amount of glucose to the solution enabled the small intestine to absorb the water and salt. Ten years later the British medical journal *Lancet* hailed Phillips's discovery as "potentially the most important medical advance of this century." Practical application proved difficult, however, and it was not until 1968 that this treatment was first used under epidemic conditions.

In 1975 UNICEF ordered its first million packets of salt and sugar for the oral rehydration solution. And, even though oral rehydration proved to be useful for diarrheas of all types, the packets lasted 18 months. "Finally, with a strong impetus from USAID as well as from WHO [World Health Organization] and UNICEF, and extensive social marketing, traditional practices began to change," explained Henderson. "Today, it is estimated that more than 1 million packets are used *daily,* and in Egypt, for example, deaths due to diarrhea decreased by 50 percent. Research, in part supported by USAID, is continuing to develop simpler, more applicable formulations."

A second important development of the past 25 years has been the development and application of vaccines. As of 1962 the principal vaccines available were DTP (diphtheria, tetanus, pertussis), poliomyelitis, smallpox, BCG (tuberculosis), yellow fever, and rabies. DTP and polio vaccine were seldom given in any developing country, however, and the other vaccines, except for the UNICEF-supplied BCG vaccine, were



generally of poor quality and thermolabile. Fortunately, significant developments, beginning in the early 1960s, changed this situation.

In 1961 USAID supported the first field trials of the new measles vaccine in a developing country and the subsequent series of studies at both the National Institutes of Health (NIH) and the Centers for Disease Control (CDC). These efforts demonstrated that several vaccines could be given simultaneously with safety and efficacy. With the advent of a U.S. Army-developed practical jet injector suitable for field use, USAID launched a smallpox eradication and measles control program in 1965 for 100 million persons living in western and central Africa. This stimulated WHO to undertake its intensified program of smallpox eradication in 1967. U.S. contributions through the CDC and USAID were critical to the eventual success of the program.

The smallpox program, and the family planning programs that began about the same time, provided an important impetus for vaccine development and application, as well as for changes in health policy, priorities, and mechanisms for the delivery of health services. Success in both of these programs required the marketing and delivery of health services throughout a population, not just to those able to travel to health care centers or hospitals. Thus, researchers began to seek alternative approaches to operations, health education, and behavior modification, now known as social marketing.

The success of the smallpox eradication program revealed how much could be achieved and at how little cost, emphasized Henderson. As a result, the World Health Assembly decided in 1974 to launch an expanded program of immunization against poliomyelitis, measles, diphtheria, tetanus, pertussis, and tuberculosis. Today nearly 50 percent of all children are receiving their primary DTP series, up from only 2 percent just 10 years ago. The goal is to reach 80 percent immunization by the year 1990.

In 1984 the Pan American Health Organization (PAHO) launched a hemisphere-wide campaign to eliminate poliomyelitis by 1990. Supported by USAID, WHO, UNICEF, and Rotary International, the program is well under way. It includes a research effort to improve diagnostic capabilities and to better understand the epidemiology of the disease, especially in the tropics.

Greater priority is now being given by USAID, as well as other agencies, to the development of other vaccines given the potential offered by modern biotechnology.

Henderson

Development of a malaria vaccine, supported largely by USAID, "will lift from the developing countries one of the most onerous disease burdens that they now bear," said Henderson. Other promising vaccines include those used against hepatitis B, rotavirus (a diarrheal disease agent), respiratory syncytial virus, typhoid, shigellosis, and leprosy.

Despite the successes, warned Henderson, the use of modern biotechnology to develop new vaccines and approaches for handling the major problem diseases of the tropics has progressed less rapidly than it should for two principal reasons. First, government intervention and support for research in tropical disease problems diminished sharply in the postcolonial era, and there are few prospects for improvement. The tropical disease research program being conducted through WHO amounts to only $25 million, and USAID is providing as much support as it can from a limited health budget. The funds provided by NIH, the military, foundations, and other governments are too modest to unravel the complexities of at least a dozen diseases of major importance. Second, the private sector has exhibited little interest in new vaccine development because of the marginal profits to be expected from vaccines, drugs, and diagnostic instruments for diseases primarily found in the world's poor areas.

The third major advance of the past 25 years was the discovery in 1984 by Dr. Alfred Sommer and colleagues in USAID-supported research in Indonesia that vitamin A deficiency is associated with much more than visual impairment and blindness, and that marginal but important deficiencies of vitamin A are far more widespread than suspected. In comparing two groups of Indonesian village children—one given vitamin A and the other a placebo—investigators found that death rates of children under five years of age was 35 percent lower among those who had received a single vitamin A supplement once in six months. Further studies have shown that vitamin A is important in sustaining the integrity of the epithelial lining of the respiratory and gastrointestinal tracts, in red blood cell production, and in the functioning of the immune system. Studies in other areas are beginning to confirm those in Indonesia, and they have led WHO and UNICEF to advocate the community-wide use of vitamin A in all populations where, as an indicator, deaths from measles exceed 1 percent.

The discovery of the importance of vitamin A . . . and the recognition that iodine deficiency, for example, is also a serious problem in . . . the developing world, raises the question of whether there might not be other micronutrient deficiencies that could readily be corrected.

Henderson

Problems to Address

Despite the progress made over the past 25 years and all the promise that advances in biotechnology hold, there remain many obstacles to future improvements in the health status of the developing countries. Henderson includes in his list of obstacles a lack of resources to conduct the necessary research into disease processes, a lack of capable scientists willing to commit themselves to the problems of the Third World, and a lack of institutions interested in the major diseases of the tropics. He also called attention to the constraints imposed by traditionally trained physicians whose experience and education have been in curative practices, rather than in public health and preventive medicine, and who have little grasp of epidemiology, the techniques of social marketing, management, and disease surveillance. "We must not forget that if we intend to be serious in our efforts, all of these constraints must be addressed."

CONTRIBUTIONS OF POPULATION PROGRAMS

According to Dr. Ronald Freedman, Roderick D. McKenzie Distinguished Professor Emeritus of Sociology of the University of Michigan Population Studies Center, governments, international agencies, and private organizations have responded to the real and perceived consequences of demographic change by trying to alter, on an unprecedented scale, the course of demographic trends. As a result, since 1960 fertility, mortality, and rates of population growth have declined significantly. Moreover, an inexorable trend toward urbanization continues to tax already sprawling cities, and the age structure of the population is undergoing change.

Much more is known today about the basic demographic processes and the methods for their study. This has stimulated creation of a worldwide network of demographic research and training institutions that employ an increasing number of social and public health scientists who are undertaking theoretical and applied work in population.

According to estimates by the United Nations, the world's population was 3 billion in 1960, 70 percent of which was located in the developing countries. By 1985 it had grown to 4.8 billion, of which 75 percent was found in Third World countries. Thus, 89 percent of this 25-year growth took place in the developing world, now the home of three-quarters of the world's population.

In 1960–1965, the world's population was growing at a very high rate of 2 percent per annum, largely as a result of the very high growth rate—2.4 percent—found in the Third World. This substantial growth rate stemmed mainly from an earlier large drop in mortality in these countries, made possible by medical and public health programs, as well as by improvements in the standard of living.

Between 1960–1965 and 1980-1985 the rate of world population growth declined from 2.0 to 1.6 percent, in part due to the decline in fertility in the Third World. Although this decline was substantial in some countries, Freedman noted that it is still not evident in large parts of the Third World, particularly in sub-Saharan Africa, Southwest Asia, and the Arab world.

The total fertility rate for developing countries has fallen by about 33 percent in the last 25 years (22 percent, excluding China). In some developing countries, fertility rates have fallen even more sharply— for example, about 70 percent in Taiwan in the 25 years after 1960 and 45 percent in Thailand during the same period. The decline has leveled off in some countries, but it is uncertain whether this is a temporary deviation from the long-term decline.

Further major mortality declines in the Third World are almost certain if we apply what we know and if there is reasonable progress in social and economic development.

Freedman

Fertility declines in the Third World have had only a moderate effect on the population growth rate because of the simultaneous decline in mortality, and for this reason some scientists have denigrated the fertility decline in developing countries. Freedman finds this to be a rather short-sighted view, however, for three reasons. First, the decline in mortality is important because it saves lives and is a crucial facilitating condition for further fertility declines. Second, the fertility decline under way is likely to continue. And finally, the decline will lead to fewer children in the population. The burgeoning numbers of children and the investments in health, education, and employment that they require are a major problem in many countries.

Methodological and Substantive Contributions of Social Demography

"A major contribution of social demography in recent decades has been the development of 'indirect' methods for utilizing poor Third World data to [estimate the] basic demographic measures needed for population and development research and policy analysis," stated Freedman. Demographic data and the basic principles for their interpretation are, of course, indispensible in the development and implementation of population policy. "This does not mean that there is a direct line between demographic data and population policy," he warned. "Demographic facts and relationships attract the attention of policymakers when their relevance to central problems of government are obvious."

Another important finding of social demography is that even when fertility in Third World countries has fallen to replacement levels with two-child families and low mortality, populations continue to grow for decades because of the very young age structures that resulted from the previous history of high fertility. Japan, for example, reached a replacement fertility level of 2.1 in 1957 and has been at or below that level ever since. Its population has grown by about 31 million since then, however—and will not stop growing until about 2015—because there was such a high proportion of young couples of childbearing age in 1957.

The female population aged 20–35 in developing countries will increase by about 36 percent over the next 20 years (compared with a 4 percent decline in the more developed countries). The developing countries can therefore count on further population growth. Yet another important finding is that an increase in the interval between births lowers the birthrate. Thus, policies constructed to reduce population growth should consider the timing as well as the number of births in each family, noted Freedman.

With the recent development of demographic survey methods and new population models, demographers can now estimate the notable increase in the use of family planning measures in the Third World. According to Freedman, contraception is the primary immediate cause of the decline in fertility, with rising age at marriage and abortion as the secondary causes.

> ***The work on new effective, convenient, and safe methods [of birth control], and especially male methods, is an important technological and scientific issue for the future of population and family planning. However, . . . very considerable increases in contraceptive prevalence are possible with the currently available contraceptives.***
>
> *Freedman*

In 1960 only a small percentage of Third World women were deliberately using fertility control measures. This proportion rose to an estimated 41 percent (about 260 million women) by 1984. The increase in the practice of contraception has been especially rapid in East Asia and parts of Latin America.

More effective methods of contraception are also being used. Sterilization utilizing relatively safe and inexpensive methods is increasing rapidly, but Freedman speculated that Norplant^{R}, an implant that is effective for five years, is likely to replace much sterilization, if essentially commercial problems in its introduction are overcome.

Role of Family Planning Programs in Declines in Fertility

In 1960 only a few developing countries had official policies for either reducing their birthrates or supporting family planning activities. By 1984, however, 76 percent of the people in the Third World were living in countries with official policies to reduce birthrates, and an additional 17 percent were in countries supporting family planning activities for health and welfare reasons. Those countries with neither policy were mainly small ones containing only 7 percent of the total Third World population.

> ***Longer birth intervals and smaller families contribute to the health of the mothers and children, and to the development and education of the children. That makes family planning a form of investment in human capital which is a crucial ingredient of social and economic development.***
>
> *Freedman*

He then posed a question: 'To what extent have family planning programs produced fertility declines in addition to what would have happened anyway as a result of social and economic development?' Lapham and Mauldin[1,2] found in their study of 93 developing countries that socioeconomic development and family planning each had an independent effect on contraceptive use and fertility decline, but that together they had a major effect. Other evidence

indicates that, given historical precedent, the rapidity with which the disadvantaged in Thailand, Taiwan, and Indonesia, for example, have adopted contraception is unlikely to have occurred without their well-organized family planning programs.

Twenty-five years ago, observed Freedman, experts believed that social and economic development, urbanization, higher educational levels, and work in the modern nonfamilial economy increased the cost and decreased the benefits of children. They also believed that these factors increased the value of investing more in a small number of children and that small families planned with the use of contraception would become the norm.

In recent decades, however, empirical studies have indicated that the causes of the transition from high to low fertility are not so simple. Historical studies have demonstrated that the decline in fertility began in various parts of Europe under widely varying social and economic conditions and were considerably influenced by cultural factors. In the Third World, fertility has declined especially rapidly in countries with considerable social and economic development—for example, Taiwan, Hong Kong, Singapore, Korea, Mexico, and Japan—but it has also declined in countries having only some of the prescribed classical socioeconomic conditions—for example, Sri Lanka and the state of Kerala in India, which are poor and agricultural but strong in education, health, and nutrition.

Freedman pointed out that the World Fertility Survey of 42 developing countries (see box, page 9) found that such structural variables as education, labor force activity, and urbanization are only modestly related to contraceptive use and fertility.

"Partly [because] socioeconomic factors fall far short of explaining everything about reproductive levels and trends, the so-called 'ideational' hypothesis is becoming more prominent," said Freedman. According to this theory, ideas in themselves make a difference apart from socioeconomic factors. "Most obviously, the diffusion of the idea of family limitation as legitimate in marriage greatly facilitates the adoption of fertility control and of choice about family size." Ideas also play a role in the rising aspirations fomented by the exposure of Third World populations to worldwide networks of markets, transportation, and communication. These aspirations in turn affect reproductive choices when people desire more consumer goods and wealth than they have.

[1]R.J. Lapham and W.P. Mauldin. 1984. Family planning program effort and birthrate decline in developing countries. *International Family Planning Perspectives* 10(4):109–110.

[2]Ibid. 1987. The effects of family planning on fertility: research findings. Pp. 647-680 in *Organizing for Effective Family Planning Programs*, edited by G.B. Simmons. National Academy Press, Washington, D.C.

Importance of Pilot Projects

Although social and economic development is important for its own sake, Freedman suggested that in many of the poorest developing countries high-quality family planning services may help families adopt contraception to improve the health and welfare of the mothers and children, as well as to reduce fertility. He warned, however, that well-monitored pilot projects are a necessary first step in establishing such services.

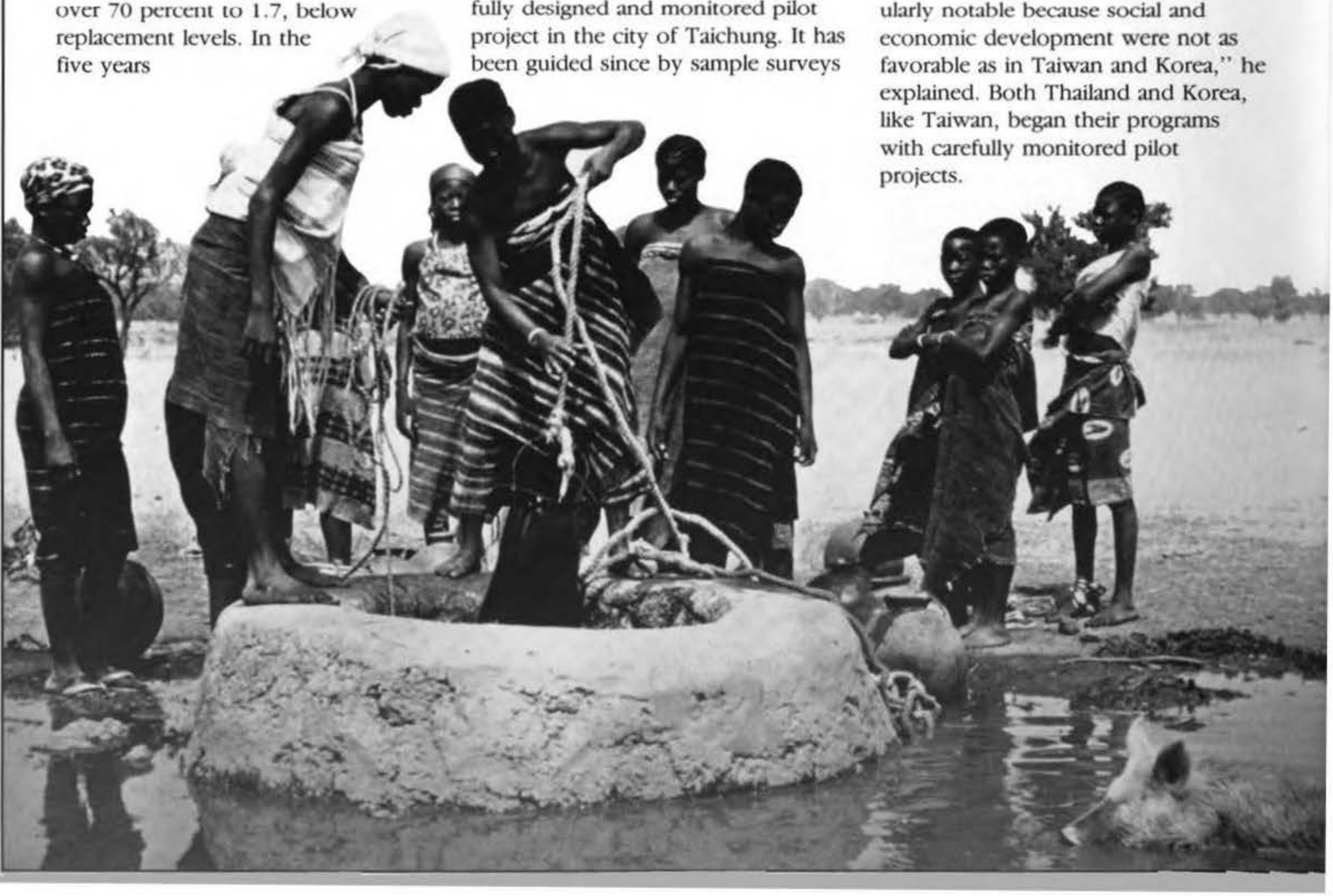
The highly successful family planning programs of the 1960s and 1970s in Taiwan, Korea, and Thailand were initiated by just such projects. In Taiwan, for example, the total fertility rate was about 6 in 1960, and contraceptive use was still at low levels. By 1976 the total fertility rate had fallen over 70 percent to 1.7, below replacement levels. In the five years from 1965 to 1970 alone the level of contraceptive use doubled, from 28 to 56 percent. More important, among illiterate women contraceptive use increased from 19 to 51 percent in that same five-year period. By 1975 the differentials in contraceptive use among strata defined by education, urbanization, or income had virtually disappeared. By 1985 contraceptive use was virtually universal.

In following its guiding principle, the Taiwan program offered high-quality services to women who wanted no more children—initially women with at least two children and one son. It did not seriously attempt to persuade couples that they should want fewer children.

The program was initiated with what was learned from a large, carefully designed and monitored pilot project in the city of Taichung. It has been guided since by sample surveys and studies, and new ideas have been tested in pilot studies before their application on a large scale.

The success of Taiwan's family planning program was undoubtedly influenced by that country's rapid social and economic development. Historical precedent elsewhere, however, makes it unlikely that the disadvantaged poor, rural dwellers, and illiterate would have adopted family planning so rapidly without this program.

Freedman then pointed out that the Korean family planning program has been comparable to Taiwan's program in many respects—with similar but not equal results—because of its large rural sector. "The very rapid decline of fertility in Thailand, associated with its family planning program, is particularly notable because social and economic development were not as favorable as in Taiwan and Korea," he explained. Both Thailand and Korea, like Taiwan, began their programs with carefully monitored pilot projects.



In contrast, the lesser success of programs in some large Asian countries, for example, has resulted partly from the initial application of uniform national policies without sufficient reference to local conditions and without adequate testing and continuous monitoring. Even where official family planning programs have been unsuccessful in either increasing contraception or reducing fertility to any significant extent—almost all of these are in countries in which both the development levels and the family planning program efforts are at low levels—there is evidence of a latent demand, at least as a means of spacing births and in some cases of limiting family size.

In Bangladesh, for example, the conventional view has been that high fertility and low interest in family planning are inevitable in a country so poor, and with young couples so dependent on children and relatives for subsistence and support. Many women with three or four living children had begun to say when surveyed that they wanted no more children, but this evidence of latent demand for fertility control was written off by most respected observers because it was not followed by the adoption of contraception.

A pilot project launched in the Matlab area of Bangladesh to provide a carefully designed, intensive program of family planning services as well as modest maternal and child health services rather quickly brought contraceptive use up from very little to 45 percent, with a commensurate fall in fertility. Whether application of what was learned in Matlab can make a major difference on a national level is a scientific and policy question of great importance both for Bangladesh and for other very poor developing countries.

Freedman emphasized that the significance of this project is that the latent demand indicated by the survey was real and that many couples adopted contraception when offered a high-quality service by a well-organized program. He then described a family planning program at Chogoria in Kenya somewhat similar to the Matlab project, but functioning in a completely different cultural and social situation. This program too brought contraceptive prevalence up to the 40 percent level and showed that the potential demand was real.

In many developing countries, including Bangladesh and Kenya, lower mortality means higher child survival so that many Third World women, by the time they are about 30, already have alive the number of children they want. Thus, more and more women with years of childbearing still ahead are saying that they want no more children. The increasing number of living children creates pressures on traditional institutions that were developed on the implicit assumption that many children would die. Many women too are feeling the pressure caused when traditional values and institutions clash with new realities and ideas. For some of these women sound family planning information and services can help crystallize latent demand for contraception. "In both the Bangladesh and Chogoria pilot projects a significant part of contraceptive acceptance is for spacing rather than limiting births, basically a health and welfare motivation, but with a fertility-reducing effect," summarized Freedman.

Finally, Freedman noted that part of the contribution of social science to population policies has been the development of methodologies useful to population and family planning programs. These include estimates of fertility and mortality trends, population structure, and changing reproductive patterns; microstudies of the quality and content of client-provider relations in clinics; and field research to evaluate new initiatives in family planning programs in their local contexts.

> ***Each country should, so far as possible, study the evolving changes in its population and population policy just as it studies its economy.***
>
> ***Freedman***

These developments require a variety of personnel in demography, epidemiology, public health, and medicine. Fortunately, the few centers for population research and training existing 25 years ago are now complemented by more than 20 centers in the United States alone. Outstanding centers are also located in Australia, England, and France. These centers have trained hundreds of population and family planning specialists, a large number of whom are from the Third World, where they now staff a growing number of indigenous centers and train others.

"The development of new methodologies that have been crucial to the informed development and monitoring of population policies has largely been done either directly at the population centers or by personnel trained there. The fundamental importance of these centers and their networking function is not fully appreciated," concluded Freedman.

IN PRAISE OF NINE

At an invitational dinner held in conjunction with the Symposium on Science and Technology for Development: Prospects Entering the Twenty-first Century, nine organizations were honored for their substantial contributions to furthering the application of science and technology to development over the past quarter century.

In addressing the award recipients and guests, Frank Press, president of the National Academy of Sciences and chairman of the National Research Council, observed that the honorees "represent a wide range of interests but share the characteristics of being nongovernmental and of having contributed leadership, innovation, and sustained effort in applying science and technology to development needs." He cautioned, however, that although their accomplishments give us hope for the future, "this hope will have to be reinforced with continued support and leadership in focusing science and technology on development needs."

In his remarks, former USAID Administrator M. Peter McPherson saluted the honorees as having "literally changed the face of the developing world—changed it for the better." Citing accomplishments of the past 25 years and development challenges that lie ahead for science and technology, he closed by saying, "I am very proud to have had the opportunity to lead USAID during these especially productive last six years and to be head of an organization that's done so much in partnership with all of you. I truly believe the best is yet to come."

The honored organizations and their citations follow:

Pictured above are representatives of these organizations. They are, from left to right, Alastor North, Peter Osler, S.K. DeDatta, William B. Greenough, Thomas S. Carroll, D.A. Henderson, Robert L. Clodius, George Zeidenstein and Ken Prewitt. Presenting the award is Frank Press.

ASIAN INSTITUTE OF TECHNOLOGY (AIT)
Thailand

An example of a Third World regional center of excellence in postgraduate education which, through its training of scientists and engineers from Asian countries, has effectively transferred industrial technology and skills to the developing world.

CENTRO INTERNACIONAL DE MEJORAMIENTO DE MAIZ Y TRIGO (CIMMYT)
Mexico

INTERNATIONAL RICE RESEARCH INSTITUTE (IRRI)
The Philippines

International agricultural research centers that mobilized scientific talent from both advanced and less-developed countries, carried out the research and training that made possible the "green revolution" in Asia and Latin America, and continue to serve as stellar examples of the successful application of science and technology to the most vexing problem of the world's poorest people, an adequate food supply.

CONTRIBUTING ORGANIZATIONS

INTERNATIONAL CENTRE FOR DIARRHOEAL DISEASE RESEARCH
Bangladesh

For its diarrheal disease research and its substantial contribution to global child survival, most importantly through the development of the technology known as oral rehydration therapy.

INTERNATIONAL EXECUTIVE SERVICE CORPS
United States

A leading private, nonprofit organization that has drawn on the industrial and business experience of more than 10,000 retired professionals who have contributed their time as well as their managerial, scientific, and technical expertise in developing countries to help local enterprises install new technologies.

JOHNS HOPKINS SCHOOL OF HYGIENE AND PUBLIC HEALTH
United States

An outstanding example of a private U.S. university whose research, education, information, and technology transfer activities have profoundly influenced health, nutrition, sanitation, and family planning practices in the developing world.

NATIONAL ASSOCIATION OF STATE UNIVERSITIES AND LAND GRANT COLLEGES
United States

An association whose member institutions in the United States have contributed mightily to Third World human resource development through both the training of developing country students on U.S. campuses and the building and strengthening of indigenous research and education institutions in developing countries.

POPULATION COUNCIL
United States

An organization in the vanguard of the movement to identify the problems of rapidly expanding world population growth, to bring population growth issues to the forefront of the development agenda, and to both undertake and support research and training programs that have helped stem rapid population growth in an increasing number of developing countries.

ROCKEFELLER FOUNDATION
United States

For its pioneering efforts in mobilizing and supporting scientific research to address Third World development needs in food and agriculture, health, and other fields and for its early and continuing support of developing country institutions that have provided the science and technology base in Asia, Latin America, and Africa.

ENTERING THE TWENTY-FIRST CENTURY

Scarcely a day passes without mention in the news media of another exciting biotechnological discovery made in this nation's research laboratories. Genetic engineering is being applied to human and animal health, agricultural production, and many other vital aspects of the human existence. These advances are especially relevant to Third World countries where the problems are compounded by conditions often mentioned only in the history texts of the developed countries.

Several speakers addressed the subject of biotechnology at this symposium. They described briefly how the relatively young disciplines of molecular biology and genetic engineering have affected humans, plants, and animals worldwide, and how the many amazing accomplishments made thus far are likely to affect the developing countries. They also assessed what the future holds in these fields.

Biomedical Breakthroughs

Biomedical breakthroughs using the techniques of biotechnology are contributing to human health in the diagnosis, treatment, and prevention of disease. In the *diagnosis* of both infectious and genetic diseases there is widespread interest in using simple, rapid diagnostic tests based on nucleic acid hybridization and monoclonal antibodies. In the *treatment* of disease, molecular biology can help isolate and determine the complete chemical and three-dimensional structure of, for example, receptors for drugs, the key parasitic enzymes, and the folic acid system. And in the *prevention* of disease, molecular biology and biotechnology are of particular interest in vaccine development, a subject that is well known to Dr. Kenneth S. Warren, director of health sciences at the Rockefeller Foundation.

Approximately 20 vaccines have been discovered over the last 200 years, many of which are inferior and most of which are not used today. Only six vaccines are being used by the World Health Organization's immunization program—BCG (tuberculosis), diphtheria, pertussis, tetanus, measles, and polio—and a few others are also being used in the United States (particularly mumps and rubella) and elsewhere (the yellow fever, cholera, and typhoid vaccines, for example).

Tragically, however, children are still dying—5 million in 1980 alone—from diseases for which vaccines are available, and the toll is the highest, of course, in the developing countries. According to Warren, the major causes of childhood deaths worldwide are diarrhea and malnutrition, measles, lower respiratory infection, tetanus, and malaria. For the great killers like the diarrheas there are no effective vaccines. Likewise, there are no vaccines for malaria nor for any of the other major parasitic infections such as trypanosomiasis, leishmaniasis, amebiasis, schistosomiasis, filariasis (especially river blindness), and all the helminth infections (roundworm and tapeworm).

Added to this shortage of vaccines is the inadequacy of many of the key vaccines. For example, BCG vaccine has been controversial for years, and studies in southern India have questioned whether it can prevent pulmonary tuberculosis. The side effects of the pertussis vaccine are so severe that England, Japan, and some of the Scandinavian countries no longer use it, despite the fact that an epidemic of the disease is worse than the vaccine.

BIOTECHNOLOGY

Present State of Biotechnological Research on Vaccines

Before describing recent developments in vaccine research, Warren pointed out that biotechnology is "a very young discipline in terms of the practical outcomes of what's been done," yet it has already produced an excellent and very powerful vaccine. The hepatitis B vaccine has been approved by the U.S. Food and Drug Administration and is licensed for use. Hepatitis B is a major cause of liver cancer throughout East Asia and Africa.

As of April 1986 the U.S. Army had 42 new vaccines under development; the National Institutes of Health, 28 vaccines; and the Rockefeller Foundation, 6 vaccines. As for priorities for vaccine development, the Institute of Medicine compiled its own list of priorities based on a combination of the importance of the disease and the state of research that is likely to lead to a vaccine in a relatively short time.[1] The five priorities listed for the United States were hepatitis B, respiratory syncytial virus (which causes most of the croup in children in the developed world and is a major killer in the developing world), ***Hemophilus influenzae*** Type B, influenza virus, and chicken pox. Priorities for the developing countries were pneumococcal pneumonia, malaria, rotavirus (one of the major causes of diarrhea and one of the major killers of infants in the first year of life in the developing countries), typhoid bacillus, and shigella (bacillary dysentery).

[1]National Research Council. 1985 and 1986. *New Vaccine Development: Establishing Priorities.* Washington, D.C.: National Academy Press.

Acute Respiratory Diseases in Children: A Research Grant Area of the Board on Science and Technology for International Development

Acute respiratory infections (ARI) are still the world's leading killer of children. Through its research grants program supported by the U.S. Agency for International Development, BOSTID's Committee on Research Grants is funding etiologic studies in 12 countries. They will provide a critical first step toward developing effective treatment protocols and, possibly, a vaccine. An intensive effort is presently under way to analyze and interpret the substantial data that have been gathered.

In drawing conclusions from this data, grantees are grappling with such problems as the finding that the incident rate of ARI in children is no greater in the Third World than in the United States, yet the mortality rate is 20 times higher in developing countries. The available data cannot answer whether the important factors are malnutrition, other infections, or unrecognized coinfections. It has been agreed that future studies will be designed to answer these critical questions, but that the results of the current etiologic research to determine the principal causal agents are a prerequisite for an attack on the pathogenesis problem.

At a 1986 meeting of the grantees, ARI researchers reported on a rapidly expanding body of data. Respiratory syncytial virus is the virus most closely associated with severe ARIs, but other viruses are also seen. Speculation centered on the idea that the viral infection leads to severe bacterial infections in the worst cases.

The polio vaccines have made news again. The protective antigen from polio vaccine 3 has been genetically engineered into polio vaccine 1, resulting in one vaccine that protects against polio viruses 1 and 3. Most likely polio vaccine 2 will soon be combined with the other two into one vaccine that immunizes against all three strains of the disease.

As for the two childhood diseases pertussis and measles, a new acellular vaccine has been developed for pertussis in Japan that is much less toxic. It is being tested in Scandinavia. And the newest measles vaccine, Edmonston-Zagreb, is being tested for administration to children as early as four months of age.

In another development, genetic engineers have cloned the entire gene structure of *Mycobacterium* tuberculosis, of respiratory syncytial virus, and of human immunodeficiency virus (HIV), the cause of acquired immune deficiency syndrome (AIDS).

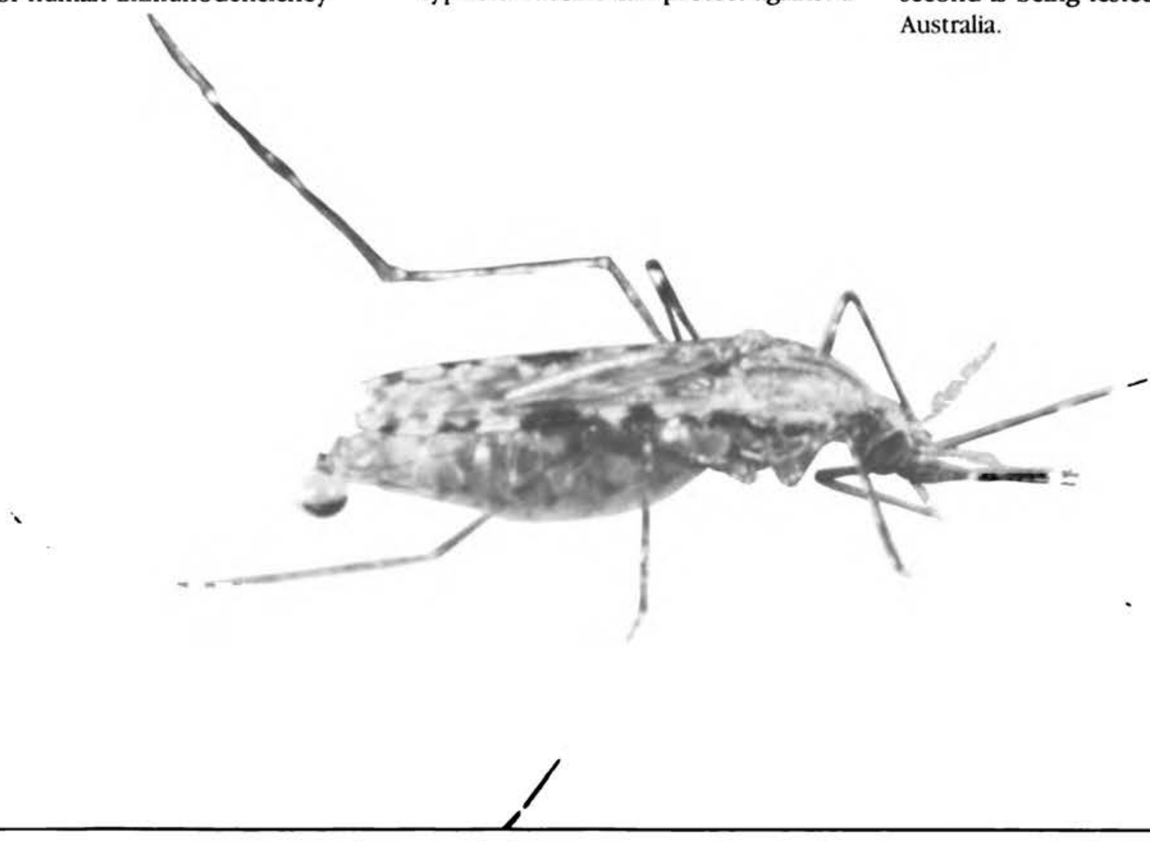
Challenge studies recently undertaken with mosquitoes carrying living malaria have shown that the first synthetic malaria vaccine in human trials offers hope for protection against malaria. According to Warren, this is indeed a major breakthrough and may signal the introduction of a practical malaria vaccine.

The new typhoid vaccines are living typhoid bacteria with a defective biochemistry. Thus, when given to children the living bacterium penetrates the intestinal wall, and because it is missing certain crucial enzymes, it slowly dies in the tissues. Immunization results from the inability of the living bacillus to live within human tissues. Other genes can be inserted into the *Salmonella* bacterium so that theoretically one oral dose of the typhoid vaccine can protect against a whole range of intestinal infections.

The gene deletion technique—deleting the part of the gene responsible for causing disease—has been used to delete the cholera toxin from cholera bacillus. This toxin causes severe diarrhea.

The new and very powerful technique of gene insertion is being used to turn the vaccinia vaccine (the old smallpox vaccine) into a vaccine that can protect against a large number of different diseases. As many as 20 different genes can be inserted into this vaccine, which is then scratched into the skin in a simple procedure. The twenty-first disease is smallpox itself, which fortunately is no longer needed because this disease has been eradicated worldwide.

Even antifertility vaccines have been developed, and the first was tested in India several years ago. The second is being tested now in Australia.



Finally, the latest finding in vectors is the shuttle plasmid, a phage that goes into mycobacteria as well as a plasmid that goes into *E. coli.* According to Barry Bloom, author of "Introduction of Foreign DNA into Mycobacteria Using a Shuttle Plasmid" (*Nature,* June 11, 1987), "it may be possible to develop mycobacteria into useful multi-vaccine vehicles."

One almost unbelievable problem faced at the moment, noted Warren, is the plethora of prototype vaccines for some diseases. At least six different rotavirus vaccines are now being tested in children, and at least eight different vaccines for controlling schistosomiasis are in the laboratory.

Warren ended his presentation by calling attention to the efforts being made by UNICEF, WHO, USAID, and others to make universal childhood immunization a reality. In a big step toward this goal, China has agreed to raise its childhood immunization rate from 50 percent to 100 percent, and India has dedicated to Indira Gandhi a major campaign designed to immunize all its children by 1990.

"The feedback loop has been established," concluded Warren. "The children of the world are being immunized and if the power of biotechnology to produce new and better vaccines is fostered, the well-being of children throughout the world will be remarkably improved."

Mosquito Vector Field Studies: A Research Grant Area of the Board on Science and Technology for International Development

With the support of the Office of the Science Advisor, U.S. Agency for International Development, BOSTID's Committee on Research Grants is funding a small number of research projects in developing country institutions that focus on the population ecology of mosquito vectors in relation to the epidemiology and control of human diseases.

These investigations are seeking to characterize vector habitats; quantify vector abundance and seasonal or year-to-year variations and survivorship; document the interaction of vectors, vertebrate hosts, and pathogens; and identify the factors affecting vector abundance (including survival).

Despite research advances in mosquito vector studies, the disease problems have worsened. Malaria is spreading to areas where it had not recently been a problem, and resistance of mosquitos to insecticides and of parasites to medication is spreading at an alarming rate. Several BOSTID researchers have revealed issues that are more serious than anticipated, involving genetic-linked geographic diversity (implying that experience with control of an anopheline species in one place may not be valid for the same species in another) and interaction of vector species with human habitats. Some new technologies have proved successful, however, in the battle against malaria—for example, enzyme-linked immunosorbent assays (ELISA) for detecting infected mosquitoes and DNA probes for identifying hard-to-distinquish sibling species. ·

Human Reproduction and Contraceptive Research

The exciting advances being made in reproductive biology will undoubtedly lead to safer, more effective family planning in both developed and developing countries, and a greater number of contraceptive options from which to choose. The relationship between heterosexual transmission of AIDS and choices in contraception must, however, also be considered.

With this introduction, Dr. Gary Hodgen, professor and scientific director at the Jones Institute for Reproductive Medicine of the Eastern Virginia Medical School, described the state of contraceptive technology today and the new research areas that will garner attention in the future. He also described the Contraceptive Research and Development Program (CONRAD) being undertaken at the Jones Institute for Reproductive Medicine (see box).

About 70 percent of the population of the developed countries uses some method of fertility control, reported Hodgen, ranging from the highly effective to the moderately effective. In the developing countries—using Nigeria as an example—5 percent or less of the population practices family planning. Thus, there is much to be done in the developing world. In undertaking such work, cautioned Hodgen, it is important to realize that contraception is not just a tool for limiting the number of births. It is also a tool for managing the spacing of births, thereby allowing healthy children to be raised in a more nurturing environment.

U.S. investigators are now on the threshold of a major conceptual change in the development of new

methods of birth control. This change is based on prevention of the interaction between the egg and sperm that achieves fertilization (local effects), rather than suppression of the reproductive function (systemic effects). The idea is to render the egg or oocyte incompetent for fertilization and development, while avoiding any effect on hormone production by the ovary or the testes. Achievement of a local effect avoids the host of side effects that result when hormone levels are altered—for example, problems with bloodclotting factors, liver metabolism, skin, and cancer, just to name a few. The sperm cell may be another selective site of action, particularly the site of the epididymis where sperm cells gain fertilizing capability, rather than the spermatogenic epithelium within the testes itself where hormone production might be affected.

Another contraceptive possibility is GnRH (gonadotropin-releasing hormone), a 10-amino decapeptide made in the hypothalamus, located at the base of the brain. In the use of GnRH analogs for contraception, complete suppression of hormone production is being avoided, Hodgen emphasized, because of all the side effects created. The male would lose libido, for example, while in a female the severe hypoestrogenic status that would result from daily treatment could promote the risk of osteoporosis in young women. Fortunately, the early data reveal that intermittent administration of the GnRH antagonist will halt the production of a fertilizable egg, while maintaining the hormonogenic function (estrogen production) of the first half of the ovarian menstrual cycle. Oral progesterone or some other progestin must be provided, however, to avoid an "unopposed estrogen status" and the risk of indomitable carcinoma. An orally active form of progesterone is now being tested because many of the progestins have undesirable side effects, such as androgenization. Some progestins do not have the desired selectivity or specificity, and they affect hair growth, cause acne and weight gain, and shift important HDL (good cholesterol) toward LDL (bad cholesterol). A new progestin, Norgestimate, has a low androgen effect and a selective progesterone-like action on the uterine endometrium. It is now in phase three clinical trials.

Hodgen also mentioned the research being undertaken on nonsteroidal gonadal hormones such as Inhibin, a heterodimer which can produce inhibition of follicle-stimulating hormone secretion from the pituitary.

Contraceptive Research and Development (CONRAD) Program

The Jones Institute for Reproductive Medicine at the Eastern Virginia Medical School is the primary center of the CONRAD program, which began in the fall of 1986 with funding of $28 million and the support of USAID. The objectives of the program are to develop and identify technologies useful in family planning and to provide the scientific basis for their safety and mechanisms of action.

The intramural research effort (30 percent) consists of the basic studies and phase one and two clinical trials, while the extramural research effort is undertaken off campus in conjunction with the Population Council, Rockefeller Foundation, Mellon Foundation, World Health Organization, and National Institutes of Health, among others. When possible, projects that may result in improved means of contraception are organized with investigators from the United States and, especially, Third World countries. Additionally, the assistance of pharmaceutical and biotechnology companies is sought in the development of new products.

Acquired Immune Deficiency Syndrome (AIDS)

The relationship between human sexuality and a high rate of AIDS transmission—perhaps more than 20 percent of the population in some areas—means that researchers can no longer develop or advocate contraceptive methods without taking into account their impact upon transmission of the deadly human immunodeficiency virus.

Since little is known about the vector sources or routes of HIV transmission among heterosexual couples, reported Hodgen, it is also not known what impact the contraceptive methods used today have on transmission—whether they have no effect, a greater effect, or a protective effect. "It is imperative that we get those answers as rapidly as we can," declared Hodgen. "I think it is appalling that we have come as far as we have looking at this cloud called AIDS transmission and we have done as little as we have." He advocated rapid action in this area and appealed for information on how well the heterosexual transmission of AIDS in developing countries is being tracked.

Of interest to Hodgen is the spermicide Nonoxynol 9, which is known to have some protective effect as a viricide. Although it was not designed to serve that function, observed Hodgen, perhaps reagents can be developed that are contraceptive through their spermicidal action while at the same time acting as a potent and reliable viricide. They can then kill viruses before they can enter the body and cause contamination with HIV.

In a related area Hodgen advocated aggressive pursuance of the SAIDS (simian AIDS) model. SAIDS is a series of viruses that attacks macaque monkeys, including the rhesus. The familiar rhesus monkey, Hodgen believes, would be a good model for understanding the roots and vectors of AIDS and for testing what might be a potentially useful viricidal agent to accompany a method of contraception. Hodgen called, moreover, for quick steps to evaluate the commonly used methods of birth control to determine the primary risk factors in terms of roots and vectors. He warned, however, that the public's perception would be important in any pronouncement that a particular method of birth control is vulnerable to AIDS transmission. The data must be on hand to back up any such statements, he stressed.

Animal Biotechnology

Genetic Improvement of Farm Animals

According to Dr. Tilahum Yilma, professor of virology at the University of California at Davis, genetic improvements in farm animals over the next decade will largely result from the manipulation of gametes and embryos, the use of transgenic organisms, and the use of a new class of genetic markers.

The techniques of embryo manipulation were originally used to study the dynamics of early embryogenesis. Today, however, these techniques—much improved over time—are being applied commercially, and improved farm animals are obtained by gene transfer, cloning, and in vitro fertilization. Thus, it is now possible to produce animals with specific traits in one gestation period, rather than having to use the time-consuming classical genetic techniques. Yilma described some techniques that will be used more frequently in the future:

- Nuclear injection, in which cloned genes are injected directly into the nucleus of an embryo for integration into the host DNA, requires special techniques for the achievement of gene injection, gene integration, gene expression, gene regulation, and inheritance of the injected foreign genes. Because the success rate of this procedure is considerably higher than that of cytoplasmic injection, it will probably be used more commonly in farm animal production.

• **Nuclear transplantation** is used to produce parthenogenetic, gynogenetic, and androgenetic embryos, and could possibly also be used to clone embryos. The latter has been demonstrated successfully in amphibians, but there has been little success in its application to cloning mammalian embryos.

• **Embryo splitting** has been used widely in livestock to generate identical offspring. The individual blastomeres of embryos can give rise to normal young.

• **Chimeras**, formed by aggregations of cells from different embryos, have been used to study the regulation of early embryo development.

• **Injection of sperm** from foreign species, using micromanipulation techniques, into oocytes to form normal pronuclei has been carried out, but Yilma was unaware of any reported births from such a technique.

A transgenic animal is one in which foreign DNA has been stably integrated into its germ line so that a foreign gene is transmitted as a normal inheritable trait. Using transgenics, a genetic trait determined by a single gene, such as the gene for growth hormone, can be introduced into an animal by microinjection of the cloned gene directly into the pronucleus of a fertilized egg, or by the use of retroviral and other viral vectors. Diseases associated with single genetic defects could possibly be treated by introducing a normal counterpart of the defective gene. Transgenic animals could also be engineered for use as animal models for those human hereditary diseases for which no natural animal models have been identified. Finally, explained Yilma, transgenic animals give information not only about random insertion and expression of a cloned gene, but also about insertion of the gene in a specific tissue and its regulated expression, as determined by specific enhancers and promoters.

Quantitative traits—those that are not determined by a single gene product (polygenic in nature)—may in the future be identified by a new class of genetic markers (restriction fragment length polymorphisms), which are detected using cloned DNA sequences as probes.

Animal Health

The use of recombinant DNA methods to identify and diagnose animal diseases in the next decade will be particularly beneficial for Third World countries. According to Yilma, this technology will most likely contribute to the following research areas: common disease alleles, alleles arising from new mutations, genetic linkage analysis, forensic application of allele markers, neoplasia-acquired genetic alteration, infectious diseases, and detection of sequences.

The four kinds of animal vaccines used today depend on modern biotechnological techniques. These vaccines are: subunit vaccines, in which only the component of the agent that induces protective immunity in the animal is used as the vaccine; recombinant DNA-derived vaccines; synthetic peptide vaccines; and anti-idiotype vaccines.

Animal Nutrition

Genetic engineering of microorganisms in ruminant digestive systems allows the use of hard (high-lignin) fibers in animal feed. Lignin has long been theoretically regarded as indigestible and is the main factor limiting the use of some forages. The genetically engineered organisms, however, are able to convert hard fibers into products that can be used by the host animal for energy.

Marine Animals and the Marine Environment

Biotechnology will also have a bearing on the future of aquaculture, which is being carried out in many developing countries. Among its contributions, biotechnology will permit the identification and cloning of fish, mollusc, alga, and crustacean genes. In those countries bordering seas and undertaking commercial aquaculture, such a contribution will increase the production of food as well as that of important chemicals and drugs based on marine life.

In a related area, it is known that the petroleum-based pollution of the marine environment has dire environmental and economic consequences. Engineering of a bacteria able to degrade petroleum products will be welcomed by all countries.

Plant Biotechnology

The "green revolution" in the United States and elsewhere has been fueled by three technological advances: (1) plant breeding, particularly wheat and rice; (2) breakthroughs in the use of crop chemicals for controlling weeds, for reducing losses during the growing period, and for improving grain storage; and (3) farm mechanization and the ability to till land faster and more efficiently. As a result of the careful selection and application of these technologies, many Third World countries have become self-sufficient in supplying their own food. Nevertheless, even given this enormous progress, the most important advance in agricultural production in this century is just emerging, supported by advances in agricultural biotechnology and information science (see the chapter on "Information Sciences and Communications Technology"). Dr. Robert Fraley, director of plant science technology at the Monsanto Company, focused on agricultural biotechnology in his symposium presentation, and more specifically on recombinant DNA and its use in the genetic modification of plants.

How Agricultural Biotechnology Works

Technology for introducing genes into plants revolves around the use of the soil bacterium *Agribacterium tumafaciens.* This bacterium is able to bind to a plant cell and introduce part of its genetic material into the chromosomal parts. Once introduced into the chromosome, the DNA is replicated, and it eventually becomes part of the plant's genetic information. It is then passed on through the seed. With the help of research, this system—which was established in the early 1980s—has been modified and improved so that it can be used routinely. The refinements over the last three to four years have been "spectacular and explosive," according to Fraley.

One of the key aspects of this technology is its minimal use of laboratory resources and equipment. In a simple procedure, small pieces of leaf or stem are sterilized and exposed to the agribacteria in a solution. The bacteria then bind to the plant cells and inject the genes into the plant material. Subsequently, the plant material is cultured in the laboratory under defined and sterile culture conditions.

This technology is now being applied to over two dozen plant species and the list is growing. Almost all of the vegetable crops, a growing number of the oilseed crops, and some of the important legumes can now be routinely manipulated using this technology. The cereals, including wheat and rice, are not yet on this list, because the *Agribacterium* system used to introduce genes is not compatible with gene introduction into the cereals. There have been remarkable breakthroughs, however, in the technology for the introduction of DNA into the cells of corn, rice, and wheat, and reports of these are just starting to appear in the scientific press. Fraley predicted that within the next three to five years every major agronomic crop will be manipulable using gene transfer technology.

State of Agricultural Research

In describing the present state of agricultural research in the United States, Fraley noted the concentration of research in terms of funding and expertise in universities and the private sector. The emphasis is on improving production efficiency, not necessarily yield, as in the past. The critical factor now is the unit cost of production, reported Fraley. Differentiating commodity products and an increased market orientation using taste, texture, flavor, and nutritional value, for example, are also important. Finally, the environmental contamination and pollution that stem from some of the agricultural technologies are of concern to many.

U.S. efforts in agricultural research are compatible with the long-term objectives of research aimed specifically at Third World needs. For example, despite the continuous improvement in crop production through advances in plant breeding, plant pests, particularly caterpillars and beetles, cause enormous damage in tropical agricultural areas. Molecular biology, however, allows scientists to clone the gene that codes for an insect control protein and use gene transfer technology to insert the gene into *Agribacterium,* where it is introduced into plants. The plants then regenerate to form transgenic plants that produce this insect control protein in their leaves. In the United States, this biotechnology-generated protection against insects is considered a value-added trait that will replace a certain amount of chemical insecticide usage, and it is an opportunity for developing countries, as well.

Another example of research oriented toward the U.S. market but of benefit to developing countries is weed control, probably the single biggest factor supporting yield increases in U.S. crops. Researchers developing new weed control chemicals are increasingly sensitive to how these chemicals will affect the environment, and research in molecular biology is focusing on understanding how these chemicals work, improving them, and designing safer, more effective molecules.

Yet another research topic of particular relevance to Third World countries is plant disease, and especially plant viruses. Viruses cause huge crop losses, particularly in tropical areas. One recently developed technology is a kind of plant immunization strategy based on molecular biology. For example, by cloning just the coat protein gene for tomato mosaic virus (a rod-shaped virus which has an RNA nucleic acid surrounded by a coat protein) and engineering it into a plant, the steady state production of the coat protein somehow interferes with the replication when that plant is infected with the virus. Although the molecular mechanism is not known precisely at this point, emphasized Fraley, the resistance created is dramatic and is applicable to Third World agriculture.

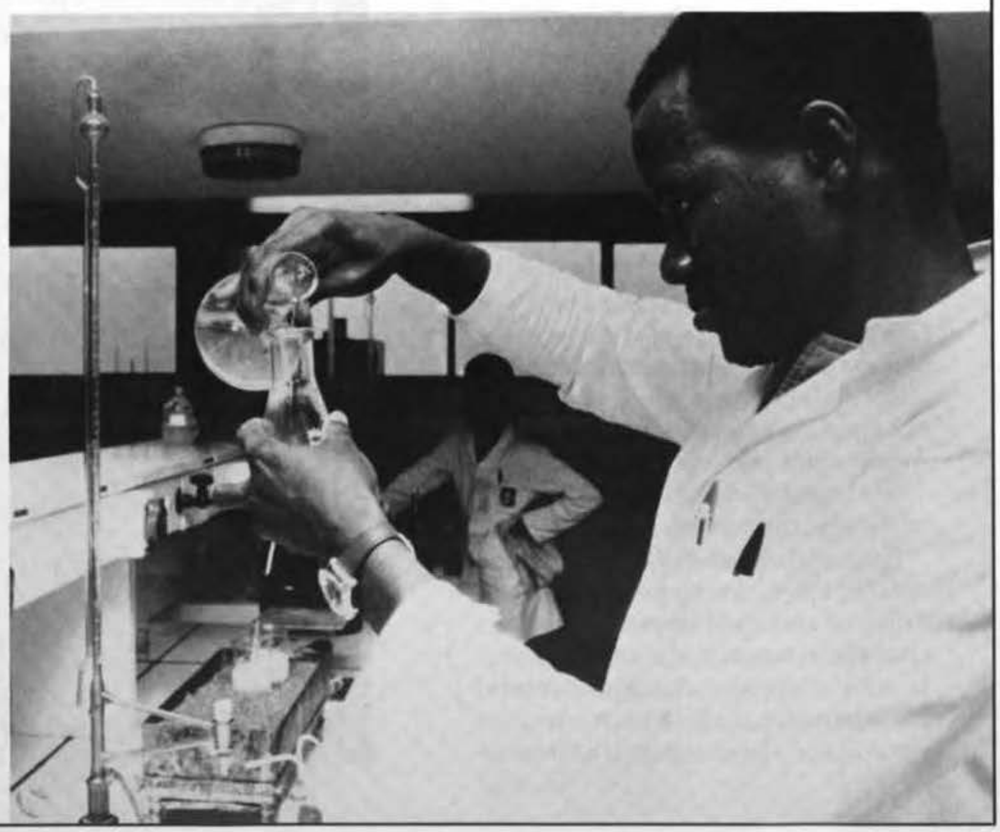
Transfer of Biotechnology

In looking at the transfer of this technology, Fraley referred to a 1982 report by the Office of Technology Assessment[1] which dealt with the impact of technology on agricultural production. It concluded that the biotechnology-based plant improvements he had briefly described will have a dramatic effect on Third World agriculture—greater, in fact, than on U.S. agriculture. The report predicts, however, a three- to five-year delay in the transfer of this technology.

Another factor supporting the accessibility of the newest agricultural technologies based on molecular biology is that these technologies are being provided to farmers in a familiar form—seed. "More than anything else, that is the reason why this technology will be accepted much faster than anyone predicts today," said Fraley. He also predicted that the same agricultural chemical companies and multinational seed companies now selling seed to 150 countries worldwide will supply farmers in developing countries with these value-added packages of genetically engineered seed. "It will follow very much the same trend—in a different way, of course—that has developed in this country where private industry has taken over much of the responsibility of the agricultural extension system because it is a profitable, target-driven business."

In concluding, Fraley voiced concern that the impact of the advances being made in agriculture will not be fully exploited, largely because of the growing ambivalence in the United States toward agricultural research. The concern in the United States and around the world about the health and safety of agricultural technologies has resulted, Fraley believes, "in a general antitechnology movement that has caused confusion and has led to a poor understanding of risk-benefit issues in this case." He continued: "We are without a doubt on the verge of the most important agricultural advance of this century. It is really up to us how this technology will be developed, managed, and exploited."

[1]Office of Technology Assessment. 1982. *Impacts of Technology on U.S. Cropland and Rangeland Productivity.* Washington, D.C.: OTA.



"At the very moment when modern science is about to allow us to reap benefits from our biological resources to an extent never before dreamt of, major portions of it are about to be forfeited permanently. Accordingly, and just in the nick of time, biological diversity, its peril and promise, is edging onto the development agenda." With these words, Dr. Thomas E. Lovejoy, executive vice president of the World Wildlife Fund (U.S.) and of the Conservation Foundation, went to the heart of the matter—the need to recognize and preserve the world's "biological capital."

Lovejoy reminded the audience of the incalculable wealth represented by the earth's spectacular variety of plant and animal life. Each species contributes to our understanding of the science of biology and to the ability of that science to pass on benefits via the more applied life sciences. Only by learning more about the full array of plant and animal life is it possible to understand the relationships between species and the controls of biological and ecological processes.

We are at a pivotal moment, stressed Lovejoy. "We are entering a period of potential extinction without equal during our history as a species." For example, the tropical forests of the world have been reduced to about half their original extent with an average annual deforestation rate of about 72,000 square kilometers. Without knowing exactly how many species exist, one can only guess that 10,000 species, mostly undescribed, are being extinguished each year.

Because there are only one to two decades left to do the job, the conservation of biological diversity must be undertaken aggressively, emphasized Lovejoy. Moreover, the driving forces for destruction, such as population growth, and the environmental impact

Biological Diversity: A Frequent Subject of Studies of the Board on Science and Technology for International Development

Tropical Legumes: Resources for the Future (1979)

The Winged Bean: A High Protein Crop for the Tropics, Second ed. (1981)

The Water Buffalo: New Prospects for an Underutilized Animal (1981)

Amaranth: Modern Prospects for an Ancient Crop (1983)

Little-Known Asian Animals with a Promising Economic Future (1983)

Firewood Crops: Shrub and Tree Species for Energy Production. Vol. I (1980); Vol. II (1983)

Mangium and Other Fast-Growing Acacias for the Humid Tropics (1983)

Calliandra: A Versatile Small Tree for the Humid Tropics (1983)

Casuarinas: Nitrogen-Fixing Trees for Adverse Sites (1983)

Leucaena: Promising Forage and Tree Crop in Developing Countries, Second ed. (1984)

Jojoba: New Crop for Arid Lands (1985)

Quality-Protein Maize (1988)

Triticale: A Promising Addition to the World's Cereal Grains (1988)

Microlivestock: Little-Known Small Animals with a Promising Economic Future (Forthcoming) of technology and development, must be addressed as part of the solution. He cautioned, however, that "efforts to protect biological diversity will fail if solely use-oriented," and he stated emphatically that the protection of biological diversity must never be viewed as a choice between conservation and human welfare, indicating that environmental degradation has gone too far.

He suggested several steps to address the problem:

• A crash effort in biological exploration is needed to map the world biologically so that both development and conservation can be undertaken with the right emphasis. Such an effort should include remote sensing (see the chapter on "Space Science and Remote Sensing") to indicate where the worst problems and best opportunities may lie and to settle the disagreements about the rate and extent of tropical deforestation.

• Training and institution building are essential for strengthening the existing scarce human resources and fragile scientific and environmental institutions so that they can cope with this enormous task.

• The establishment of new reserves and the strengthening of existing ones is fundamental.

• Sustainable use projects on alternatives to destruction are needed, especially pilot projects. In many areas agroforestry and forest extraction projects are the key to the solution. Freshwater fisheries throughout the tropics need ecologically sound management projects. Research on ecosystem management could guide efforts at sustained use in the tropics.

• Biological engineering and even simple exploration of biological diversity are likely to produce new crops for poor lands. From a biological perspective, 'badlands' are some of the last refuges of many species.

• Although perhaps three-quarters of the earth's biological wealth belongs to the developing nations of the tropics, some areas with extremely high biological diversity are in countries not receiving assistance from USAID. Brazil is an example. USAID needs to consider how it might work with the advanced developing countries on conservation of biological diversity.

• The emerging discipline of landscape ecology should be used in deciding how to integrate development and biological diversity into relatively large units of landscape.

• Finally, sensitivity to North-South issues is essential to avoid the perception that protection of biological diversity is a ploy to keep the developing nations from becoming developed. Any economic benefit from the exploitation of biotic resources should be shared by the country of origin and the investor nation.

Examples of Activities in Biological Diversity Supported by USAID in Fiscal Year 1987

Africa

Madagascar
Matching grant to World Wildlife Fund (WWF) for integrating the conservation of protected areas with the needs of local populations.

Mali
Matching grant to International Union for the Conservation of Nature (IUCN) for Inner Niger Delta conservation and development programs to inventory wetland areas and develop plans for management of wildlife habitats.

Regional
Matching grant to the African Wildlife Foundation to help the Mweka College of African Wildlife Management, Tanzania, establish a conservation education/extension curricula with links to basic human needs.

Asia/Near East

Nepal
Matching grant to WWF for research on interactions between humans and wildlife to improve protected area management.

Burma
Training collaboration with the U.S. National Park Service and WWF to assist the Burmese government with training for national park and wildlife management.

Philippines
Collaboration with the Haribon Foundation and International Institute for Environment and Development (IIED) on surveying and developing a strategy for biological diversity conservation.

Indonesia
Grants to WWF to develop biological diversity programs with Indonesian nongovernment organizations.

Regional
Collaboration with the U.S. Fish and Wildlife Service on a biological diversity small grants program.

Latin America and the Caribbean

Belize
Collaborative grant to the Belize Audubon Society, with WWF, to implement a management plan for the first marine park on the Belize barrier reef.

Costa Rica
Collaboration with the WWF and the government of Costa Rica on preserving and restoring a unique tropical dry forest as a component of the national park system.

Ecuador
Matching grant to the New York and Missouri botanical gardens and Ecuadorean universities to study economic botany of plant resources in eastern Ecuador.

Haiti
Matching grant to WWF and the Haiti Department of Tourism to establish and manage a national marine park in Les Arcadins Archipelago.

Peru
Matching grant to the Nature Conservancy and two Peruvian nongovernmental organizations to develop and implement a management plan for the Yanachaga/Chemillen National Park.

Consultative Group on Biological Diversity

With encouragement from USAID and the National Research Council, a Consultative Group on Biological Diversity was formed in 1987, with initial membership of USAID and a number of private U.S. foundations that support work in both conservation and development. Founding private members include the Ford Foundation, C.S. Fund, Alton Jones Foundation, Geraldine R. Dodge Foundation, Tinker Foundation, Rockefeller Foundation, John D. and Catherine T. MacArthur Foundation, Jessie Smith Noyes Foundation, the Pew Charitable Trusts, and The Rockefeller Brothers Fund. The purpose of the Group, which is currently developing its membership and mode of operation, is to enhance financial support for and collaboration on the conservation of biological diversity in developing countries. It is expected that the Group will expand to include other public and private donors and to establish close relationships with developing countries and conservation organizations.

The Rockefeller Brothers Fund, with funding from USAID, is establishing a secretariat to support the Group in its organizational and program development phase. Initial efforts will include sharing information, identifying priorities and biological diversity conservation programs that merit donor support, and developing information on nongovernmental sources of funds.

INFORMATION SCIENCES AND

"There is perhaps no area of modern technology that combines so many potential difficulties and problems of transfer and implementation with such high promise," began Dr. Philip F. Palmedo, chairman of the International Resources Group, in introducing information and communications technologies and their applications in the fields of agriculture, health care, and education.

"Information technology" is defined broadly to include conventional communications systems (telephones as well as satellite and fiber optic communications), radio and television, microprocessors, computers, and all the software, applications, and combinations of these technologies, including, for example, robotics and computer/video systems.

According to Palmedo, information technology is perhaps most valuable when used to provide people in developing countries with the information they need to make a correct decision—be they farmers trying to determine when they should plant their crop, or health workers trying to diagnose an illness. The timely availability of information and know-how is one of the critical barriers to development. Palmedo cautioned, however, that the application of post-industrial state technologies to preindustrial or industrializing countries "raises profound issues of both desirability and feasibility."

What are the issues surrounding use of these technologies in developing countries? According to Palmedo, they are:

- **The dazzle effect**. It is not safe to assume that dazzling and exciting new information technologies can solve major problems. There is already a tendency to overestimate the role of hardware, which traditionally is considered first in importance, followed by software, adaptation and training, and institutional development. This list should be reversed, argued Palmedo. For example, in one educational program the fascination with television interfered with the progress being made with use of the radio as a tool. The result was a deterioration in the services provided because the television system absorbed all the attention and funds. The lesson to be learned is that applications of information technologies should be driven by the needs, not by the technologies. Technical assistance agencies must understand where and how (in detail) to apply the appropriate technology and must implement accompanying programs in policy and institutional development so the new system will work.

Microcomputer Applications in Developing Countries: A Project of the Board on Science and Technology for International Development

Microcomputers are an increasingly important tool in all aspects of development as the need to handle and assimilate vast quantities of information becomes ever more critical for both the international development community and the developing countries. . . . Unfortunately this new technology represents not only an opportunity if properly exploited but a threat if ignored. The widespread and increasing incorporation of microcomputers into all aspects of the developed countries represents a major technological advance and an inevitable social change. If a developing country fails to take advantage of the opportunity that microcomputer technology represents, its level of development in relation to developed countries will be significantly lowered.

—*Microcomputers and Their Applications for Developing Countries*
(Westview Press, 1986)

This volume is the first publication emanating from a BOSTID project of the same title. In 1983 the U.S. Agency for International Development asked BOSTID to convene a series of four symposia to assess the implications of microcomputers for developing countries. The first symposium was held in Sri Lanka in 1984, and it addressed applications in agriculture, health, and energy (the above volume is a product of that meeting). The second symposium, which looked at applications in education, was held in Mexico in 1985, and the third was held in Lisbon in the fall of 1986 to examine expert systems and cutting edge technologies. Policies, priorities, and economic and public administration issues were the subject of the final symposium held in Washington, D.C. in January 1988. The proceedings of all four symposia are being published by Westview Press.

- **Dual sector problem**. A national capability in information technologies is useful only if it contributes to the development of other national priorities, such as improved health services, increased agricultural production, and advances in education.

- **Structural realities**. Information is a valuable resource. In some countries power is derived from the withholding of information. Thus, in the transfer of information technologies the structural characteristics of developing country governments must be considered. Two-way flow of information is essential. For example, technical information must flow from the government to the farmers and information on requirements and results must flow from the farmers to the government.

- **Quantification of benefits**. Although the benefits attached to the use of information technologies are usually indirect, it is important that they be measured no matter how difficult that may be. According to Palmedo, "it may well be that from a development perspective we have seriously underinvested in communications systems in the past."

- **Role of the private sector**. Much of the technology in this area resides in the private sector, leaving the door open for closer ties between foreign assistance agencies and private industry than has been the case in the past. For example, the U.S. Telecommunications Training Institute, an organization funded by AT&T, MCI, COMSAT, and others, has been used to train developing country professionals. USAID makes it possible for developing country technicians to take advantage of this training by funding their travel.

Applications to Agriculture

Although there have been dramatic improvements in agricultural science during the past 25 years, the transfer of research results to applications has been a problem. This finding was reported by Dr. James W. Jones, professor of agricultural engineering at the University of Florida. Recent advances in information science and computer technology have narrowed the gap between research and application in developed countries. Similar success is needed in developing countries. For example, if a country is importing much of its cooking oil and wishes to expand peanut production to meet national needs, this technology can suggest where and how the expansion should occur and which proposed agricultural projects should be considered. By using computer technology to integrate, organize, and store information and make it available to users in a timely and efficient manner, scientists, planners, and farmers can increase their ability to predict the outcomes of agricultural systems under various conditions. This approach is illustrated in Figure 1, which depicts the framework used by the IBSNAT (International Benchmark Sites Network for Agrotechnology Transfer) project.

Simulation models, data bases, and expert systems are the computer tools used to accomplish these tasks. The first tool, crop simulation models, integrates what is known about the crop-soil-weather-management processes so that crop yields can be predicted. Changes in temperature, humidity, precipitation, wind, solar radiation, and soil conditions cause tremendous variability in crop yields—over time and space. Crop simulation models cannot, however, be used without testing, cautioned Jones. These models should be tested and modified by researchers as needed for their own cultivars. Experiments can then be simulated on the computer and analyzed to help design critical field experiments to evaluate model results. This more efficient approach saves time and reduces the cost of field experiments.

Crop simulation models need databases, the second computer tool, to work. Computers can quite effectively organize and store data on soils, weather, crops, management, and economics for predictive models. With the advent of the more powerful microcomputers, spatial data (data on soils over a region) can be used to predict crop yields for a region and display them on maps.

The third computer tool, expert systems, has considerable potential for developing countries. Expert systems

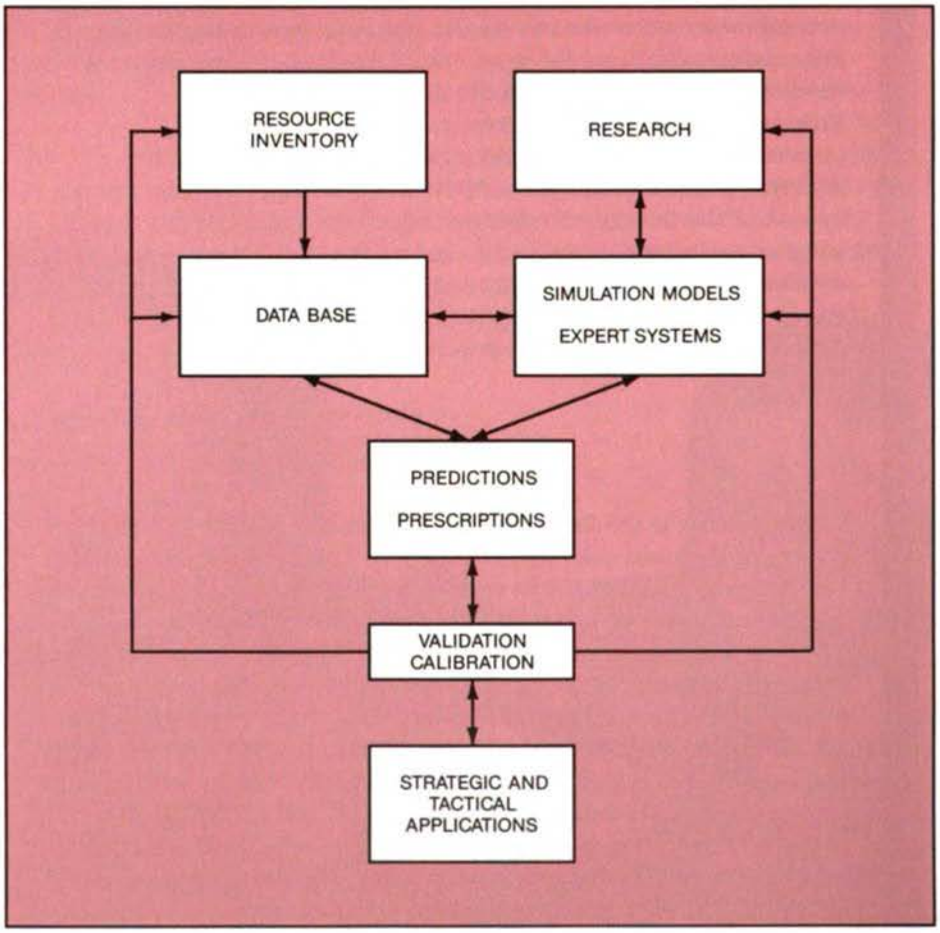


Figure 1 IBSNAT's framework for agrotechnology transfer.

are computer programs that can search stored knowledge for answers to specific problems. Much of our agricultural knowledge is based on experience that has not evolved far enough for direct integration into simulation models. For example, cited Jones, diagnoses of plant diseases or soil fertility problems, or recommendations of crop varieties or pesticide types and the amounts to use, do not lend themselves well to simulation. An expert system can store this information in the computer, thereby making expertise available when real experts are not. These systems can be adapted to specific locations and can be used by extension workers, with the appropriate training, to advise farmers. Of the various expert systems that have been developed, one of the most notable is for managing soil pH in Indonesia. According to Jones, this methodology is only in its infancy, but it shows considerable promise and should be developed further. The IBSNAT project is evaluating the capabilities of these technologies.

In concluding, Jones called for science and education programs to encourage the integration of this technology into existing research and technology transfer programs for developing countries. "Emphasis should be placed on research to develop and test crop simulation models and the expert systems needed to help analyze critical problems, and to develop spatial databases. . . . In this way the tools of the information age can be used by scientists around the world to help integrate, organize, and store agricultural knowledge in a form that can be easily transferred to and used by others."

IBSNAT International Benchmark Sites Network for Agrotechnology Transfer

IBSNAT, a program supported by the U.S. Agency for International Development and carried out by the University of Hawaii, uses advanced computer technology to overcome the bottlenecks that prevent new or alternative crops, cultivars, products, and practices from being quickly integrated into Third World farming systems. A decision support system, devised by combining soil, crop, weather, and farm management data bases with simulation models and expert systems, allows long-term strategic planning and day-to-day tactical decisions by farmers.

Participants in this program—scientists from developing country research centers, planning agencies, and universities, as well as international research centers—hope to accelerate the transfer of agrotechnology and to maximize its successes and minimize its risks. They will also assess the long-term effects of agricultural practices on the agroecosystem.

With the recent advances in computer technology and artificial intelligence, the costly and time-consuming trial and error method of technology transfer can be supplemented by a systems-based approach. This approach can predict the performance of a crop, product, or practice in any location during any season and for a wide range of management alternatives. The advances in information technology include personal computers with near-mainframe capabilities, large-capacity data-base management systems that are easily accessed, and new developments in the field of artificial intelligence.

The scientists participating in this program have already made considerable progress using these advanced technologies. Five two-week workshops have been held in various countries to train agricultural scientists in these concepts, and crop simulation models for corn, soybean, wheat, and peanut have been developed and are being tested (models for other crops are being developed). Work on expert systems is just beginning.

Applications to Health Care

In trying to apply information and communications technologies to health care systems in the twenty-first century, developing countries will face many difficulties. The most obvious, of course, is the lack of the requisite hardware, software, and skills. Less obvious difficulties are long-term development policies that frequently do not include plans to immediately use this technology (developing country policymakers are frequently unaware of what is available in artificial intelligence technologies); inappropriate cultural backgrounds in informatics; and managers who expect fast results with low investment, resulting in the use of black box, inappropriate, or obsolete applications.

After identifying some of the difficulties in utilizing cutting edge information and communications technologies, Dr. José Negrete, director of the Institute of Biomedical Research at the National Autonomous University of Mexico, proposed that if these technologies are to be used in developing countries, their indirect benefits should be maximized. That is, they should be used to increase standardization of medical care procedures, to lower the cost of health care, to increase the quality of patient care, and to help both physicians and teachers keep current with advances in medical science. For example, according to Negrete, the direct benefit of the use of microcomputers to provide decision theory and cost-effectiveness calculations for medical decision making would be lower health costs—because the information needed for the otherwise simple calculations is not available. The indirect benefits of this technology would be both short and long term. One short-term benefit would be the acceptance that decision making in medicine can be openly and rationally discussed, using the appropriate statistical or other data. This indirect benefit will lead eventually to the desirable standardization of medical care procedures and to a reduction in health care costs.

The long-term indirect benefit would be obtained after the short-term benefits have permeated medical

and paramedical training in the form of tutorial programs that work with local data and locally constructed decision trees.

The use of computers in medical diagnosis and patient management would also have large indirect benefits, such as the unique opportunity to take a close look at the local medical expertise, a necessary step before feeding useful knowledge into the computer, and the eventual diffusion of this reviewed and revised expertise into the classroom. Such an examination of medical knowledge will significantly improve the quality of the patient care.

Applications to Education

Well over a billion persons worldwide are affected by issues of literacy and education, stated Dr. Kurt D. Moses, director of service systems of the International Division of the Academy for Educational Development. Over 600 million people lack basic abilities in literacy and numeracy. But, in a sense, said Moses, applications of new information and communications technologies should concentrate on the estimated 340 million students who are receiving a primary education.

Using gross data from UNESCO, the World Bank, and the International Monetary Fund, Moses reported that the developed countries, excluding Eastern Europe and the Soviet Union, spend an average of $2,055 per student per year on educational operating expenditures, while the developing countries, very broadly defined, spend an average of $210 per student per year for all levels of education (kindergarten through university). Africa, a special case, spends an average of $88 per student per year in operating support for education.

Another measure that relates directly to the impact of information and communication technologies is based on that very small portion of the operating budget dedicated to materials and supplies (about 2–10 percent of the operating budget in most countries). In developed countries about $270 per student per year is spent on materials and supplies, while the respective figure for the developing countries is $15 and for Africa, $8.

Moses noted that the expectations of political leaders play a big role in the acceptance of technology and innovation designed to enhance education and literacy. These expectations are that new technologies will: (1) reduce costs and permit expansion of services (the strongest expectation), (2) upgrade the quality of education, (3) provide unique opportunities and services where none existed before, and (4) lead to human resource development and economic growth. The "dazzle effect" is responsible for many new technologies—particularly computers, satellites, and certain telecommunications innovations—being viewed as symbols of modernization. "In my experience," said Moses, "[the latter] counts for at least 40 percent of the reasons for implementation of a variety of efforts."

Examples of Specific Applications

By giving examples of how information and communications technologies are already being applied to education and literacy in developing countries, and their respective cost structures, Moses was able to show why the cost-benefit structure often determines the use of many of the newer technologies.

In Indonesia, 13 universities located on various islands in the more than 13,000-island archipelago are linked by a single-channel, narrow-band telephone circuit. This telephone line is being used for teacher and student training, some administration for a newly established open university, and short-term training assistance for health and agricultural workers (see Figure 2). This USAID Rural Satellite Program has served 3,500 students per semester in 17 courses, and its "up time" averages about 92 percent. Many of these activities would not have been underaken without this satellite effort, partly because of cost. The basic cost of this system is about $10 per course per student (or about $100 per student per year) versus an estimated cost of $64 per course per student using the visiting lecturer approach. Comparison of this figure to the average support per student per year shows that in fact there is an implicit cost-benefit ratio in operation as to whether or not some efforts will be undertaken; some are appropriate for higher education but not for lower levels, where funds are less.

A second example offered by Moses is the use in Kenya of a more mass-oriented technology, instructional radio, to teach English in grades one through three. Carrying the core of the curriculum through daily broadcasts, this USAID radio project provided 98 instructional hours per grade per year. The basic cost of this program, assuming that the FM stations were in place, was between $.22 and $.40 per student per year, including programming. Here then is a technology that is to a certain extent affordable within current cost structures.

Thus, Moses concluded, in applying information and communications technologies "we will have to be extremely careful in the political environment to find the time when the cost curves and the benefit curves are at the right point for a lot of Third World countries."

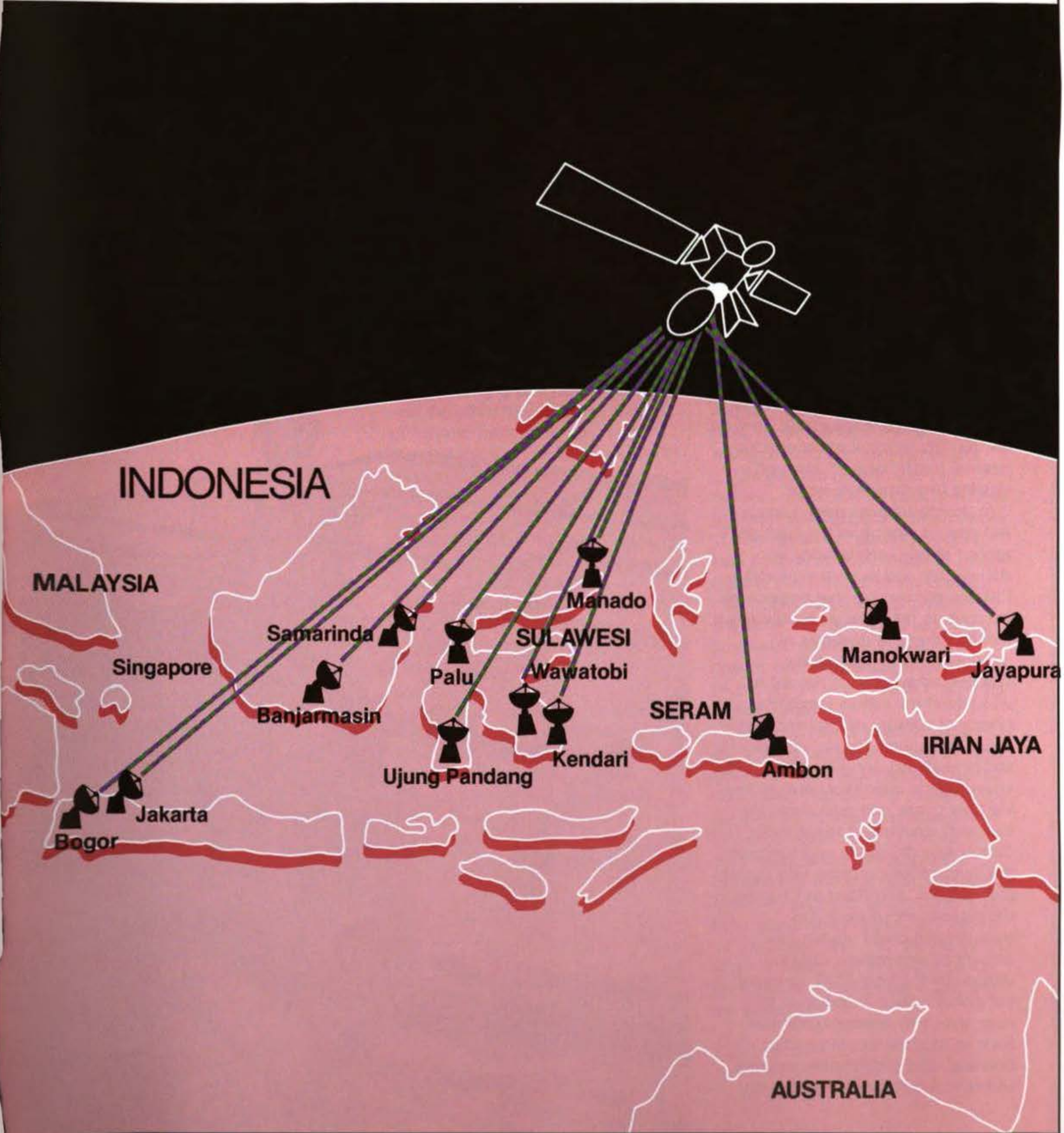


Figure 2 Rural Satellite Program Indonesia Project Sites (Academy for International Development)

SPACE SCIENCE AND REMOTE SENSING

Introduction

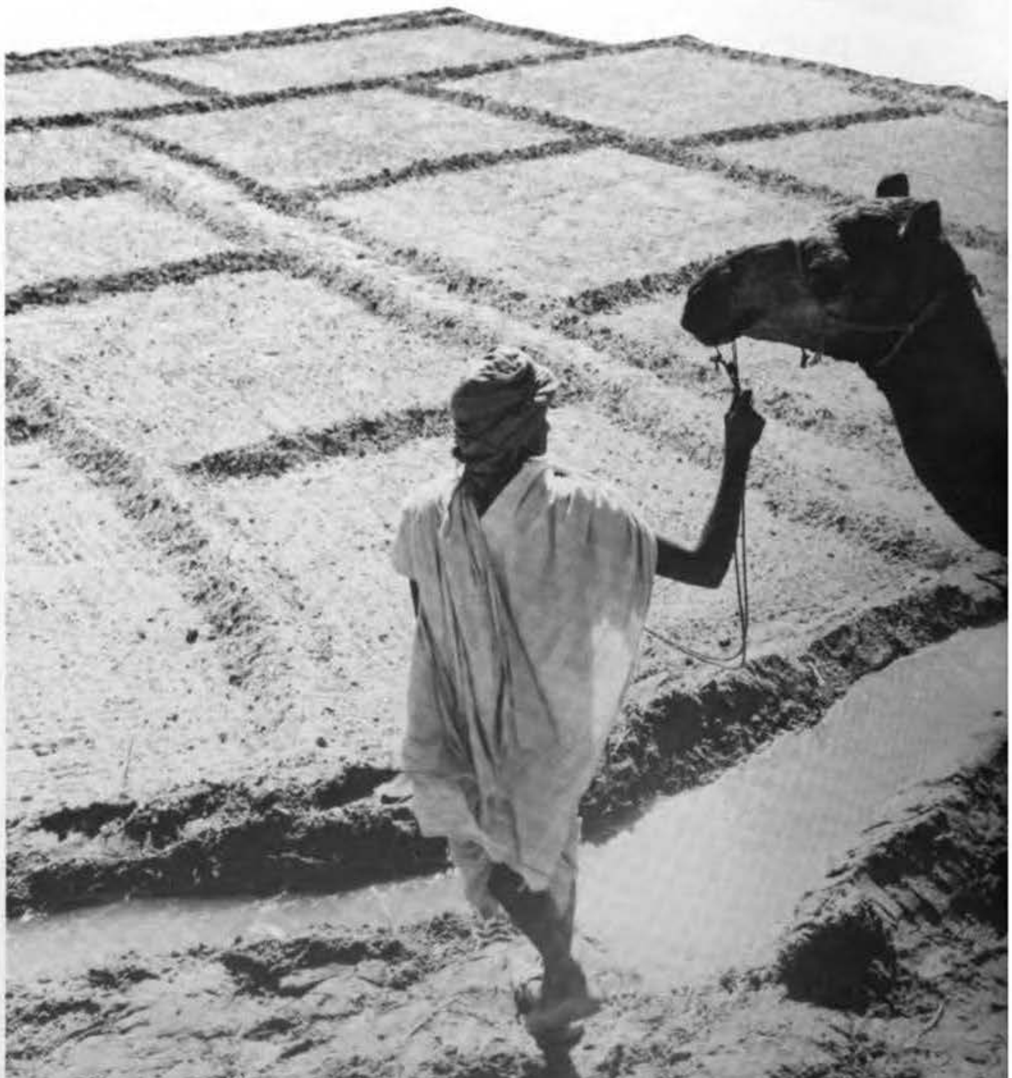
Of all the techniques available for study of the planet Earth, spacecraft are recognized as the most valuable. Today's spacecraft are far more sophisticated than the first weather satellite, Tiros I, which was launched by the United States more than 25 years ago. They can monitor such diverse resources as crops, minerals, and fisheries, as well as atmospheric pollution. Moreover, according to Dr. Moustafa T. Chahine, manager of the division of earth and space sciences at the California Institute of Technology's Jet Propulsion Laboratory, the remote sensing tools now on the drawing board show enormous promise for the next 25 years of viewing the earth from space.

In describing how space science and remote sensing technology are applied to crop production, agroclimatology, and mineral exploration, Chahine pointed out that researchers are now on the verge of establishing a remote sensing system that can provide the long-term, global, synoptic measurements needed to understand the earth's interactive system of oceans, atmosphere, continents, cryosphere (snow, ice, glaciers, and permafrost), and biosphere. Such knowledge is essential to understanding how nature will respond to the increased amounts of atmospheric carbon dioxide, sulfur, and methane that humans are pumping into the air they breathe. According to Chahine, the present rate of fossil fuel consumption could double the amount of atmospheric carbon dioxide by the year 2020, elevating the global surface temperature by more than two degrees centigrade. Such an increase would produce flooding, alter precipitation patterns, and have a considerable impact on regional fresh water and agriculture. Sulfuric acid rain is the result of the additional atmospheric sulfur (almost twice that produced by natural processes) generated by human activities.

Today, the lack of accurate global data on life-sustaining carbon, nitrogen, oxygen, and sulfur greatly impedes our ability to study the movements of these key chemical constituents of the earth's system. Global variations of the hydrological cycle in all its phases—evaporation, precipitation, water flow—need to be monitored.

The two most important elements of a remote sensing system that gathers data on the earth's interactive system are in situ measurements and satellite observations.

Deep ocean and underground processes are not generally amenable to observation from satellites, explained Chahine. Land-based biological processes and some important tropospheric chemical reactions require in situ measurements as well. Long-term in situ observations are also needed to ensure the stability and accuracy of the various space-borne sensors. A



worldwide effort is required to gather such data, suggested Chahine, perhaps in the form of a broad composite data system that uses ground stations, ocean buoys, aircraft, and balloons, as well as satellites, which have a special role to play in the collection of in situ data and its subsequent transmission to users.

Space-borne sensors are presently operating at many wavelengths and observing a variety of geophysical phenomena. According to Chahine, space-acquired data fall into four major categories of study: (1) sun-atmosphere interactions that involve the composition, chemistry, and photochemistry of the stratosphere and variations in the output of the sun; (2) land-atmosphere interactions that involve the exchange of water, gases, aerosols, and heat; (3) ocean-atmosphere interactions that include the transfer of water and gases, heat, and momentum; and (4) the ozone budget, the global hydrological cycle, and the other biogeochemical cycles of carbon, sulfur, nitrogen, and phosphorus that regulate the earth's metabolic system.

Using the latest in supercomputers, researchers can run interactive numerical models able to simulate to a limited degree the earth's entire system. Chahine warned, however, that such models must be tied to global synoptic observations if our understanding of the causes and effects of global change are to advance.

Today, a large number of geostationary and polar-orbiting satellites launched by the National Aeronautics and Space Administration (NASA), the National Oceanic and Atmospheric Administration (NOAA), and the Department of Defense are measuring daily the variability of such important parameters as solar radiance, ultraviolet flux, volcanic aerosols, total ozone, earth radiation budget, atmospheric temperature, winds in the tropics, atmospheric water vapor, sea surface temperatures, land-use changes, and vegetation cover. Better knowledge of some of these parameters is vital to the economic development of Third World countries.

"The greatest single unmet need at present is for acquiring global information on the biosphere and on land biology," emphasized Chahine. This need as well as that for other types of data are being met by the development of several improved and more sophisticated experimental sensors.

The ultimate objective of the research under way in earth science is to obtain simultaneous measurements of selected sets of parameters over long periods of time for use in analyzing and synthesizing global change. During this measurement phase, emphasis will shift to the use of the new space platforms in polar and geosynchronous orbits, as envisaged by NASA's proposed Earth Observing System (EOS).

"Major advances in earth science will come from the synthesis of ideas drawn from the study of such global data," said Chahine. For example, the accuracy of weather predictions has increased significantly as a result of the present understanding of the dynamics of the large-scale circulation of the atmosphere, which is derived from global observations. It is clear, he concluded, that "we are on the verge of being able to comprehend the coupling between the ocean and the atmosphere."

Applications in Crop Production and Agroclimatology

Data from global satellite remote sensing systems can be used to inventory crops, estimate crop production, and provide information on which to base agricultural management decisions. These data must, however, be delivered rapidly to farmers and to others who make management decisions affecting agricultural production if they are to be of value. If these data are monitored over a growing season, it might be possible to predict crop production on a regional scale.

Unfortunately, the management promise of space remote sensing has not been fully realized (even in the United States) for two reasons. First, the relatively poor spatial resolution of the instruments used has limited their utility, particularly in developing countries. For example, the ground area examined by the first generation of Landsat sensors was about the size of a football field, which is considerably larger than farmers' fields in most developing countries. While the most advanced Landsat sensor can look at an area about the size of a basketball court, it is often inadequate for dealing with the small, irregularly shaped fields found in developing countries. Second, it has been difficult to deliver the products of satellite remote sensing quickly. The revisit frequency of the Landsat satellites, which is approximately two weeks, does not provide timely enough data for monitoring crops during the growing season. Thus, the data are virtually useless for crop management decisions.

Despite these problems, which were cited by Dr. Charles F. Hutchinson, director of the Arizona Remote Sensing Center at the University of Arizona, remote sensing has been used by foreign assistance agencies and others to monitor agriculture worldwide. Efforts to apply the general remote sensing techniques developed in the United States to Third World countries have had only mixed results, however. Difficulties have resulted from the problem with field size just mentioned; gaps in important geographic areas that result from spacecraft malfunctions, cloud cover, and limitations of the ground receiving station network; and the unreliability of the historical crop production data needed to determine how the current crops are performing relative to past years. The most important problem, however, is the difficulty in establishing developing country institutions that can carry on the assessments after donor assistance is removed.

Agricultural climatology deals with the processes that occur at the earth's surface, particularly the transfer of mass and energy between the surface and the atmosphere. The fields of meteorology, crop physiology, and soil science are therefore of interest to agroclimatologists. Using remote sensing and other technologies, these scientists have been able to determine

rainfall and temperature patterns in the Sahel region of Africa.

According to Dr. Edward Kanemasu, professor of agronomy at Kansas State University, researchers have discovered a very strong correlation between the onset of the rainy period and its duration. Early onset of the rainy season was found to be typical of a long growing season. Similarly, they also saw a strong correlation between the total amount of rainfall and when the rainy period began. For the last 16 years in the Sahel, however, there has been a change in this correlation, explained Kanemasu; the amount of rainfall has decreased. This is consistent with the climatic analysis undertaken by others that suggests a change in the Sahel's weather pattern.

Knowing the length of the growing season, farmers can determine what kind of crop management practices should be considered. Crop yields can be predicted using some of the more recent crop simulation models, such as those developed under IBSNAT. (See p. 50) These models require minimum biophysical data for a particular site.

Unfortunately, these models have had only mixed success, particularly when used in the stressful environment of the Sahel. One problem is trying to determine the amount of leaf area generated by each crop—that is, trying to simulate the growth of the leaves. The Landsat and Spot satellites are able to estimate the amount of leaf area, but such an estimate is affected by a number of things that the models cannot easily simulate, for example, the amount of water available to the crop. The amount of precipitation may be known, but how much of it is lost to runoff? In determining fertility, how much fertilizer does a particular farmer have? In terms of disease, when was the onset and what was the severity of damage caused by a disease or insect?

The ability of remote sensing to estimate leaf numbers is based on the unique spectral distribution of reflectance of a green, healthy leaf. A green leaf absorbs strongly in visible light and reflects highly in infrared light. An index that uses that ratio allows one to tell the difference between a plant and the background of the soil. While satellites can estimate global and large regional changes in vegetation, explained Kanemasu, limitations are attached to those kinds of data because the satellite is in a fixed orbit, and, as also pointed out by Hutchinson, has a rather low spatial resolution. Moreover, there is the delayed turnaround of data.

Video remote sensing aboard an aircraft is one possibility for obtaining more current data. The requirements for instruments and equipment are relatively simple, and data are available as soon as the aircraft lands. More important, data can be obtained when needed. For a satellite in fixed orbit this is not possible.

Forecasting Food Emergencies Using LANDSAT Data

During the 1985 growing season, the U.S. Agency for International Development used Landsat data to forecast sorghum and millet crop failures in the Sudan and to support planning food relief operations. The forecast permitted the timely delivery of U.S. food grains to over 1 million starving people in western Sudan. The photo maps made from the satellite data were also distributed to U.S. helicopter pilots who used them to navigate the uncharted terrain and to get the critical food supplies to those most badly in need. Other U.S. federal agencies (NASA, NOAA, and USDA) provided assistance in carrying out the forecasting effort and the Sudanese air force supplied the aerial photography necessary to confirm the satellite data interpretations.

The successful use of Landsat data for Sudan emergency relief efforts led to the development of the Agency's Food and Early Warning System (FEWS), in which eight African states historically subject to famine are being monitored for vegetation browning indicative of crop and pasture failure. The USAID mission in Sudan replicates this successful procedure every year in its Emergency and Rehabilitation Information Surveillance System.

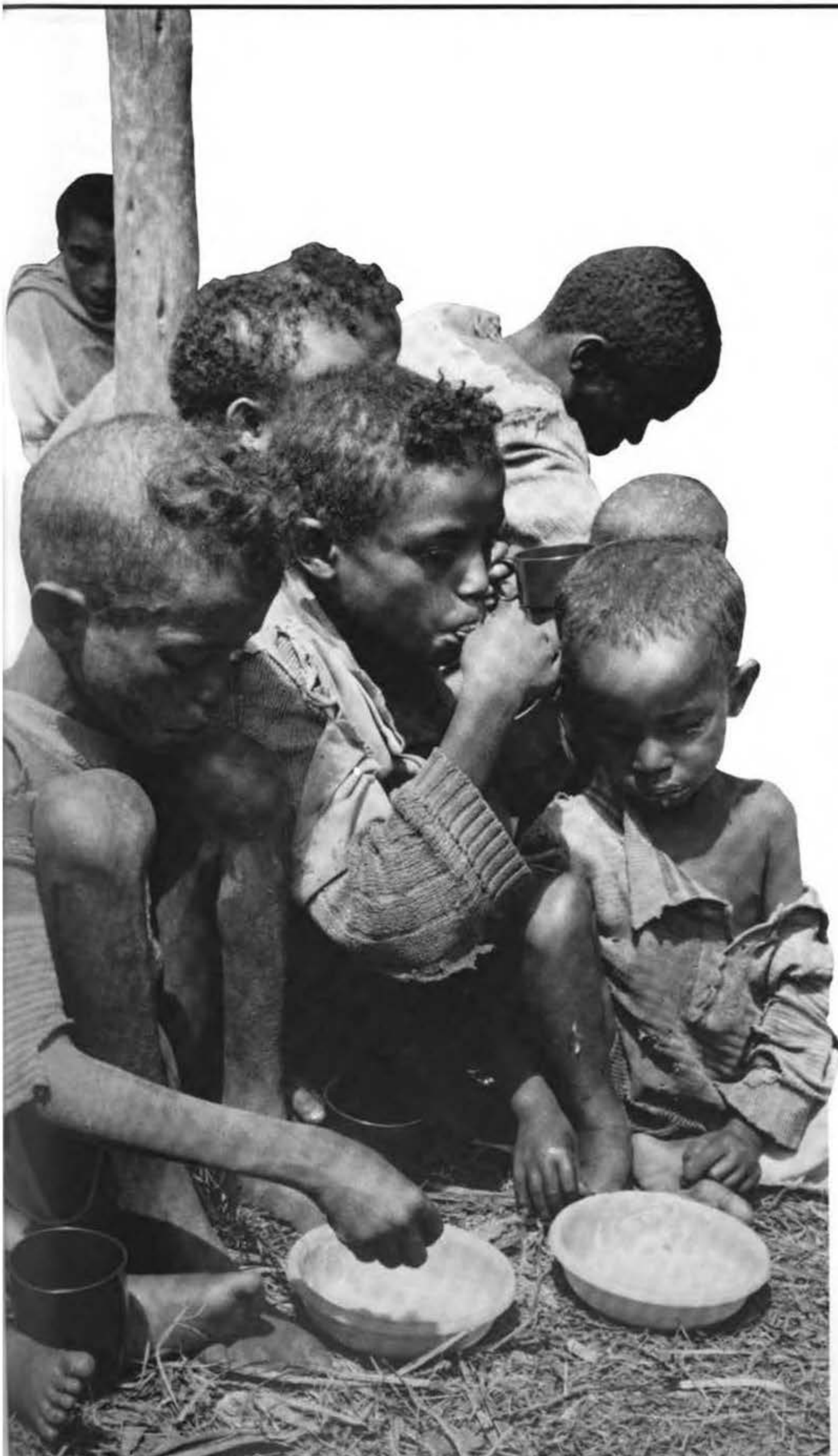
Applications in Mineral Exploration

Dr. Ronald J. P. Lyon, professor of mineral exploration at Stanford University, was not optimistic about the suitability of satellite technology for mineral exploration—in particular, lead, zinc, copper, uranium, and gold—in developing countries. Better spatial resolution is needed, he believes, before satellite-based remote sensing can be practicably applied to the search for minerals.

According to Lyon, the multispectral scanners designed specifically for the mineralologies of deposits such as copper, lead, and zinc are used more appropriately in aircraft than in spacecraft. Deeply buried oil is more effectively discovered using various geophysical and seismic techniques, but Lyon admitted that the Spot satellite is "extremely attractive" for evaluating potential fracture systems for oil and coal basins. Also, data acquired by the Landsat Thematic Mapper are used by multinational firms to explore for hydrocarbons in the developing countries. Lyon added though that aircraft camera and scanner systems should not be dismissed. Any search for building materials—phosphates and the materials needed for cement, for example—lends itself more to black-and-white aerial photography followed by seismic testing.

Ten years ago, the U.S. Agency for International Development and the U.S. Geological Survey assisted the government of Bolivia in the discovery of some of the world's richest lithium deposits in the Salar de Uyuni. Landsat data were used to identify salt brines with extremely high concentrations of lithium (2,600-3,000 parts per million), and the subsequent ground samples taken by the investigators confirmed the high concentrations. Following these discoveries, which were covered by the major news media, an American-based multinational corporation invested $137 million in Bolivia's economy to extract some of the lithium.

USAID's application of remote sensing to mineral exploration is currently limited to using Landsat data to construct photogeological atlases that are combined with seismic and aeromagnetic data to locate and map petroleum, mineral, and groundwater resources in Egypt.



The Future

In predicting future developments in this field, Hutchinson predicted new satellites (Spot), new sensors (video), new platforms (high flyer), and inexpensive powerful computers, but no major technical or scientific breakthroughs. "Techniques for monitoring crop production have evolved to the point where their regular and reliable application in developing countries is possible now," declared Hutchinson. The U.S. Department of Agriculture (USDA) and USAID are using satellite remote sensing to monitor crop production both in the United States (USDA) and in other countries (USDA, USAID).

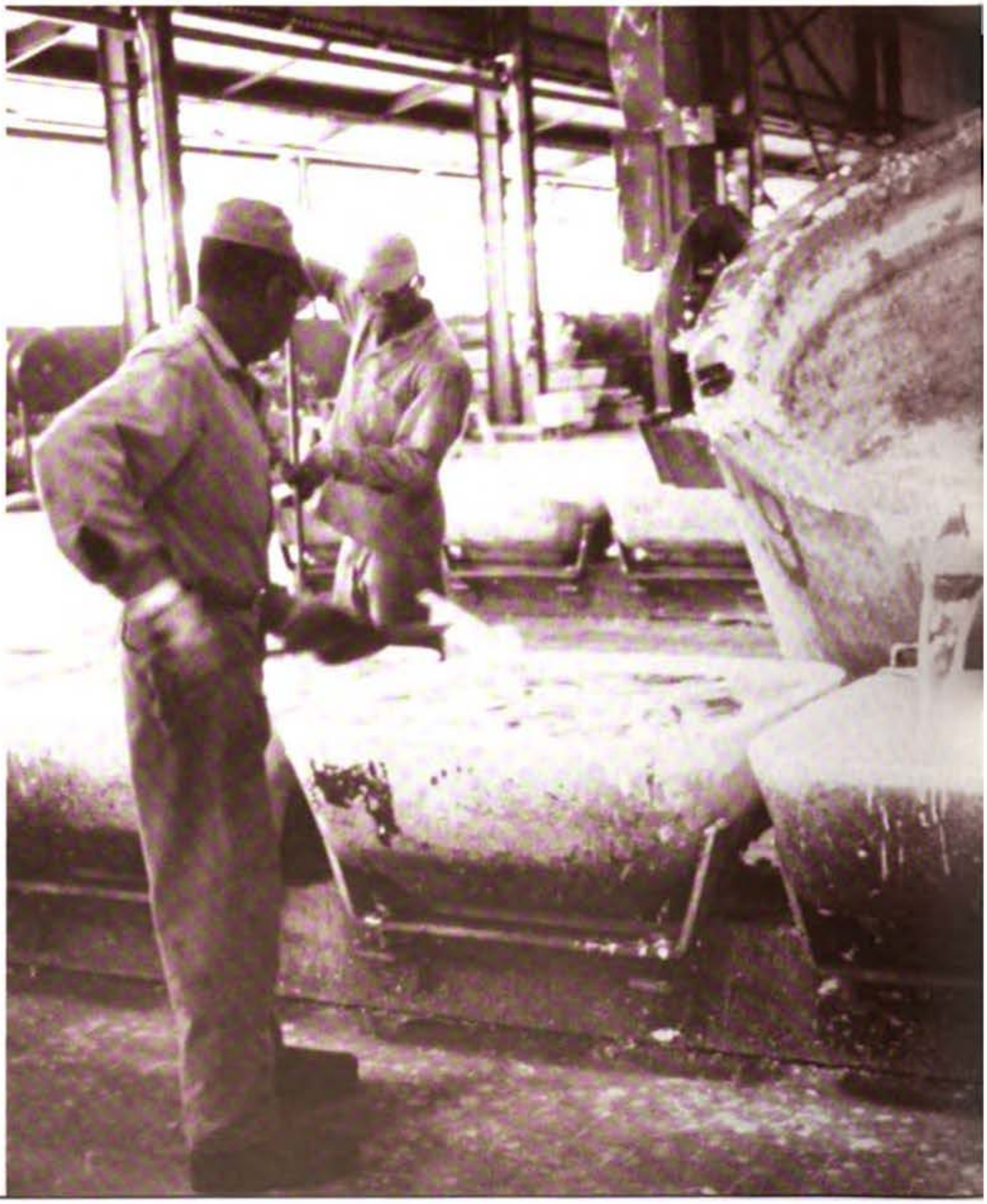
The need for information on crop production, particularly in Africa, has not lessened as the pictures of the drought-burdened land and people of Sahelian Africa have disappeared from the pages of newspapers and magazines. According to Hutchinson, the two most prominent features of arid climates are low rainfall amounts and extreme interannual variability. Thus, monitoring in times of relative plenty is much more important than monitoring in times of drought. Remote sensing offers the opportunity to forecast crop failures in the making, so that steps can be taken beforehand to prepare for food emergencies.

MATERIALS SCIENCE AND TECHNOLOGY

Four scientists spoke about materials science and technology at this symposium, highlighting the remarkable advances made in supercomputers and silicon and semiconductor technology, as well as the development of new materials and advanced processing techniques for existing materials. These scientists found it difficult to predict what impact some of these advances will have in developing countries, which often lack the capital and resources required for fabrication of expensive new materials. Other new materials or new technologies are, however, already being used in developing countries. Semiconductor technology, for example, is the basis of satellite-linked instructional networks, and the artificial intelligence techniques used in expert systems applied to medicine and agriculture.

The first speaker, Dr. Edward Starke, dean of the School of Engineering and Applied Sciences at the University of Virginia, summarized the likely progress in the next 20 years in materials science and technology. He indicated that scientists will have to learn to do more with less when developing advanced materials and manufacturing technologies.

Materials are often the controlling factor in the development of new technologies, as, for example, in *microelectronics*, energy systems, and transportation systems. In the field of microelectronics new or improved materials will be developed for encapsulation of microcircuits, high-resolution etching, microchips, electromagnetic shielding, chemical switching, and optoelectronics. In the *energy field*, nuclear power systems will require more radiation-tolerant materials, effective systems for waste encapsulation, and materials for fusion reactors. Special challenges will be faced in the *transportation* sector, where aerospace systems will need lighter weight materials. Improvements in engine technology will be based on ceramics and metal matrix composites, direct interfacing between electronic and mechanical systems, and the increasing use of nonflammable materials. The automotive industry will use polymer composite structures with high productivity, and there will be a move toward greater use of lightweight, corrosion-resistant structures. More efficient automotive engines will run at higher temperatures, calling for ceramic parts in coatings. And, finally, if there is a move toward electric automobiles, lightweight batteries that are much more efficient and longer lasting than those available today must be developed.



Advanced Processing Technologies

According to Starke, "improvements in material performance depend as much on advances in processing as they do on the introduction of new compositions." He believes that industrial engineers should take another look at old processes to evaluate how new advances in processing can make an old technology more efficient and cost effective. Improved material quality and advanced processing technology can improve reliability, he stressed. For example, improved material quality can have a significant impact on semiconductors, electro-optic materials, ferroelectrics, ferromagnetics, and fracture-resistance structural materials. Controlled improvements in processing and careful control of the processing can narrow the "envelope" of various properties of a material. In fact, Starke pointed out that a 10–20 percent shift in the positive direction of the "allowable value" can make as much of an impact as developing a new material.

Advanced processing technologies that have been developed over the last 10–20 years include laser photochemistry, which can be used to make, for example, silicon carbide for reinforced composites, and rapid solidification technology, which offers the opportunity to decrease segregation and to increase supersaturation in materials, and to actually make metastable materials that cannot be made using any normal casting technique. Powder metallurgical methods allow one to make a particulate and then rapidly consolidate it into a product that is almost in its final shape, thereby reducing manufacturing and engineering costs. Thermomechanical processing can be used to tailor the microstructure of a material, and therefore the final product, for a specific property—for example, resistance to fatigue cracks. Superplastic forming is another recent advance. With this technology one can deform metals into shapes in the same way that one can deform plastic.

Other advances have been made with what might be considered old materials, noted Starke. For example, during the energy crisis about 10–15 years ago a big effort was made to lighten transportation vehicles by substituting either epoxy matrix composites or aluminum alloys for steel. Instead, dual-faced, high-strength steels were developed for use with thin gauges. Thus, it is projected that steel will continue to be used by the automotive industry. The amount of steel used by that industry has remained relatively constant over the last few years even though vehicles have become lighter.

During the next 20 years the metal industry needs to develop an on-line identification system for materials in process. For example, an on-line surface defect identification system for sheet and plate materials while they are being processed could identify defects in a material so that they can be eliminated or modified during the processing operation. On-line measurement of physical and mechanical properties will allow slight adjustments in the processing to control the properties of a material while it is being processed, instead of waiting to measure the material after production, and possibly scrapping it if it does not meet specifications.

"By using advanced materials and processing technologies," concluded Starke, "one can develop complex engineering structures that will operate over a longer and more reliable lifetime and reduce the quality of scarce materials. Once we understand the role that certain elements have in materials, we can essentially tailor a material's properties by tailoring its microstructure."

New Materials

Some of the newly developed materials have great promise. For example, lithium, the lightest metal known, can lower the density of an aluminum alloy approximately 3 percent for every weight percent that is added, and it can increase the material's strength. Thus, the substitution of aluminum lithium alloys for the aluminum alloys used currently will mean about 10 percent savings in weight. In the airline industry, for example, this can make a big difference. It has been estimated that the use of aluminum lithium alloys to reduce the weight of an aircraft by about 10 percent will save 15–20 gallons of fuel per year per pound of weight saved (about 35,000 pounds for a Boeing 747). Thus, an airline can save millions of dollars each year in fuel costs.

Most of the powder metallurgy alloys are being developed for either their greater strength or their resistance to high temperatures. The high-temperature titanium alloys and rapid solidified aluminum alloys are 10–20 percent stronger and more temperature resistant than the aluminum alloys available today.

Fibrous Composites

Modern fibrous materials are composed of many kinds of fibers—graphite, boron, silicon carbide, and fiberglass—which designers are able to put together in different forms: chopped fiber, continuous fiber, or prepreg, in which some resin polymer is preimpregnated into the system. Even fabrics can be made of composite materials.

The individual layers of a structure can then be oriented in different directions to optimize the properties for the designed applications—perhaps strength, stiffness, or dimensional stability. The properties of a structural component are all a function of the individual layers used, the kind of fiber used, the matrix material surrounding the fiber (perhaps a polymer or metal), the orientation of the fibers in each of the layers, and the stacking sequence.

According to Dr. Carl T. Herakovich[1], professor of engineering science and mechanics at Virginia Polytechnic Institute and State University, the fact that composites are lightweight is probably the biggest reason for the widespread interest in them over the last 25 years. Other engineering advantages of composites are their stiffness, strength, and dimensional stability (the coefficient of thermal expansion of some of these materials is actually zero). Moreover, composites are fatique resistant, crease resistant, and damage tolerant. They also have low friction and, a very important feature, they can be designed.

Some of the economic advantages of composites are their very low maintenance costs (owing to their resistance to corrosion), the low capital investment required (particularly for the manufacturing facility), their small number of parts (especially when using adhesive bonding techniques as opposed to bolts or rivets), and their low fabrication costs. One disadvantage of composites is that there are not enough experienced designers to work with these

materials. This situation will change over time, however. The current high per pound cost of composites will also drop.

The applications of composites are wide ranging, from beams and filaments to commercial aircraft (many composites are fire resistant), from helicopters to hulls for America's Cup contenders.

Silicon and Semiconductor Technology

According to Mr. J. Franklin Mayo-Wells, staff assistant for technical coordination/operations at the Center for Electronics and Electrical Engineering, U.S. National Bureau of Standards, the many exciting advances recently made in electronic materials relate to a wide range of components, devices, and systems. For example, new materials are being used for electromagnetic shielding, optical fibers, and electromagnetic antennas. "In each case," he noted, "the new materials provide some significant advantage in reliability, performance, or cost compared to materials now in common use."

Semiconductor technology, which underlies many of the advances in electronics and electrical engineering, is largely silicon semiconductor technology, although other materials are used occasionally. Materials are vitally important in the complex fabrication of a modern integrated circuit, and all must be of the highest quality and purity. Silicon has transformed life in the twentieth century because it is used to construct circuits that provide control and calculation functions. With the control function we can switch electric power to regulate power levels and routing and, perhaps most important, implement the results of the calculation function.

The transistor has remained the heart of most semiconductor devices, including power devices, digital devices such as microprocessors and memory, and microwave (very high-frequency) devices such as amplifiers and receivers. Power transistors, explained Mayo-Wells, implement the control function, while signal transistors and memory, in the biggest and fastest computers, and microprocessors and memory, in all the rest, implement the calculation function. Without the control-microprocessor-memory combination many of the devices that make life easier would not be possible. For example, this combination regulates the ignition and fuel-air flows to automobile engines, regulates the heating and cooling in vehicles and engines, and controls household appliances and power tools. And virtually all modern manufacturing technology depends on it. The microprocessor-memory combination is the heart of personal computers, it plays important roles in communication systems, and it is a building block for many electronic systems.

Although Mayo-Wells finds the future of semiconductor technology "at best cloudy," the pace of semiconductor development has not abated, and memory technology is at the leading edge. The 1 million-bit dynamic random-access memory (1M-bit DRAM) is appearing in the newest personal computers, and attendees at a 1987 conference described fabricated 4M-bit devices and discussed the design of 16M-bit chips. Moreover, some very challenging fabrication requirements are emerging in the form of semiconductor structures for high-speed devices and optical communications.

Thus, pointed out Mayo-Wells, "it is very difficult to make more than the most generalized predictions for electronics 10 years down the pike." Silicon technology will probably still dominate, he predicted, given the wealth of existing experience in silicon semiconductor processing technology. Gallium arsenide semiconductor devices are not as prevalent because the practical speed advantage that this material offers over silicon has steadily eroded as the ability to construct increasingly smaller silicon devices with greater control of the electrical and physical properties has grown. Nonetheless, more gallium arsenide and other compound semiconductor devices will probably appear commercially as their processing technology catches up with that of silicon. The speed advantage of gallium arsenide in the context of microwave circuits has already made it the technology of choice for some applications, principally those related to communications and defense. "Josephson-junction technology," noted Mayo-Wells, "formerly restricted to operation at the 4 Kelvin temperature of liquid helium, offers advanced performance with the technologically thrilling development of superconductors that can be cooled to superconducting state above the 77 Kelvin temperature of liquid nitrogen."

Examples of other exciting semiconductor materials that may well be in the marketplace by the turn of the century are the diamond films formed by a chemical vapor deposition process at low temperatures and pressures. "These apparently offer potential for semiconductor devices of high performance, coupled with high-temperature operation and excellent radiation resistance compared to silicon," observed Mayo-Wells. The commercial apparatus for forming these films on a substrate already exists.

[1]Dr. Herakovich joined the faculty of the School of Engineering and Applied Sciences, University of Virginia, in fall 1987.

Superconductors

Although the enormous publicity that this technology has recently received might lead some people to believe that it was just invented, Dutch scientist Kammerlingh Onnes actually discovered superconductivity in 1911. Superconductors offer no resistance to the passage of electricity, which means that currents can flow through superconducting wires with absolutely no loss. Thus, electricity can be generated and distributed much more efficiently than before.

The materials used currently, however, do not superconduct at anywhere near room temperature, they are not durable, and they are expensive to manufacture. After pointing out these constraints to the widespread use of superconductivity, Dr. Richard E. Harris, leader of the cryoelectronic metrology group at the U.S. National Bureau of Standards (NBS), offered more details. Until 1986, the highest temperature at which superconductivity was observed was 23.5 Kelvin (−417° Fahrenheit). Such a temperature can only be achieved using liquefied helium, which is technically difficult to prepare and absorbs very little heat before boiling away. Furthermore, the wires used today for superconductivity are not very ductile and must be handled carefully to avoid damage. Finally, because superconducting wires must be formed in a copper matrix to work properly, their manufacture is very expensive.

Nevertheless, numerous rather large applications of superconductors have been made, explained Harris. For example, superconducting magnets are used at Fermilab, which has the most powerful accelerator for high-energy physics research in the United States. A superconducting magnet is also used for magnetic resonance imaging (MRI), a new technique for imaging soft tissue in the human body.

Electronic applications of superconductors include the superconducting quantum interference device (SQUID), which is the most sensitive means of measuring magnetic fields. SQUIDs have been used to sense the magnetic fields of the heart and the brain, and they are able to locate problems better than conventional electrocardiograms and electroencephalograms. They have also been used in geological experiments that might lead to new prospecting techniques. Researchers at NBS have already made the first SQUID that works in liquid nitrogen (that is, without liquid helium), and they are now working toward measuring a magnetocardiogram with it. Finally, a new superconducting device

for making fast electrical measurements—a time domain reflectometer—is also available commercially. It is three times faster than any other completely electrical system.

Although other applications of superconductivity—such as a Japanese test train that floats above a track on superconducting magnets—have captured the imagination of the scientific community and the public, they have not yet made it into production. "Highly efficient generators and power transmission lines have been tested, but none are in use," noted Harris.

One of the difficulties with these unrealized applications is the need for refrigeration. Refrigeration for liquid helium is expensive, making only the largest scale applications economically feasible. Thus, the projections have been for big generators, big computers, and big transmission lines.

As for new developments in superconductivity, the maximum transition temperature for conductivity was at 23.5 Kelvin for over a decade, but in January 1986 researchers at IBM's Zurich research laboratory were able to push this temperature up to about 30 Kelvin using a compound of lanthanum, barium, copper, and oxygen. And in January 1987 workers at the University of Houston changed the chemical elements to yttrium, barium, copper, and oxygen, and achieved a transition temperature of above 90 Kelvin. Thus, in achieving superconductivity, liquid nitrogen could be used for cooling since it makes cooling much easier and since a given amount of liquid nitrogen can absorb about 60 times more heat before boiling away than the same amount of liquid helium.

In concluding, Harris noted that many of the incredible applications reported in the newspapers may come about, but not overnight. It may be that reducing the cooling requirements to those of liquid nitrogen will not be sufficient to make some of the applications economically attractive. And it may be that the best uses of superconductivity have not yet come out of the laboratory. It is hoped that when practical applications do become possible, perhaps in the next 10–20 years, the marginally reduced costs of electricity generation will benefit the developing countries.

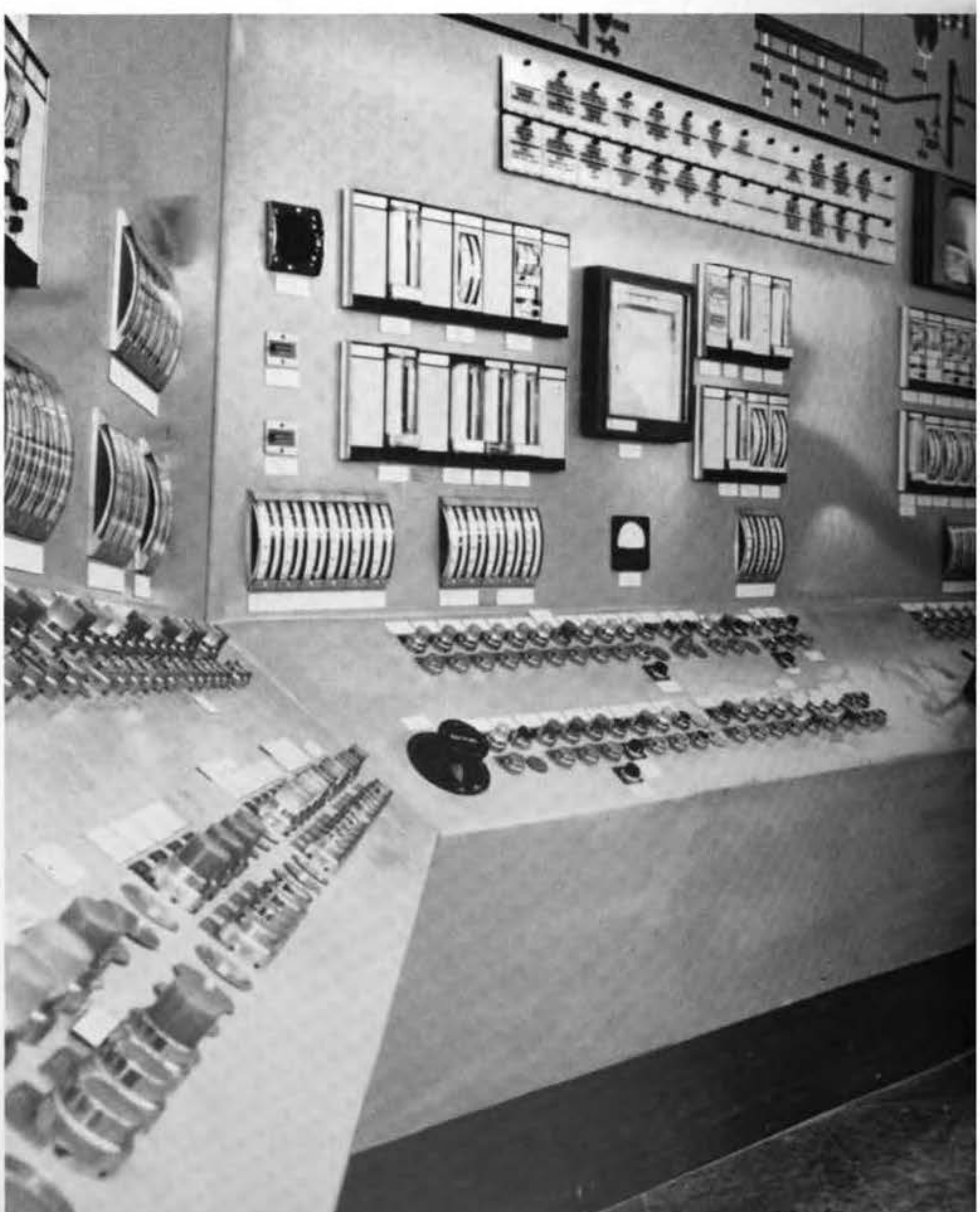
MANUFACTURING TECHNOLOGY

Expansion of the private sector in developing countries has been an integral part of the U.S. foreign assistance program and an important vehicle for helping these countries help themselves. Because the private sector is responsible for about 75 percent of the gross national product in some Third World countries, any advances in manufacturing technologies appropriate for use in these countries are sought eagerly, particularly the latest microcomputer hardware and software.

In describing the current state of manufacturing technologies and postulating future developments, Dr. Barbara A. Burns, manager of the Systecon Division of Coopers & Lybrand, was quick to point out that the application of advanced manufacturing technologies in developing areas is not without its challenges and special requirements. For example, changes in the local infrastructure to use or benefit from the technology may be needed. Logistics in the form of roads and shipping modes, a good postal system, and adequate telephone and power networks may be a problem, as well as the training and education of workers and managers.

The promise of advanced manufacturing technology may lead, moreover, to disappointment if the citizens, government, and industry have unrealistic expectations. For example, the new system may not work as well as expected. Or if it does, it may not work for everyone. Some people will see their jobs improve, while others may lose theirs. And finally, the self-interests of the local government, the regional development authorities, the foreign government or funding agency, and the manufacturing company may clash.

According to Burns, technology is changing rapidly in all areas of manufacturing, and the appearance of increasingly sophisticated computer hardware and software is making much of this change possible. They in turn support many other advances, from the sensors that control process flow in chemical production to the capability to collect and analyze data in R&D laboratories. Their decreasing cost and increased ease of use have further strengthened their appeal to the manufacturing sectors in developed and developing countries alike.



Because the capabilities of computer chips are expanding at an astonishing rate, resulting in more power in smaller packages, and because the cost per unit of memory has been greatly reduced, smaller businesses are now able to develop their own in-house capabilities. Companies of all sizes can use computers under a wider range of conditions. For example, Burns explained, design has moved from the drawing board to computer terminals, and parts and processes can be tested before construction, particularly where maintenance or an adverse environment may be a problem. Machine tools are sprouting microprocessor controllers and sensors. Supervisors and analysts on the factory floor can use computers to monitor the production flow. The movement of material can be controlled by automatic identification tags, such as bar codes, that can be read into the computer system by sensors. Material, parts, and tools can then be automatically moved and stored during the production process.

Software is developing at an even faster rate than hardware. Personal computer software is both easy to use and flexible, "enabling new users to become proficient (or dangerous) in far less time than when the early languages such as Fortran and Cobol kept computers in the domain of experienced programmers." Moreover, the new query languages and operating systems available for mainframes and minicomputers offer much of the flexibility associated with personal computer packages.

Manufacturing management technology—the experience with and knowledge of manufacturing that is still in the worker's domain—also depends in part on computers. "Total quality control, just-in-time manufacturing, engineering design management, and logistics management are current manufacturing philosophies that can benefit from computer technology in their implementation," observed Burns. But she added that they depend even more on the training and capabilities of managers.

Manufacturing Technology and Developing Countries

Burns suggested to her audience that three modes for applying manufacturing technology can be utilized in developing countries. She labeled these modes decentralization, diffusion, and development.

Decentralization refers to the distribution of production facilities by industry to take advantage of either natural resources, availability of labor, or access to markets. Decentralized facilities are often no more than satellite plants used to produce components, or to package and distribute products for local markets. Such facilities usually do not manufacture the entire product. Building local manufacturing capabilities, leading to autonomy, is *not* the intention of decentralized operations. Any effects that the operation may have on local economic well-being are secondary to the expected return on the investment. Jobs are created locally, but there is little long-term development of technical capability and intellectual growth. This may reflect in part the need to protect intellectual property, management difficulties in stretching across cultures and distances, or the realities of available skills or perceptions of available skills.

Diffusion refers to what are usually government programs aimed at helping companies adopt and modify processes and techniques and produce products or services that meet local needs or can be used for export. Because the key objectives are usually basic learning and building manufacturing capabilities, with profits as a secondary consideration, the time frame of the program is longer and the range of benefits expected is wider.

The program itself may fund research, education, and training; provide computers or tools; or subsidize companies to set up production facilities. Moreover, it will identify local factors—such as education, social policies, or cultural attitudes—that influence effective use of the technology, and it will match the technology to the local market or labor conditions.

Finally, stated Burns, "there is probably no direct connection between the source of program funding and the 'owners' or 'generators' of the technology, unlike in decentralization where they are probably the same."

Development refers to the payoff of industry and government programs: developing areas reach the point where they can use their own technology and resources to develop new products or services, often for developed nations. For example, a number of Pacific rim companies are now offering engineering services at a quality and price that are attracting major U.S. companies. The development mode is more likely to occur in countries where the educational and business infrastructure is well developed, perhaps through earlier diffusion efforts.

Indigenous development is more likely to use the local skills and resources because those in charge are aware of what is available. Wide distribution of the economic gains, however, depends on the funding and ownership of the enterprise.

Robotics

Dr. Howard Moraff, program director of automation and systems integration at the National Science Foundation, predicted at this symposium that by the year 2037 there will be more robots than people in the world. The competitiveness of the marketplace is driving many manufacturers to use the sophisticated automated machinery now available, including robots, on their production lines. As a result, the cost of the work force participating in the manufacturing process has been reduced to 10 percent of the cost of the product, and this percentage can be expected to edge toward zero in the future.

According to Moraff, the relatively cumbersome, unintelligent robot of today, adequate for the simple, highly repetitive tasks of mass production, will be replaced by sleeker, more dextrous robots capable of wider applications, including complex, low-volume manipulations and operations. The "intelligence" of these advanced robots will be embodied in a collection of sensing and computing microchips. 'Even the expensive mechanical components can be expected to yield to advances in design and materials," said Moraff.

Research in robotics is currently addressing the dynamic control of robot mechanisms and systems, including adaptive and sensor-based control, and the design of more dextrous and versatile manipulator mechanisms. Automated machine vision and understanding of visual images for recognition of objects and guided control of manipulation is yet another research topic.

The introduction of robots into factory operations faces several problems: workers worried about losing their jobs resist the use of robots; managers often do not understand this advanced technology; robot hardware is expensive; and the design and programming of robot tasks and operations is difficult.

Moraff contended that the use of robots in routine jobs is an inevitable result of the need to compete in the marketplace. He also predicted that the current high cost of robot hardware will drop as the hardware improves and the demand for robots increases—just as it did for computers. The design and programming of robot operations are generally demanding and expensive, but powerful, easier to use programming languages, task planning, and control methods are being explored.

"Robotics research will soon therefore allow us to develop new generations of advanced robots that will vastly enhance our ability to automate most of the tasks and operations of manufacturing," concluded Moraff. "It will then be very difficult to compete in manufacturing without such extensive automation."

TECHNOLOGY IN OUR CHANGING WORLD

Some Reflections by Thomas R. DeGregori

According to Dr. Thomas R. DeGregori, the concluding speaker at the symposium and a self-classified "technology optimist," the choices made by the visionaries among us over the past 30 years have made an extraordinary difference in the world. The power of science and technology has been harnessed to transform the world at a pace and at a magnitude that is unprecedented.

DeGregori challenged his audience to imagine what kind of world we would now have if the visionaries—such as the Rockefeller and Ford Foundations—had not decided on their own to fund basic research, thereby defying the arguments of those who believed in the 1950s that we should not engage in research? We should only transfer the existing technologies, they argued; research was too long term. Today, we would be growing 50 million tons less grain, he declared, and we would be feeding one half billion fewer people.

What kind of world would this be if we had followed the advice of those who during the 1960s and 1970s were advocating "triage"—that is, allowing starvation in large areas of the world? We learned later that the basic analysis upon which the triage recommendation was based—namely, that the world could not accommodate the growth in population that was occurring—was fundamentally false. In fact, a look at the world food supply shows that world food production records have been set in 33 of the last 37 years. And in 1986, the last year for which the data are complete, a record was set in per capita food production. Thus, the world has been able to accommodate this population growth. Moreover, the evidence is overwhelming that the catastrophe predicted by many will simply not come about. The indicators—life expectancy, child mortality, infant mortality—confirm this.

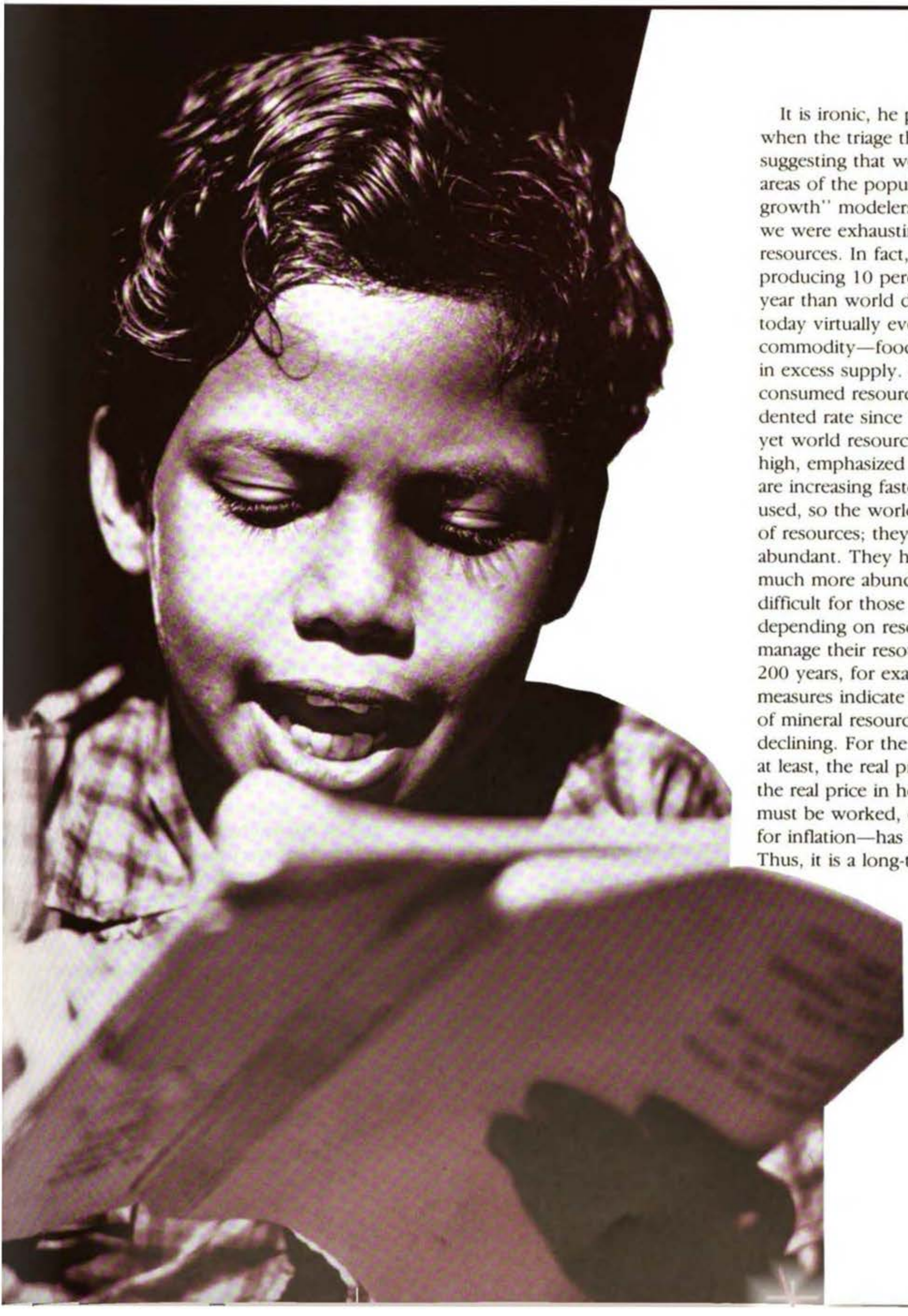
In fact, as was emphasized repeatedly in this symposium, the transition experienced over the last 30–35 years is unprecedented in human history. The gain in global life expectancy during this period is greater than that of the last 10,000 years, and infant mortality has been halved. In simple terms, the number of people who died of all causes in 1950 was greater than those who died of all causes in each of the next 24 years. And even today with world population doubling, the number of people dying is not that much greater than it was in 1950.

And what about those who say that the changes of the last decades were a one-time anomaly that will not be replicated, asked DeGregori. They should remember, he said, that "in 1950 we looked back at the previous 200 years of the industrial revolution and agreed that those years brought about an advanced standard of living, a transformation in the way of life, and a rapid increase in life expectancy that was unprecedented in human history." Even earlier, at the beginning of the industrial revolution, Adam Smith described the wealth of nations as a result of the previous several hundred years, which he said brought about a change in Europe that was unprecedented in human history. Yet the unprecedented change that he described was dwarfed by the one that followed.

Thus, the pace of human change and of scientific change is cumulative, concluded DeGregori; it builds on itself. And because it builds on itself, it has accelerated through time. "Based on any reasonable historic perspective, therefore, in projecting change in the twenty-first century the various panelists in this symposium were being circumspect."

If all countries continue to enact policies that encourage scientific and technological research, the technologies needed to sustain development as well as to bring about even greater acceleration will become available. He acknowledged, however, the question often raised in development circles: If we are doing all of these things and growing rapidly, won't we exhaust the world's resources?

Dr. DeGregori is a professor of economics at the University of Houston and author of *A Theory of Technology: Continuity and Change in Human Development* (Iowa State University, 1985).



It is ironic, he pointed out, that when the triage theorists were suggesting that we abandon large areas of the population, the "limits to growth" modelers were saying that we were exhausting the world's resources. In fact, the world is producing 10 percent more food each year than world demand. Moreover, today virtually every major raw commodity—food, fiber, mineral—is in excess supply. It is a world that has consumed resources at an unprecedented rate since World War II and yet world resources are at a record high, emphasized DeGregori. Reserves are increasing faster than they can be used, so the world is not running out of resources; they are becoming more abundant. They have become so much more abundant, in fact, that it is difficult for those in countries depending on resource exports to manage their resources. Over the last 200 years, for example, all economic measures indicate that the real price of mineral resources has been declining. For the last hundred years at least, the real price of food—that is, the real price in hours of labor that must be worked, or the price adjusted for inflation—has been declining. Thus, it is a long-term trend.

As one economist has said, DeGregori quoted, "Resources are not; they become." Resources are not original properties of objects, but capabilities that humans, through intelligence, apply to them. A million years ago, our hominid ancestors turned stones into tools, thereby turning the stones into resources. "There was nothing inherent in those stones that were resources until we created those resources. Thus with our ideas, we created resources," he said. Later, fire was made into a resource and a tool, as were various parts of the ground, such as metals.

When we were gatherers and hunters, he continued, we had apparently reached the limits of our environment without expanded technology. Yet agriculture was developed, and this could not have been predicted. Agriculture did not depend upon arable land; arable land depended upon agriculture. DeGregori continued to build the case, using numerous examples, that mankind has created the conditions for its existence throughout the world. "We created ourselves with technology, as the physical anthropologists and the evolutionary biologists have pointed out. Thus, the reason that we are not running out of resources is that we are creating them."

Science and technology, therefore, has a purpose beyond that of contributing to development, DeGregori concluded. Equally as vital, science and technology are the very stuff of the creative process that is essential for mankind's survival. If the earth's resources are fixed, even with falling birthrates in the world and the population dynamics presented at this symposium, the continued growth from the previously large birthrate as well as the continual growth in economic development would soon exhaust these resources. Science and technology are the remedy, DeGregori reasoned. For example, from 1945 to 1975 the world used one and a half times as much copper as was known to exist in 1945, yet in 1975 four times as much copper was available than in 1945. Had not new sources of copper continually been sought and had not new technologies been developed that allowed the use of lower and lower grade copper ore and cheaper processing, the world would have run out of copper. He added, however, that the one exception to his optimism about the endurance of the world's resources is the diminishing pool of potential biological resources.

In drawing a final implication of the issues raised by this symposium, DeGregori admitted that changes brought about by the introduction of new technologies also create new problems. Zambia, for example, built a $200 million cobalt processing plant in 1979, when the price of cobalt was $40–$50 a pound. Now they have an idle plant and two years' worth of cobalt lying on the ground because they cannot sell it. Why? Because thanks to its high price, innovators have substituted ceramics for cobalt in magnetos and have come up with high-temperature alloys that use less cobalt. By August 1986 the price of cobalt was down to $4 a pound. In 1986 a look at the commodity index for all raw commodities showed that the money price of commodities was the same as it was 10 years earlier, even with inflation, and that the real price adjusted for inflation was back to depression levels.

Thus, the new technologies are creating new sets of problems that will have to be dealt with simultaneously, thereby compounding the difficulty. The developing countries especially may have to attack problems of poverty and abundance. Countries such as Zimbabwe and Malawi may have food shortages one year because of drought and a bumper crop of coarse grains the next year that they cannot sell on the world market because of the food glut worldwide. Thus one year they are hit with the problems of poverty, and the next year they are impoverished and victims of the problems of abundance. Development programs and international policies must be able to deal with the multiplicity of problems simultaneously.

DeGregori concluded by observing that we will always have problems; it is the nature of the life process. Had we not solved past problems, our plight would be far worse. The ongoing human endeavor of solving problems and creating new ones should be understood as a challenge and an opportunity. For it is in this problem-solving process that we have devised not only the basis of our physical existence but have also crafted the means for artistic and intellectual expression. It is not by accident that the earliest *Homo sapien sapien* (about 35,000 years ago) was associated with art (the cave paintings of Lascaux, for example) as well as with advances in technology and population. One could reasonably argue that in tool using and problem-solving, humans have evolved with a built-in curiosity, creativity, and desire to know. In the words of T. S. Eliot[1]:

We shall not cease from
exploration
And the end of all our
exploring
Will be to arrive where we
started
And know the place for the
first time.
Through the unknown,
remembered gate
When the last of earth left to
discover
Is that which was the
beginning.

[1]T. S. Eliot. 1952. "Little Gidding,"last of the Four Quartets. *The Complete Poems and Plays, 1909–1950.* New York: Harcourt, Brace, Jovanovich.

APPENDIX

Symposium Speakers and Presentations

Opening Remarks	Frank Press President, National Academy of Sciences Chairman, National Research Council Jay Morris, Acting Administrator, U.S. Agency for International Development (USAID)

The Contribution of Science and Technology for Development: The Past Twenty-five Years

Moderator	Nyle C. Brady, Senior Assistant Administrator, Bureau for Science and Technology, USAID
Contribution of the Social Sciences	John D. Montgomery, Ford Foundation Professor of International Studies, Harvard University
Contribution of the Agricultural Sciences	Robert D. Havener, President, Winrock International
Contribution of the Health Sciences	D.A. Henderson, M.D., Dean, John Hopkins University School of Hygiene and Public Health
Contribution of Population Programs	Ronald Freedman, Roderick D. McKenzie Distinguished Professor Emeritus of Sociology, Population Population Studies Center, University of Michigan

Prospects Entering the 21st Century

BIOTECHNOLOGY

Biomedical Breakthroughs	*Moderator:* Kenneth Bart, Agency Director for Health, Bureau for Technology USAID *Speaker:* Kenneth S. Warren, Director, Health Sciences, The Rockefeller Foundation
Human Reproduction and Contraceptive Research	*Moderator:* Duff Gillespie, Agency Director for Population, Bureau for Science and Technology, USAID *Speaker:* Gary Hodgen, Professor and Scientific Director, Jones Institute for Reproductive Medicine, Eastern Virginia Medical School
Animal Biotechnology	*Moderator:* Duane Acker, Agency Director for Food and Agriculture, Bureau for Science and Technology, USAID *Speaker:* Tilahum Yilma, Professor of Virology, Department of Veterinary Microbiology and Immunology, University of California, Davis
Plant Biotechnology	*Moderator:* Duane Acker *Speaker:* Robert Fraley, Director, Plant Science Technology, Monsanto Company

BIOLOGICAL DIVERSITY

Moderator: Jack Vanderryn, Agency Director for Energy and Natural Resources, Bureau for Science and Technology, USAID

Speaker: Thomas Lovejoy, Executive Vice-President, World Wildlife Fund (U.S.) and The Conservation Fund

APPENDIX

INFORMATION SCIENCES AND COMMUNICATIONS TECHNOLOGY:
APPLICATIONS FOR DEVELOPING COUNTRIES

	Moderator: Walter A. Rosenblith, Institute Professor, Massachusetts Institute of Technology
Overview	Philip F. Palmedo, Chairman, International Resources Group
Applications in Agriculture	James W. Jones, Professor of Agricultural Engineering, University of Florida
Applications in Health Care	José M. Negrete, Director, Institute of Biomedical Research, National Autonomous University of Mexico
Applications in Education and Literacy	Kurt D. Moses, Director of System Services, International Division, Academy for Educational Development

SPACE SCIENCE AND REMOTE SENSING:
APPLICATIONS FOR DEVELOPING COUNTRIES

	Moderator: Walter A. Rosenblith
Overview	Moustafa Chahine, Manager, Division of Earth and Space Sciences, Jet Propulsion Laboratory
Applications in Crop Production	Charles F. Hutchinson, Director, Arizona Remote Sensing Center, Office of Arid Lands, University of Arizona
Applications in Agroclimatology	Edward Kanemasu, Professor of Agronomy, Kansas State University
Applications in Mineral Exploration	Ronald J.P. Lyon, Professor of Mineral Exploration, Stanford University

MATERIALS SCIENCE AND TECHNOLOGY:
APPLICATIONS FOR DEVELOPING COUNTRIES

	Moderator: John H. Gibbons, Director, Office of Technology Assessment, U.S. Congress
Overview	Edgar A. Starke, Jr., Dean, School of Engineering and Applied Sciences, University of Virginia
Fibrous Composites	Carl T. Herakovich, Professor of Engineering Science and Mechanics, Co-director, NASA Virginia Tech Composites Program, Department of Engineering Science and Mechanics, Virginia Polytechnic Institute and State University
Applications for Electronic Materials	J. Franklin Mayo-Wells, Staff Assistant for Technical Coordination/Operations, Center for Electronics and Electrical Engineering, U.S. National Bureau of Standards
Applications for Superconductivity	Richard E. Harris, Group Leader, Cryoelectronic for Metrology Group, U.S. National Bureau of Standards

MANUFACTURING TECHNOLOGIES:
APPLICATIONS FOR DEVELOPING COUNTRIES

	Moderator: John H. Gibbons
Implications of Manufacturing Technology Advances	Barbara Burns, Manager, Systecon Division, Coopers & Lybrand
Applications for Robotics	Howard Moraff, Program Director, Automation and Systems Integration, National Science Foundation

Closing Remarks:

Technology in Our Changing World	Thomas R. DeGregori, Professor of Economics, University of Houston