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Future National Research Policies Within the Industrialized Nations: Report of a Symposium

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THE NATIONAL ACADEMIES
Advisers to the Nation on Science, Engineering, and Medicine

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Future National Research Policies Within the Industrialized Nations

Report of a Symposium

GOVERNMENT-UNIVERSITY-INDUSTRY RESEARCH ROUNDTABLE

National Academy Press
Washington, D.C. 1992

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The Government-University-Industry Research Roundtable, established in 1984, is a forum for discussion and debate among representatives of government, universities and industry. Discussions focus on issues related to research that challenge, confound and occasionally divide those in the U.S. research community. The Roundtable does not make recommendations regarding specific government policies or programs. Its purpose is to help all participants develop a better understanding of complex issues, to stimulate imaginative and creative thought and to provide a setting for seeking consensus. The Roundtable is jointly sponsored by the National Academy of Sciences, the National Academy of Engineering and the Institute of Medicine.

The Roundtable's agenda is set by a 25-member Council. The Council's membership is comprised of distinguished scientists, engineers, administrators and policymakers from government, universities and industry. The presidents of the Roundtable's three sponsoring institutions also hold seats on the Council. With the exception of the federal agency officials, who serve as long as they are in office, Council members are appointed to three-year terms.

Through all of its work, the Roundtable Council maintains working relationships with the vast array of parties with an interest in the conduct of research in the United States. These include professional associations, scientific societies, executive agencies, congressional offices, industries and state governments. Contact between the Roundtable and these groups takes place at various venues, including large symposia, workshops and smaller meetings.

Occasionally, working groups are appointed by the Council to examine selected topics in depth. Membership on the working groups is drawn from the Roundtable Council and includes other leading participants in the U.S. research system. The results of working group discussions are reported to the Council, where they receive critical review. Discussion papers, based on the working group deliberations, are disseminated to interested constituencies in the hope of stimulating a wider discussion of these issues.

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FOREWORD

Throughout the world, national research policies are currently undergoing intense review and revision. Rapidly changing social, political and economic events, coupled with new and exciting research avenues emerging within the scientific community, are profoundly affecting the organization and resources for the conduct of research. In this report, research policy leaders from the European Community, Germany, the United Kingdom, Japan, the former USSR, and the United States present their views of the challenges ahead for national and international research policies and programs.

In many ways, there appears to be convergence among the major industrialized nations in the organization and purposes of their national research systems. The European nations, individually and within the emerging European Community, are undertaking major new initiatives for revising decisionmaking mechanisms, ensuring new generations of scientific and engineering talent, and adapting the organization of their research activities. Japan is pursuing new approaches to enhancing academic research and drawing top scientists and engineers to the universities. The Russian Academy of Sciences has assumed most of the membership and responsibilities of the former USSR Academy of Sciences. Yet the profound problems and challenges described in this volume for the former USSR are still relevant to the new Russian Federation and the other republics as they pursue more "Western" models of research organization.

The United States also faces many of the challenges confronting other nations. Policymakers in government, universities, and industries will benefit from greater understanding of these worldwide changes and implications for U.S. research policies. We hope that the information presented within this symposium report contributes to that learning process.

JAMES D. EBERT

Former Chairman

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The Roundtable also acknowledges the staff members who organized the symposium and prepared this symposium report, especially Don I. Phillips, Executive Director of the Research Roundtable, and John P. Campbell, Project Director for the Working Group on the Academic Research Enterprise. Peter Pocock played a critical role in writing the symposium summary and editing the proceedings.

Special thanks go to the National Science Foundation and the John D. and Catherine T. MacArthur Foundation for their financial support of the symposium and this report.

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PREFACE

One of the major areas of interest for the Research Roundtable has been academic research in the United States. In 1987 the Roundtable Council assembled the Working Group on the Academic Research Enterprise to study this issue. Among the many concerns driving this effort were the changing nature of research, the changing demographics of the college-age population, the increasing financial and human resources required for carrying out research, and the growing expectations placed on academic research. These concerns raised questions about the role of universities and colleges within the U.S. research system, the nation's ability to support academic research, the management of research institutions, and the responsibilities of those who sponsor research.

The charge to the working group was fourfold: (1) to examine recent trends affecting academic research in the United States, (2) to consider the impact of these trends on the current academic research enterprise, (3) to identify the longer-term issues that will affect the enterprise in the decades ahead, and (4) to explore ways in which the enterprise might best meet the challenges of the future.

The working group divided its work into two phases. During the first phase, the group addressed the status of the current academic research enterprise, reviewed statistical evidence of recent trends, and identified pertinent issues for further consideration.[1] During the second phase, the working group examined plausible options for the future of the U.S. academic research enterprise.[2]

To gain a better international perspective on the issues addressed by the working group, in March 1989 the Research Roundtable and the National Science Foundation cosponsored a symposium entitled "The University Research Enterprise Within the Industrialized Nations: Comparative Perspectives." The purposes of the symposium were to compare the histories of the research systems of the United States, Japan, the Soviet Union, the United Kingdom, Germany, and France, with special emphasis on university research. The symposium was organized around presentations by six historians of science and technology, each an expert in the evolution of the research system in one of the countries. In March 1990 the Round-table published a symposium report summarizing the major themes presented

[1] Government-University-Industry Research Roundtable, *Science and Technology in the Academic Enterprise: Status, Trends and Issues*, Washington, D C.: National Academy Press, 1989.

[2] Government-University-Industry Research Roundtable, *Fateful Choices. The Future of the U.S. Academic Research Enterprise*, Washington, D.C.: National Academy Press, 1992.

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in the symposium discussion and including the formal presentations of the symposium speakers.[3]

In February 1991 a second international symposium was held to address current issues. This symposium, entitled Future National Research Policies Within the Industrialized Nations, included senior government officials and leading scientists directly involved in formulating research and higher education policies in the United States, Japan, the Soviet Union, the United Kingdom, Germany, and the European Community. Symposium panelists were invited to discuss the following topics:

- What major trends in the size, mission, and character of research do they see occurring in their nations' research enterprise, including universities, government research institutes, industrial laboratories, and other independent research laboratories?
- How are their nations responding to trends occurring within the research enterprise?
- What new strategies or approaches are their nations planning for the research enterprise during the next 20 years?

An agenda for the symposium, as well as panelist biographies and a list of symposium participants, is found in the Appendix.

This report is divided into two parts. Part One summarizes the major themes presented in the symposium presentations and open discussion. Part Two contains the formal presentations of the symposium speakers, describing research policies within the European Community, Germany, the United Kingdom, the Soviet Union, Japan, and the United States. Also included are discussion sessions following each country presentation.

[3] Government-University-Industry Research Roundtable, *Tile Academic Research Enterprise Within the Industrialized Nations: Comparative Perspectives*, Washington, D.C.: National Academy Press, 1990.

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PART ONE

Symposium Summary

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SUMMARY

INTRODUCTION

Every nation will develop its research policies with an eye to the shifting international arena

Three broad, interrelated issues emerged frequently during the symposium discussion of future national research policies: decisionmaking, people, and organization. In an era of constrained budgets, acknowledged by all participants, the availability and targeting of funds for science and technology will shape the amount and kinds of research performed; a clear understanding of funding processes and criteria is essential for everyone involved in scientific and technological work. Research organizations working in a constantly shifting environment are challenged to recruit and maintain adequate numbers of appropriately trained workers, essential to successful research efforts. Finally, the very structures of those organizations require continual examination and revision to respond effectively to the rapidly changing circumstances.

DECISIONMAKING

Research policy decisions will seldom reflect purely scientific concerns Politics will play a major role

Many of the decisions and policies that control the flow of funds for research arise in a political context. Research policy is just one component of a national or corporate economic strategy shaped by issues of economic welfare and international competition. General goals for research are developed by politicians and managers, usually in consultation with scientists, but the ultimate decisions are seldom based on purely scientific considerations. Politics plays a major role in the formulation of decisions about the proportions devoted to civilian and military research, the balance between big and little science, and the relative funding levels for such emerging technologies as biotechnology and alternative energy. Parochial interests often enter into the mix as well, as when legislators seek funds and facilities for the districts they represent. Furthermore, the competition for funds sometimes reflects divisions within the science community itself—between partisans of big science and advocates of more smaller-scale experiments, for example, or between junior investigators and more established scientists.

National Politics and Research

Research policy in Germany, nonpartisan for most of its history, became the subject of partisan debate about 10 to 15 years ago. There now are divisions of opinion along party lines over such subjects as alternative energy technology, biotechnology, and genetics. In addition to its effect on the development of research, the debate has an economic impact, and it is increasingly difficult for a scientist to get involved in policy issues with

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out being caught up in the partisanship. Nevertheless, the complexity of the funding process buffers the research establishment against conflicting demands, and some funding bodies are relatively immune from politics because they can play different factions against each other. Furthermore, the major parties favor increased spending on research, and the government's overall science budget is a measure of the effectiveness of the relevant government ministers. These politicians work hard to get bigger increases for their respective ministries. When spending cuts have been necessary, the government first has worked to convince industry to increase its share, resulting in more money overall with less coming from the government.

The complex German funding process buffers the research community against growing partisan divisions

In the United Kingdom the impact of partisan politics is found in structural changes initiated under the free-market philosophy of recent conservative governments. Although some cuts in public spending have been balanced by funding from industry, the government has placed less emphasis on prodding industry to take up the slack. University researchers in particular are experiencing a shift from long-term government financing to more diversified funding sources—often tightly focused, short-term research contracts.

Amid growing wealth, Japan forges policy consensus among all interested parties

The Japanese system for formulating research policy is not easily reduced to an organizational chart. Its paramount feature is consensus, which is arrived at through a wide variety of committee meetings, symposia, workshops, and informal discussions. The government supplies just 20 percent of all research funds, but it takes an active role in convening these consensus-building gatherings through several agencies and government-industry associations. Agreement on goals and policies gradually emerges as scientists, engineers, and managers come together repeatedly to discuss research-oriented issues.

In the decentralized political system of the United States, research policy formulation often has a more adversarial nature, particularly in an era of budgetary constraints. Federal funding for research has risen over the past decade, but symposium participants expressed concerns that recession and the imperatives of deficit reduction could pose problems for similar increases in the near future. Because the political system responds to broad-based public demand, American science officials are calling for educational efforts to raise public awareness and understanding of research and its potential benefits for society.

Meanwhile, the federal government is working to identify critical technologies. The present administration has undertaken to make the funding system more efficient by coordinating the activities of agencies that have jurisdiction over different parts of broad scientific or technological endeavors, such as high-performance computing or global change. The administration also is developing mechanisms for bringing input from the private sector into the highest levels of policy determination.

In the Soviet Union the advent of market-oriented policies has had a significant impact on the research establishment. The political turmoil has

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made decisionmaking difficult, and the confusion is compounded by the lack of laws defining the authority and responsibilities of the various scientific organizations.

U.S. research priorities will be established by independent decisions throughout the system

One area where problems are acute is applied research, formerly conducted according to directives from high levels of the government or party. With the demise of the centrally directed system, the factories no longer have an impetus for research and development, which competes in their budgets against production outlays. Managers have little appetite for cutting production budgets since there is still strong demand for existing products, and they have no firsthand experience of the long-term benefits of R&D.

A new law, signed in 1990, made the Soviet Academy of Sciences an independent organization, that is no longer under the official direction of government and party authorities. The new law also established a new all-union foundation for basic research, that distributes funds to academies, universities, and other research organizations through a grants process similar to that of the U.S. National Science Foundation.

Strategic Investment

Because of growing research costs and a shifting international balance of economic and scientific strength, it is unlikely that any nation will be preeminent in all research fields. Instead, nations may aim to play a dominant role in specific areas where they have a vital strategic interest or a comparative advantage. In other areas they may pursue international collaboration in research efforts or simply import frontier scientific and technological knowledge from abroad.

Members of the EC will pool their resources to undertake big basic science programs

Nowhere is this pattern more clear than among the nations of the European Community, now preparing for substantial economic integration in 1992. The EC Commission has a science policy of its own, independent of the individual members. The EC Commission is considered the best manager of large projects in precompetitive areas, such as the present venture in magnetically controlled nuclear fusion that combines virtually all the efforts in that field in Western Europe. In addition to one large center located in the United Kingdom, the program includes facilities in other countries and staff, from all member states, who move freely from one center to another. The benefit of this arrangement is that it allows each participating country to retain a foothold in an area that most could not support independently.

In smaller, more competitive arenas the members of the European Community will operate more independently. Germany will devote some resources to staying current with scientific and technical advances in most fields, in order to avoid being left behind by unexpected developments. A larger part of German research investment, however, will go to areas where the nation can retain a global competitive edge.

The United Kingdom will follow a similar path, maintaining at least a small but high-quality effort in every discipline while putting major resources

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into areas of growing scientific and economic importance. The main selection criteria include the quality of the proposed research and of the scientists involved and secondarily, the potential exploitability of the research. Flexibility is also important, for it allows resources to be shifted as warranted by scientific advances and changes in strength. One currently targeted area is molecular biology, with lively activity in genetic engineering and engineering of antibodies.

Japan's government sets up industry groups to share the risks of speculative research.

Japan will focus its basic and applied research efforts on economically significant subjects, such as new industrial technologies, energy production, and biotechnology. The government will organize industry associations to share the risks of highly speculative research. In some cases, however, where costs appear too great and risks too high, the government will encourage collaboration with foreign industries or research organizations.

The United States, in contrast, continues to pursue a wide variety of large, expensive research programs, including manned space flight, the human genome project, and the superconducting supercollider. However, specific competitive areas also are targeted, including a major initiative on high-performance computing and communications. The stated goal of increased funding for this program—intended to double in the next four years—is to expand the speed and power of computer systems by factors of between one hundred and one thousand, and to make that power available to far more people through a national broad-band data network spanning the nation.

Problem Application

Urgent social, health, and environmental problems confront all nations. Public support doubtless will continue for scientific and technological research programs that contribute to solving these problems. Expanded research efforts in these areas will probably lead to the establishment of larger, more multidisciplinary research organizations, some with international participation.

German industry is under tremendous pressure to develop new technology that contributes to sustainable, ecologically sound development, especially through the full product cycle to waste recycling and waste treatment. Furthermore, German scientists will be expected to become much more involved in solutions to problems of the global biosphere, an area in which they have been less active than some European nations.

Environmental science will be an important target of Japan's future research program. The government recently founded an institute for research on innovative environmental technologies. Jointly funded by government and private industry, the institute will conduct experiments in its own laboratories and will sponsor work by individual investigators and research groups in Japan and around the world.

Social and ecological problems have taken on new importance in the Soviet Union and will occupy high places on that nation's research agenda.

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Particular attention will be focused on such areas as efficient food production, ecologically sound transportation, and clean industrial processes. Global problems are cited as areas for international cooperation that would allow concentration of resources without redundant efforts.

PEOPLE

The retraining of scientists will become an important mission for universities.

All countries worry about having enough talent in place to do high-quality research in the future. In several industrial countries the college-age population is declining; in some, students are shying away from the physical sciences and showing a preference instead for social sciences. A reduced number of graduates can severely affect research organizations, which require constant infusions of freshly trained talent to keep abreast of rapidly evolving scientific knowledge. Other constraints on the numbers of highly qualified scientists include overlong education and emigration—a particular worry of the Soviet Union.

Numbers

In the European Community the dwindling college-age population is generally reducing the number of students in science and engineering (Germany is an exception). One proposal for dealing with the problem is to augment university enrollments with older scientists, who will retrain in their own fields or in new ones. Such retraining, at intervals of about 10 years, can give scientists and engineers the study time they need to stay abreast of the latest advances and to maintain their productivity, which might otherwise lag as their careers progress.

Educating a science elite leaves the U.K. short at lower levels.

The reduced number of science students in the United States is attributed not only to the absolute decline in the college-age population but also to a decline in the proportion of students interested in and qualified for a science education: dropouts occur at every educational level, inadequate science and math programs in primary and secondary schools leave students unprepared, and uninspired university courses fail to excite and motivate students to pursue careers in research.

Problems in the United Kingdom are similar. The educational system, which still produces an elite of scientists and engineers, pushes many other individuals out of the system at lower levels, without helping them to pursue alternative technical careers. Efforts are under way to broaden access to higher education—to bring people with diverse qualifications and backgrounds into the universities. The problems of science education are exacerbated, however, by the failure of the primary and secondary systems to attract the best science teachers; the result is that many of the most creative students steer clear of the sciences early on.

Germany has already begun to deal with the problem of dwindling numbers of science students by making mathematics and science courses mandatory throughout secondary school. These requirements had been dropped in the 1970s in an effort to expand the secondary school system,

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but the result was a drop in university science and engineering enrollments. Reinstating the requirements reversed the trend; apparently some students came to understand and enjoy subjects that were too intimidating to approach voluntarily.

Graduate Students and Research

Japan's universities lose best graduate students to industrial laboratories.

Symposium participants agreed that a good supply of graduate students is essential for the continuation of high-quality research in those universities that are traditional wellsprings of advances in basic research. Candidates for higher degrees are also well-trained scientists and engineers who work for very low wages; without their contributions, the productivity of university research groups would be reduced greatly. This fact may play a part in the phenomenon of stretchout, acknowledged by several participants; graduate students are taking longer to get their degrees. In the British and German systems of higher education, efforts are underway to combat stretchout by limiting the period of funding for higher degrees.

Japan has a different problem in higher education. Its universities are losing too many Ph.D. candidates to industry before they graduate. Industrial laboratories often are better equipped than those in the universities, and a student who takes a job can still gain the Ph.D. degree by submitting a thesis. University faculties suffer under this system, for many of the best potential faculty members leave their schools instead of staying on to teach and do their research in the university laboratories. Of the students who now remain in school to pursue a Ph.D., half are not Japanese; largely drawn from other Asian nations, the foreign students generally return home after obtaining their degrees.

Mobility

Scientists crossing borders advance research everywhere.

There was general agreement that the ability of scientists to work abroad is beneficial to a nation's research establishment, and it helps as well to advance the scientific endeavor worldwide. Many EC programs specifically support such mobility, mainly within Europe but also on a global basis. Participants agreed that universities and laboratories in the United States are still important way-stations in many scientific careers, but they noted that the flow is now more balanced, with European facilities in particular drawing greater numbers of visiting scientists. Japan, which has experienced less success in attracting foreign scientists, is stepping up its efforts.

The negative side of mobility emerged in discussions of brain drain from research establishments of the Soviet Union and Eastern Europe and, to a lesser extent, from some parts of the European Community such as Ireland. In the Soviet Union neither salaries nor facilities measure up to the highest international standards, making emigration an enticing prospect, particularly for top-echelon scientists. Thus, the benefits that an increasingly open society brings to Soviet research may be countered by a crippling outward flow of the nation's best scientific talent. One proposed solution

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to this problem is for foreign corporations to establish research facilities within the Soviet Union to take advantage of this pool of well-trained research workers.

Mobility means a brain drain for the USSR and eastern Europe.

The exodus of scientists has already begun from the overpopulated research establishment of the former East Germany. In the short term, little can he done to stem the tide, but longer-term measures to improve facilities may eventually draw some scientists back and keep others from leaving. Central to this effort is the establishment of well-endowed research universities that not only educate the young people of particular regions but also spark the development of businesses based on technologies emerging from the university laboratories.

ORANIZATION

The effective deployment of research resources concerned most participants, who agreed on the importance of conducting research in suitable environments. With the exceptions of Japan and the Soviet Union, most nations look to their research universities for progress in basic research; applied research is carried out in industrial laboratories and large government facilities.

Upgraded research universities may keep good scientists in eastern Germany.

Some established scientific organizations are no longer as responsive as they might be to national research goals. National laboratories in particular are cited for their inefficiency in the increasingly competitive research arena. Another area of concern is the effect of emerging organizational forms on the quality of research. Collaborations among national industries, universities, and governments may be restrictive, and dissemination of results with implications for commercial strategy may he delayed or even prohibited. For example, university-based investigators involved in joint applied research efforts with industrial and government laboratories must retain their ability to explore "nondirected" research avenues.

Government Laboratories

Several participants raised concerns about national laboratories in the United States, the United Kingdom, and the European Community. Heavy in bureaucracy, with missions that are sometimes ill-defined, these laboratories may be wasteful of research resources. The problem is to find ways to integrate them more directly with the academic and industrial research establishments. In Germany these links are much closer; for example, industrial researchers and scientists at Max Planck Institute facilities frequently hold professorships at nearby universities.

Most nations will seek to integrate national labs more directly with academic and industrial research.

The United States has more than 700 government laboratories with a total annual budget of about $20 billion in 1991. Many were founded with a clear mandate that was fulfilled long ago, and they are now searching for new work in such fields as the environment and energy resources. New missions are essential since the political realities of the congressional budget process make it difficult to close these labs. It is not yet clear whether the single-customer culture of government laboratories can adapt to com

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pete successfully in these new arenas. The government hopes to improve the odds by developing partnerships with universities and industry so that other interested parties can have a hand in determining the direction of research programs at national laboratories.

In the United Kingdom national research institutes are being encouraged both to develop better links with universities and, in some cases, to relocate near university campuses. The balance between different modes of supporting research will continue to receive careful scrutiny.

Germany will attempt to avoid new bureaucracies by funding temporary consortia.

The German government is working on a new, flexible mechanism to achieve specific scientific goals without establishing permanent institutions that cannot be closed down. The idea is to establish temporary consortia, drawing individuals and groups of researchers from various institutions. The consortium works on a job for several years, with sufficient funds, and then disbands at the end of the project. The scientists return to their original institutions, where their jobs were temporarily filled by younger researchers.

The problem of government laboratories looms large in eastern Germany, where the former Communist government built up a huge publicly funded research system. In most cases the government facilities will be cut back. Some research groups will be incorporated into government-sponsored organizations, but most will become affiliated with universities; the intent is to rebuild the eastern university research system to bring it up to the level of western Germany.

The Soviet Union faces similar challenges in trying to restructure its research establishment to deal with competitive challenges. The largest organizations are being split into smaller ones; for instance, the Physical Institute of the Academy of Sciences, with 5,000 employees, is now divided into five separate institutes. In the modified system there is to be an emphasis on democratic management and provision of opportunities for individual expression. In time, scientists and engineers formerly supported by government institutes will move into new industrial research organizations.

University-Industry Ties

New Soviet labs will feature democratic management.

As governments become more involved in directing research policy and as industry expands its links with the academy, university research becomes more involved with application. The benefit of this development, in addition to increased funding, is that teachers and students are exposed to real problems. However, there is a potential danger in the trend if attention is diverted from teaching and basic research—the traditional strengths of universities dedicated to the collection and transmission of knowledge for its own sake.

In Germany the relationship between universities and industry has always been strong, especially in chemicals, pharmaceuticals, and engineering. Academia generally feels that industry funding is acceptable as long as results can be published and as long as individual researchers are free to decide whether or not they will participate. Industry provides more than 70

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percent of the funding for engineering studies at some of the important institutes in production technology or general mechanics, a trend that will probably continue. Government research grants generally are less directed since they are distributed through a system of peer review.

Links with industry will lead U.K. universities to more applied research.

Relations between universities and industry in the United Kingdom are tempered by the recognition that the training of the scientific work-force is even more important for the research base than the generation of new knowledge. Nevertheless, scientific research will continue to be centered at the universities or associated institutes, where it can be an integral part of the educational process. This proximity will ensure continuity as graduates move into scientific work.

Weak academic research sends Japanese industry funds abroad.

Improved links with British industry are leading universities and research council institutes to undertake more applied research. Future efforts will focus on improving the flow of information so that industry can quickly exploit research findings and researchers can get a clear view of the root scientific problems confronting industry. One drawback of the increase of directed research programs, however, is the increasing proportion of academic researchers working on short-term renewable contracts, now about 40 percent. Although this makes it possible to eliminate nonproductive tenured staff, it may have the effect of discouraging a long-term view of scientific work.

One consequence of the weakness of Japanese research universities is that they are unable to attract substantial support from industry. Japanese corporations have shown more interest in supporting research abroad, particularly in American universities. The government will attempt to combat this problem by establishing centers of excellence that provide funding and facilities to academic researchers, thus hopefully of drawing top scientists and engineers back to the universities.

Industry funding for U.S. universities will emphasize generic research.

Industry research funding to universities in the United States has doubled in the last 15 years—to about 8 percent of the total. This funding is expected to keep rising but to remain only a fraction of federal funding—now at 60 percent. Most industrial contributions are expected to be in basic research, with applied research reserved for corporate laboratories. Some participants expressed concern that increased funding from industry could cause cultural changes within universities that would lead to a short-term perspective, useful for applied research but detrimental to basic research.

International Collaboration

Scientific cooperation at the international level takes two forms: (1) Governments may establish explicit programs for sharing the costs and benefits of large facilities and research programs, and (2) corporations may establish research links across national boundaries. In general, government collaboration is easier in basic research than in technology, which is closer to competition in the market. Corporate international interest, on the other hand, is often focused on market-oriented applied research.

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Some participants wondered whether international research activities might come to be seen as impairing the national competitive advantage often cited as a political justification for public investment in scientific research and training. Most agreed, however, that nations can maintain robust scientific establishments, essential to competition, only through collaborative efforts.

International programs will be essential to maintaining a strong national research base.

European governments engage in a wide range of cooperative ventures through the European Community. In addition to large, centrally managed concerns, such as the nuclear fusion program, the EC Commission coordinates cooperative research, with proposed research plans carried out by the best qualified research institutes or universities in the European Community. The EC Commission also promotes open access to large installations, which may be operated by one or several member nations, by scientists from other EC countries. Proposals from facility managers and potential users are sifted and combined to produce research programs that guarantee stable support for the facilities and access for scientists who normally would not have it.

Problems arise in the mechanics of European cooperation because of the diversity of national systems and the speed of the progress toward integration. One problem for some countries, such as the United Kingdom, is that funds for international programs are allocated as part of the overall research budget. Thus, international work must compete directly with domestic research programs for funds, creating major tensions within the research community in times of budgetary constraints. Furthermore, although the basis for funding individual projects at the national level is well understood, many scientists are less confident of the procedures and criteria for allocating funds at the European level.

EC collaboration may take funds from domestic programs.

Scientific collaboration with central and eastern Europe poses new challenges for the European Community. The European Community recognizes both the crucial role of science and technology in the transition to a market economy and the importance of developing a continental research community. Despite practical difficulties, the EC Commission has begun to establish a basis for collaboration and assistance. One primary objective is to promote cooperation among the eastern European nations, in order to prevent fragmentation that would jeopardize systematic work with the European Community.

The Soviet Union will greatly expand its international research outreach in coming years, particularly in basic research, although the efforts may be hampered by the lack of hard currency. In particular, the most advanced sectors of the Soviet defense industry, which boast many good scientists, will seek to establish links with Western partners. Corporations may be invited to set up research institutions within the country, so as to employ highly trained Soviet scientists and technicians.

Open Communication

The accelerated pace of scientific advances relies on the rapid flow of scientific information made possible by the emerging global information

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environment. A nation's ability to compete in science and in technology can be reduced severely by deficiencies in communication technology and by national economic or political policies that impede the information flow. Even language is an obstacle, although, as one participant noted, "broken English" is taking the place once held by Latin as the language of learned communication.

The infrastructure for international collaboration in science and technology will require standards for the exchange of information. If, for example, nations develop their own standards for high-speed computing rather than participating in the development of international standards, the sharing of information beyond the national level will be far more difficult.

International collaboration will require standards for exchanging research information.

The political issues that could hamper communications revolve around the question of competitiveness. Just as military security has long been used to justify concealing research results, so arguments about competitive interest might lead to closing off scientific communication.

Rapid Adaptation

Beyond the short term, future trends in research are quite unpredictable. With research capability spreading across the globe, research establishments have to become more flexible; priorities and programs have to be adjustable to reflect changes in all scientific fields, wherever they may originate.

An unpredictable future mandates flexibility in research establishments.

Most participants agreed that fundamental research should be centered in universities, where flexibility and capacity for innovation are fostered by the continuing flow of bright young students. Large national laboratories generally were cited as examples of inflexibility—unlikely to receive a larger share of resources than at present. Symposium representatives from Germany and the United Kingdom reported tendencies toward funding short-term projects that could be easily terminated upon completion. All agreed that resources will be directed to institutions that have proven ability to adapt to new discoveries and changed conditions.

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PART TWO

Symposium Presentations

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THE EUROPEAN COMMUNITY

FILIPPO PANDOLFI

Vice-President for Science, Research and Development, Telecommunications Information Industry, and Innovation, and the Joint Research Center, The Commission of the European Communities

In the United States one of the most important forums to elaborate proposals and to offer orientation to all parties concerned with research is the Government-University-Industry Research Roundtable. A previous Research Roundtable symposium in March 1989 covered the history of research in the major industrialized countries; at this symposium we address the future.

In this presentation I will follow a similar sequence for the European Community (EC). First, I will give an overview of the practice of research and development (R&D) across the member states of the European Community. Second, I will identify and explain why the European Community has become active in science and technology and will describe the constraints on this activity. Third, I will set out the approaches that the European Community will need to follow in the future.

R&D Activity in the EC Member States

R&D in the European Community is extremely diversified. There are larger countries and smaller countries among the 12 member states of the Community, and there are highly developed and less developed countries and regions. The research structures within the member states reflect this diversity.

If we look at the universities first, some countries within the European Community exercise central control of the universities through a national ministry responsible for them; this is the case in France and Italy, for example. In other countries, however, universities are virtually independent or under the responsibility of local authorities, as in the United Kingdom or Germany.

Despite this diversity, trends sometimes are general, and many of these will be recognizable to a U.S. audience. A general trend since the Second World War is that the number of university students has greatly increased, but some subjects today are short of students; this is particularly the case for student enrollment in chemistry, engineering, computing, and some aspects of biology. This trend started around 15 years ago and is becoming more

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serious. It is exacerbated by demographic changes because of the falling birth rates in Europe.

We can expect some very marked shortages of skilled persons in a number of areas. Indeed, we now have the warring juxtaposition of significant unemployment rates coupled with high level demand. This shows that the skills of those in the labor market are becoming mismatched with the demands of employers.

One way out is through increased involvement of universities in the so-called Weiter Bildung—continuing or repeated training—a need the Germans were the first to address. Science and technology evolve so rapidly today that every 10 years scientists or technicians need retraining. Often, this must be interdisciplinary because the borders between traditional disciplines are shifting all the time. In some universities we can expect that the absolute fall in the number of young students who are 20 to 25 years old will be compensated for by growth in the number of older students training or retraining.

The different approaches that people with different national backgrounds bring to the world and to the European Community amount to a cultural asset, but this diversity of languages is an obstacle to rapid, effective, and thorough communication.

University research has become increasingly involved with the application of knowledge and its industrial exploitation. This is a positive move, if not carried too far, for it enables both teachers and students to grapple with real problems and it brings universities extra funding. But it can be dangerous for it can divert attention from teaching and from fundamental research into more short-term areas. It must be recognized that universities are based on the abundance of knowledge for its own sake. The EC Commission's Industrial Research and Development Advisory Committee (IRDA), which is a group of high-level industrialists appointed in a personal capacity, has issued a very strong warning against the trend of turning first-rate scientists into second-rate technologists.

The problems I have mentioned are not exclusive to Europe. The main issue that is specific to Europe is that of linguistic and cultural diversity. At the moment, the European Community operates in nine different languages. The different approaches that people with different national backgrounds bring to the world and to the European Community amount to a cultural asset, but this diversity of languages is an obstacle to rapid, effective, and thorough communication. The resultant fragmentation is probably more harmful today than it was in the past. After all, until a few hundred years ago, the university system operated in a single language: Latin.

Turning to public research institutes, we again find a very different situation in Europe. These institutes vary enormously in both size and effectiveness, with the best of them producing some of the best science to be found anywhere in the world. A special form of public research institution in the European Community is the Community's own Joint Research Center (JRC). This was set up to provide neutral advice on scientific issues, mostly related to nuclear safety. The JRC has not so far been allowed to be an outstanding success, mainly because the member states have been unwilling to relinquish national sovereignty in a number of areas. But it

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has been reorganized recently to make it more effective at the Community level and to develop a more commercial approach to its business.

On the purely industrial scene, Europe performs as well as any other country in the world in a number of areas, such as the pharmaceutical and food industries. In other areas, the small size of the individual member states has until now prevented the kind of investment levels that are seen in the United States or Japan.

> ***The European Community needs something exactly like the famous Tenth Amendment to the Constitution of the United States, which defines the line of demarcation between the competence of the federal government and the competence of the states. This principle in our system says that what is better done at the level of the member states belongs to the competence of the member states.***

The excellence of the European research system has enticed a very large number of multinationals to set up research laboratories in Europe, and this is a most important theme now in view of stronger cooperation on both sides of the Atlantic. Since these firms and their laboratories contribute to the European economy, we welcome their participation in Community research problems. This is one characteristic of our programs: they are open to European-based American companies and have had excellent experience in cooperating with them.

To sum up this look at the structure and trends in the research system in Europe, the key word is diversity: diversity in scope, structure, and mode of operation.

R&D Activity of the European Community

The basis of European Community activity in research and technological development is in its fundamental law. The European Community has no formal constitution; instead, it has a treaty, the Treaty of Rome, amended in 1987 by the Single European Act. This fundamental law establishes three principles for Community R&D activity. The first principle is competence in R&D activity. This was only formally recognized recently, in 1987, with the Single European Act. Now there is a title in the treaty, Title VI, that is the legal basis of our activity.

The second principle is "subsidiarity." What is this principle? There must be a line of demarcation between the activity in the R&D sector that belongs to the member states and the activities that it is possible to do at the Community level. The European Community needs something exactly like the famous Tenth Amendment to the Constitution of the United States, which defines the line of demarcation between the competence of the federal government and the competence of the states. This principle in our system says that what is better done at the level of the member states belongs to the competence of the member states. Conversely, what for reasons of strategic elements is better done at the Community level must be done at this level.

The subsidiarity principle defines some criteria that can justify EC Community R&D activities. First, there is the size of the effort required. Second, there is the nature of the problems being studied—for example, environmental problems, which are a typical case of an international R&D activity, or supernational R&D activity, as in the case of the European Community. Third, there is multidisciplinarity. Fourth, there is research

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to serve the Community's own policies. Now, for example, we have put some emphasis on so-called pre-normative research. In a large number of areas, the European Community sets regulations and directives that the member states have to comply with. These regulations must be based on the best science can offer.

Finally, the third principle of the Treaty of Rome is the scope of EC activity. The aim of EC R&D activity is laid down in the treaty in Article 130F. The objective of the Community is precisely to strengthen the scientific and technological basis of European industry and to encourage it to become more competitive at the international level. This formulation does provide support for basic research, but, nevertheless, it is difficult to justify support for curiosity-oriented or disinterested research.

The objective of the Community is precisely to strengthen the scientific and technological basis of European industry and to encourage it to become more competitive at the international level.

The annual expenditure of the Community for R&D activities is now nearly $2.8 billion. Only three years ago it was less than $2 billion. These figures may sound surprisingly small to an American audience. Actually, the Community's own R&D expenditure represents only 4 or 5 percent of the total public and private R&D spending. But I must emphasize the fact that it is the character of the Community's R&D activity to be a catalyst: to promote broader activity in the member states and to make them cooperate in common initiatives.

Challenges for the Future

I move from this discussion of the diversity among the individual member states of the Community and the specific responsibility and competence of the EC Commission, to now offer some thoughts on the future of EC activities.

First of all is the problem of increasing integration. We have the challenge now of how to build up a really integrated Community, for despite the solemn declaration of the Single European Act and despite the fact that we have built up the legal basis of the great Market, we need to build up the factual basis of our integration. In this first phase we have overcome the barriers of isolation, separation, and compartmentalization. But this is not enough. We need to promote really integrated activities at the level of the Community, and this is not an easy task.

For example, I have introduced in the third framework program for our activities in the R&D sector a very ambitious program to interconnect the information technology (IT) systems of the 12 member states. The aspiration of this program is something like the recent and ambitious program here in the United States for high-performance computing and communications. In the United States, fortunately, the unity of the nation exists, in spite of the various competencies of the states. On the contrary, in Europe the task is much more difficult because we have to build up the essential elementary infrastructures of the great European Market.

Second is the problem of human resources—another challenge for the European Community. I would like to underline that I have proposed a

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program on human capital mobility that will allow the mobility in three years of 5,000 post-doctoral fellows. Of course, the first task for the Community is to implement this mobility within the boundaries of the European Community.

This program and this process, however, are not closed to the rest of the world, which is very important to reaffirm here in the United States. We have to remain open to the extension of this program to other parts of the world. For example, we are negotiating with European Free Trade Association (EFTA) countries—Austria, Finland, Iceland, Norway, Sweden, and Switzerland—the extension of this program in order to have joint mobility of human resources at the very crucial postdoctoral level.

We are also interested in extending this EC program to the United States. During a successful first meeting of the joint consultative group between the U.S. administration and the European Community on February 25, 1991, co-chaired by Dr. Bromley and me, we discussed ways to ensure a two-way flow of human resources—are juvenation of a historical tendency. The United States has represented for Europe an essential and indispensable term of reference for decades. Now I think the time is ripe to consider together some program for human capital mobility, for human resources have become one of the crucial independent variables of our system of R&D.

The United States has represented for Europe an essential and indispensable term of reference for decades. Now I think the time is ripe to consider together some program for human capital mobility, for human resources have become one of the crucial independent variables of our system of R&D.

A year ago I presented here in the United States a proposal for new reinforcements between the United States and the European Community in the sector of research and technological development. I cited a famous speech by Secretary of State James Baker in Berlin on December 12, 1989, with his call for a trans-Atlantic community. One year later I am happy to see that this idea has borne fruit. The first meeting of the U.S.-EC Joint Consultative Group, and also this symposium today, I think, gives evidence of this fact. The agenda of the Joint Consultative Group is remarkably wide ranging, covering the role of science and technology in the European Community and the United States, energy and the environment, R&D in central and eastern Europe, basic science mega-projects, manpower and human resources, biotechnology, and information technology.

We have now planted the seed of cooperation between the European Community and the United States in science and technology and we have nursed the seed for a year. Over the coming years our challenge and our duty are to help it grow to a sturdy tree that can offer support and shelter to both our research communities.

PAOLO FASELLA

Director General of the Directorate for Research, Science, and Development and the Joint Research Center, The Commission of the European Communities

The European Community is composed of 12 peoples who have decided to work together more closely in various forms of collaboration. As new problems are created, the Community has to find new methods to solve

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them. I should like to illustrate some of the ways in and means by which some of the EC research programs have been put into action. I will select some specific cases, not necessarily the largest, that are, in my view, original. These forms of support were developed to cope with the new situation in Europe.

Human Capital

Living in the United States, you possibly do not appreciate the advantage of living in a very large country. This advantage is that almost all of the very broad spectrum of modern science and technology is covered, which means that when a young man or woman in the United States is interested in a certain scientific or technological career, it is quite normal that he or she may take a bachelor's at Harvard and then go on to Cal Tech or whatever. All of the resources of a large, highly scientific, industrialized nation are available, so he or she can pursue this career in science, working in a center of excellence.

In Europe there are, of course, many centers of excellence which are quite as good as any in America. But there is a tendency to fragmentation. Everybody speaks broken English, so language is perhaps not the problem, but there is a more subtle side to language, and sometimes we find in Brussels that the same word does not mean the same thing for people from 12 different countries. Thus, there is a problem of understanding. There is also a problem of structures, and there is the problem of different traditions.

One of the mechanisms we have developed is a program to facilitate interactions among multiple research programs in different member states.

On the other hand, there are many cases, started almost spontaneously, where it was the explicit wish of scientists and industrialists to work together in order to go beyond frontiers. What the EC Commission does is to make such work easier. Of course, there is a tendency to become bureaucratic. I do not think the EC Commission is any less open to such dangers than any other institution. But, being relatively young, the EC Commission has not had centuries or millennia available to develop a bureaucracy. We are under tight control by our member states and our parliament. We do make mistakes, but, generally, they are spotted rather quickly. There is a joke that is popular in Brussels, though maybe it sounds strange in Washington: EC Commission civil servants say that working for the Commission is like being a man who has no wife, yet has 12 mothers-in-law. We have to be very virtuous.

One of the mechanisms we have developed is a program to facilitate interactions among multiple research programs in different member states. This is really a combination of bottom-up and top-down. It represents a small fraction, less than 6 percent, of current resources, and it is not earmarked a priori for any specific scientific domain or technological goal. It is, instead, open to new ideas, and sometimes new ideas grow at the border, not only between disciplines, but also between countries.

Of course, we have had to put together a good system for selecting the proposals that come in. The principle of the system is quite simple. We

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have put together rather a good network of referees based on personal recommendations made by individuals and their home institutions. We select proposals on the basis of scientific merit as assessed by these referees. All proposals must be transnational. As a rule of thumb, and in the name of what we have come to call "practical subsidiarity," I would say that when collaboration involves two nations, then Europe's traditional and highly developed bilateral systems—the Royal Society, the Von Humboldt Stiftung, and so on—provide excellent methods.

The best way forward is not so much for different disciplines and industries to poach in each other's hunting grounds, but for Europe as whole to produce more postdoctoral researchers. And we are proposing a system designed to do exactly that, which will perhaps be extended beyond the borders of Europe.

But when we have three or more bodies, interactions are difficult, even in chemistry. So we in the Community provide a system—I would not want to use the word "catalyst" improperly—to bring people together. Indeed, over the years there have a number of very interesting projects that were proposed by the scientists themselves. They developed fruitfully at a European level because the necessary expertise at the required level of excellence could not be found in any one single place. We have had collaboration between people from the Max Planck with people from Cambridge or Oxford or Bonn or Pisa. This has developed into a very useful and popular system, and I think we owe its success to the fact that quite a few highly placed and responsible scientists from all over Europe thought it was altogether worthwhile to invest some of their time and energy in helping the Commission to organize it.

This program was a typical European solution to a European problem. We now wish to extend it further, but with greater emphasis on training for research by doing research at the postdoctoral level. The motive for this is a considerable shortage of skilled people in Europe. The best way forward is not so much for different disciplines and industries to poach in each other's hunting grounds, but for Europe as whole to produce more postdoctoral researchers. And we are proposing a system designed to do exactly that, which will perhaps be extended beyond the borders of Europe.

Small Firms

The second form of action, which I mention because we found it interesting, has to do with the many small and medium enterprises that we have in Europe. These small firms need a Common Market sometimes even more than large firms do, for large firms generally know how to find their way around continents. Sometimes a small company in an advanced area has a greater need for access to a large market because it must amortize the investments it makes in research right away. If it is specializing in a field, it must be able to sell in its own field to a wide market.

Research can prepare for that in terms of new knowledge and so on. Following up on a suggestion from German industrialists, we established that there were many small firms that do not have the capacity or the wish to set up their own research laboratories, but that have common problems in the so-called generic technologies. They may be interested in some aspects of materials science, in corrosion, and so on. Our role perhaps is to

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act as sponsors: sometimes we provide a secretariat; sometimes we provide suggestions. The networks then form networks. In Europe now there is even an institution with a legal status, recognized in all countries. Together, the companies propose a research plan that is then carded out by research institutes or by universities, wherever the best skills are to be found throughout the Community. This proved an interesting scheme. We call it cooperative research. It is very flexible, and the results are quite encouraging.

Large Research Projects

There is also the problem of large installations in Europe. There are several that are owned entirely by one country and some that are shared by two, three, four, or five; we have all possible combinations. Sometimes there are excellent scientists or engineers from a smaller country who are interested in having access to those large installations. In general, there is good will, and the managers of installations are happy to receive good scientists from other countries. But sometimes there are technical limitations to this.

We have a program called Access to Large Installations, which has recently completed a three-year testing phase. In this program joint proposals come from the managers of large installations and potential users. For instance someone from Spain or Italy may wish to go and work in a large facility in another country. Several such requests are put together, and a common proposal is made by the administration of the facility and the potential users. After selection by peer review in competition with other proposals, a multiyear contract is signed, and the large installation managers then know they can count on a certain amount of support for a certain number of years in return. Thus, persons who normally would not have access to the installations now do.

This program has been set up in a very flexible way, without the creation of any new structures, and it seems to be working fine. The problem is that the demand is very great, especially from young people at the postdoctoral level, who have studied what can be done with these advanced technologies or tools for research, but who do not have them in their own countries. In the past these people could have encountered more difficulties in obtaining access to such facilities in other countries.

Another point again concerns large projects. The Community is actually running one such project on magnetically confined thermonuclear fusion. All efforts in this field in Europe are combined. We designed, built, and now operate the largest existing machine in the field. The machine is in Britain, but its first director was German and the current director is French, so it is very international.

I mention this because the EC fusion program is an interesting example in terms of science management. We all know that there are excellent instances of successful management of large projects that, especially when they are energy intensive, have to be located in one place; the European Laboratory for Particle Physics (CERN) probably is one of the best exam

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pies. So when I praise another model, I do not mean to say that the model at CERN was wrong. Indeed, it has been excellent, and it was probably the best for that type of approach. But, for fusion, we developed another model that I call the "planetary system." About half of the resources are centered in the large common machine, which is the Joint European Torus (JET). But there are three or four very important machines at different locations that are part of the program, and staff from all of the member states move freely from one center to another. All contribute very tangibly to the success of the central machine.

This system has proved very useful, for, especially in a project like fusion, which lasts for generations of scientists, it is very important that we keep in the various participating countries a nucleus large enough to attract good people. We have to see this in a dynamic way, and we must ensure that we do not cut our connections with the roots, which are the bright young people that may come into it.

This is a model that was successful in Europe and that perhaps could be used in some cases for larger multinational projects. It is also an excellent example of applied subsidiarity.

DISCUSSION

***Question*:** Obviously, one of the underlying driving motivations behind the programs in the European Community, as well as in the individual countries in Europe, is economic growth and competitiveness of your industry. Am I correct that that is the major thrust of the R&D program of the European Community?

> ***We are wedded to the transnationality of our program, which makes it impossible for us to support directly an individual industry because we need a combination of the various subjects.***

***Vice-President Pandolfi*:** Yes. The language of the treaty, which is our parliamentary law, is extremely clear. In Article 130F the European Community has the objective of strengthening the scientific and technological basis of European industry and encouraging it to become more competitive at international levels.

There are two ways to support European industry or, generally speaking, to support industry everywhere in the world. The first way is to support directly the activities of the industry in order to develop new products in a way directly linked to the needs of the industry vis-a-vis the market. Our interpretation of the treaty is that it excludes this kind of direct support.

There is a second way to support industry, and this way has three elements. The first element is a limitation of precompetitive R&D activities, determined by the international common opinion of what is precompetitive. This is a strict limitation. Member states are not willing to give the Commission the authority to cross this line of demarcation. The second element is that we are wedded to the transnationality of our program, which makes it impossible for us to support directly an individual industry because

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we need a combination of the various subjects. The third element of our interpretation is based on what the treaty says about the scientific and technological basis of European industry. It is essential for us to maintain the presence of the Community in basic research. When some project is submitted to us, we make sure that a certain fraction of basic research exists in our initiative.

The combination of these three elements allows us to maintain an appropriately scientific character in our research activity. Even though we are a Common Market, with an economic origin, we support a good background for our industry instead of supporting specific objectives.

Question: Dr. Fasella, is the planetary model that you talked about spontaneous or planned?

Professor Fasella: It was developed by the persons who actually did it. All persons involved in magnetically controlled nuclear fusion had first formed a club; then the club became one of the committees. When the program was launched, those persons in the club were appointed by the member states as their representatives. Working together, they found this was the best solution.

It is essential for us to maintain the presence of the Community in basic research. When some project is submitted to us, we make sure that a certain fraction of basic research exists in our initiative.

We received a very interesting proposal in a quite different field and on a smaller scale from a group of researchers around the Max Planck Institute of Plant Development in Cologne. They had already participated in our biotechnology program. Then, when we started again some seven or eight years ago, at first we could not find a molecular biology plant, for that was a relatively weak field in Europe. Many of the research groups became involved with the institute in Cologne, which is, I think, the largest in Europe of its kind. It therefore seemed reasonable that rather than having a number of small bilateral contracts, these groups could form a sort of rota program. They came to Mr. Pandolfi to see if he thought it was politically acceptable, and they have now proposed a plan that combines six laboratories, which are rather tightly connected or which are more loosely connected. Probably, the management would be done in Cologne. This of course is on a much smaller scale, at least for the time being, than the other one. But it is also what you would call a planetary program.

***Question*:** How are the events in eastern Europe of the last couple of years entering into thinking about policy on science and technology within the European Community?

Vice-President Pandolfi: First of all, there is no doubt about the key role of science and technology in building a new architecture in central and eastern Europe. Science and technology, for example, are key elements in easing the transition to a market economy. Science and technology also are essential in building up an integrated continental scientific community in Europe.

But, at present, we have a great number of difficulties in rapidly establishing a network of contacts and initiatives between the European Community and central and eastern European countries. A typical problem is the difficulty of finding the right term of reference, because there are continuous changes in public powers there.

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We have identified two main ways to implement cooperation in science and technology despite the difficulties. One is to use some part of the resources of the outreach program already in place with Poland and Hungary. So far, a small part of this $1.2 billion program is dedicated to establishing the basis for cooperation in science and technology.

Second, the Europe parliament has introduced a new budget appropriation for a small program called "Let's Go East." We are trying to put it into operation immediately, starting with some very pragmatic initiatives. Beginning next year, 1992, and in the subsequent year, this small first program is dedicated to collaboration in science and technology.

One of our main objectives for this year is to define the right initiatives. For example, we have promoted better cooperation between these countries so that together they can cooperate with the European Community. Our commitment to this program is very strong.

Question: Mr. Pandolfi, you focused on scarcity of human resources and identified the falling birth rate as the main cause. I wonder if that is the only cause. Also, the United States has depended very heavily on immigration of people from Europe and Asia to expand its resources in science and engineering. Are we competing for the same resources in the long haul?

Vice-President Pandolfi: No doubt this is one of the crucial points for the future of our scientific community. There is a certain difference between the problem in the United States and the problems in Europe. I have seen that here you are focusing on precollege education to improve the effectiveness of the educational system. In comparison, the situation in Europe is not so bad at this level; our difficulty is at the college level.

Professor Fasella: The expected decline of the work force from 1985 to 2025 is part of a study done by the industrial research committee that advises the EC Commission. The number of students rose for a certain period after the Second World War because the fraction of the population that went through a higher education increased. Now that has leveled off. Moreover, there is a certain trend away from the hard sciences toward perhaps softer ones or more attractive ones.

Vice-President Pandolfi: Another point is the problem of movement from one area to the other. This is one of the main problems for Europe. It is expected that there will be a certain tendency of scientists or young researchers in central and eastern European countries to move toward western Europe or to the United States. This is the historical trend.

Our view of that is that we must have a concerted action to develop a common approach to the problem. For example, in some of the member states of Europe, there is a certain reluctance to support our program for human capital mobility because of the phenomenon of the brain drain. It is a typical attitude in Ireland; they are afraid that this program would produce not an improvement in their scientific community but, on the contrary, some additional difficulty.

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I think the time is right to find an appropriate international forum to discuss how to avoid the negative consequences of this mobility and how to combine our efforts as far as the European Community is concerned. We are ready to put on the table our problem with human capital mobility and to discuss how to work together with you.

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GERMANY

HUBERT S. MARKL

President, Deutsche Forschungsgemeinschaft (DFG)

I have been asked to address questions regarding the future of the German research enterprise. Let me start with two disclaimers. First, I do not believe that our future is at all foreseeable, and I believe that the future of the research enterprise is even less foreseeable than our overall future and that the future of German research affairs presently is again even less foreseeable than those in other parts of the world. I believe that we cannot foresee but have to invent and build our way into the future.

> ***I believe strongly that we will only be able to cope with future challenges if we do not just assiduously follow preconceived trends and plans but are always open to surprises and unexpected opportunities***

What may sound in the following like the prediction of trends or challenges should be regarded as the present state of my perception of what might be sensible next steps in our task to build our common future together with our friends and competitors around the world. I believe strongly that we will only be able to cope with future challenges if we do not just assiduously follow preconceived trends and plans but are always open to surprises and unexpected opportunities.

Second, please note that I do not represent the government of the Federal Republic of Germany (FRG). As the President of the DFG, which is not a governmental agency but an autonomous scientific body set up as a society under private law, I can only speak for the scientists of my country.

R&D Organization in the Federal Republic of Germany

Let me first give you a quick thumbnail sketch of the state of R&D organization in the FRG, at least as it presented itself up to October 3, 1990, the date of unification. Of German R&D expenditures—in 1990 roughly 70 billion DM or around 2.8 percent of our GNP—about two-thirds derive from private industry and somewhat more than this (70 percent) are also expended there. The publicly funded R&D effort of about 25 billion DM divides into about 60 percent coming from the federal government, and 40 percent coming from the states (Länder), which are, for constitutional reasons, predominantly in charge of funding research in our 50 major and 200 minor universities. Altogether, R&D in universities is financed with approximately 10 billion DM; about 25 percent of this money comes from external grant sources, of which, again, 25 percent is from private sources. The federal government funds—mostly through the Ministry of Research and Technology but also through other Ministries—mainly the 13 large National Research Centers (Grossforschungseinrichtungen), other national laboratories, and the better part of the Max Planck Society, the

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DFG, and the Fraunhofer Gesellschaft, which all get also, in varying shares, funds from state governments.

Through the DFG, which mainly funds fundamental research of all disciplines in universities, and through the targeted mission- or application-oriented programs of the Ministry of Research and Technology, the federal government is also strongly involved in competitive grant funding of research in universities. It bears as well the major responsibility for funding German participation in international research projects, programs, or institutes of all kinds.

The flow of financial resources through the many different channels of the German federal political organization and through the many subsidiary autonomous bodies in charge of funding and/or performing research makes the German R&D system exceedingly pluralistic, frustratingly complicated, and fortunately resilient against one-sided influence from pressure groups of whatever kind. At times, however, the system also is dangerously uncoordinated, conservative, and slow moving. It is certainly difficult to push it around, but it is sometimes just as certainly difficult to push it to go in any direction at all. The system is very decentralized and reacts not lightly to central political directives or to the call of public bandwagon trumpets. It offers publicly funded individual researchers wherever they work plenty of independence in the pursuit of their research interests and a multiplicity of funding sources where they can apply for support.

The flow of financial resources through the many different channels of the German federal political organization and through the many subsidiary autonomous bodies in charge of funding and/or performing research makes the German R&D system exceedingly pluralistic, frustratingly complicated, and fortunately resilient against one-sided influence from pressure groups of whatever kind.

Working conditions generally are not bad, except for in the new eastern part of the country, but the outcome of research efforts, whether in private industry or public institutions, is more often than not impressive because of thoroughness, solidity, and breadth and depth of pursuit rather than because of avant garde imagination and inventiveness.

The human resources distribution—in full-time researcher equivalents (scientists and engineers taken together)—gives a good general overview of actual distribution of R&D performance: roughly 100,000 researchers work in private industry; 30,000 work in our universities of all kinds; and 20,000 work in all other public research institutions taken together. To these one should add altogether 120,000 technicians and approximately the same number of supporting staff, which totals about 400,000 persons involved in R&D for the old FRG (add approximately 20 to 25 percent of each category for the new unified Germany).

Although, evidently, most applied R&D in Germany is pursued in private industry, a sizable and economically highly important part of applied and application-oriented research goes on in the laboratories of our major technical universities (as in Aachen, München, Stuttgart, Hannover, etc.) and in the Institutes for Applied Research of the Fraunhofer Gesellschaft. For small- and medium-size enterprises, such as our machine-building industry, research performed in our technical universities is a life line of innovation. It deserves mention that, as a rule, you cannot become full professor in any department of engineering in Germany unless one first has

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worked successfully in the R&D sector of private industry for a couple of years. This assures lifelong links between these departments and industry, both for two-way communication and for funding, and it ensures as well that students in technological fields are taught by professors who know what they talk about from personal firsthand experience. Fundamental research, on the other hand, has its strongholds in universities, in the institutes of the Max Planck Society, and in most of the National Research Centers, which also are strongly involved in strategic and mission-oriented, often internationally coordinated and integrated research.

There is general political and scientific agreement that universities should remain strong in fundamental research and that the system of large National Research Centers should not expand very much beyond the present state.

Trends in Size, Mission, and Character of R&D

I believe, in probably typical old-fashioned German fashion, that the size relationships among the different financing and performing sectors as just described will not change dramatically in the next decade. There is, for instance, general political and scientific agreement that universities should remain strong in fundamental research and that the system of large National Research Centers should not expand very much beyond the present state.

Nevertheless, I foresee that the most influential trend for R&D in Germany will be rising interdisciplinary and intersectorial coordination, cooperation, and integration on a national, European, "Western" (or OECD), and, finally, global scale. Industrial R&D investment is already today in most major industrial branches planned and executed on a European scale, creating rapidly international and inter-enterprise links of variable geometry. It will become more so with every year, and it will become even more global with every year. Part of the reason for that may be perfectionist German environmental and other legal overregulation—as, for instance, in the areas of biotechnology or nuclear energy. But the major reasons are those of the needs of international market demand pulls and innovative pushes from active competitors.

On the national home scene it is also evident that cooperative links between different disciplines in fundamental research—for example, between mathematics and engineering, neurobiology and psychology, linguistics and computer science—will dominate and rapidly change the most active research fronts. Closer and closer cooperation, with flexible exchange of R&D personnel, common use of research facilities, and joint funding schemes also will characterize the relationship between industrial research and research in universities and public research institutes.

With every year it will be more natural to host and exchange researchers throughout Europe and beyond, especially with the Anglo-Saxon industrial nations. It is also to be hoped that our future common Europe of research and science will be a larger and more comprehensive Europe than the present 12-nation European Community (EC), including, quite naturally, all European Free Trade Association (EFTA) countries but also our Eastern neighbors, which until very recently we called "socialist bloc countries"; maybe we can soon dub them "postsocialist nations."

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What other trends can be traced?

- Evidently, and not very surprisingly, we expect major innovative impulses from advances in information technology, new materials technology, polymer chemistry, and molecular] biotechnology—just as everyone else does. We try to face these challenges—by investing heavily in all these areas both in fundamental and in applied research, in public institutions and in industry, and also in joint research centers—with varying success but with unvarying hopes for better and more of it in the future.
- Ecological constraints, coming, as elsewhere, often more from the psychological problems of the people (as fostered through a multimedia industry in this field) than from actual physical conditions, will relentlessly drive innovative technologies in resource exploitation, energy use, manufacturing processes up to the final stages of waste-use technology, and recycling in almost every industrial sector.
- The demography of a rapidly aging and (without immigration) dwindling population, in addition to labor union pressures for still shorter working weeks and ever-higher wages, will provide continuous pushing power for further rationalization and automatization of production processes, calling for continuous R&D efforts to provide the grist for this mill of industrial progress.
- Global ecological and demographic problems of different kinds certainly will be major driving forces for internationally coordinated R&D efforts to overcome at least the worst problems arising from a multi-giga-mankind with multi-tera-impact on the global biosphere. German scientists generally feel that we have to contribute more actively to joint international research efforts on global environmental, demographic, and economic problems of mankind. We will have to change our teaching institutions and their curricula in an appropriate fashion to make Germans better prepared for a common Europe, but also to better fulfill their responsibilities in a global world community.

Future R&D Roles and Responsibilities

My views on the question of optimal division of roles and responsibilities in R&D among universities, government institutes, and industrial and independent laboratories can be put rather succinctly: I do not believe that an optimum can be defined; therefore, we will never know how to reach it. We should try hard instead at least to "satisfize" rather than to optimize.

We will have to change our teaching institutions and their curricula in an appropriate fashion to make Germans better prepared for a common Europe, but also to better fulfill their responsibilities in a global world community.

It seems that acceptable and competitively fairly successful relationships can be attained in different countries using rather different mixes of the four components listed (cf., e.g., France, Italy, Germany and Japan). Therefore, it may be more important to keep a particular historically grown configuration lively and going in which the players are accustomed to operating effectively, than to dream about optimal conditions and about changing everything only to gain nothing. From this you may take it that I regard the

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distribution of roles among the four sectors as presently evolved in my country to be a rather satisfactory arrangement.

I would tend to advise putting much more effort into making the different R&D performers perform more effectively in their turf, within their respective terms of reference and constraints, rather than drawing up new blueprints or flowcharts for distribution of tasks and responsibilities. I would also, as already mentioned, tend to put more effort into bringing about more effective intersectorial, temporary, task-defined cooperation than to redistribute obligations according to a clever new optimal plan. In other words, I would rather rely on promoting more effective self-organization of R&D through those researchers who actually perform it than on more planning in the quest for a more perfectly organized total R&D system.

I would rather rely on promoting more effective self-organization of R&D through those researchers who actually perform it than on more planning in the quest for a more perfectly organized total R&D system.

I confess, however, that even after five years as president of the DFG, I have remained enough of a university professor to believe firmly in the importance of training students in universities that are actively contributing at the cutting edge of research in their different disciplines. A strong base in lively fundamental research in all branches of scholarship, driven by the inventiveness and imagination of individual researchers or groups of them together with their students in universities, seems to me the fountainhead of a humane and competitive industrial civilization. But, of course, this may be the "deformation professionelle" of a German university professor about to head back for his alma mater.

I hasten to add, however, that I am just as convinced that even the best R&D system in universities and in independent or public institutes will stagnate and become even immobile and sterile if these sectors cannot continuously link up, by transfer of researchers to and fro, with a healthy and thriving private industrial research base—as we have in Germany in many of our major industrial enterprises, I am certainly glad to say.

German Unification

What will be the consequences of German unification? As you probably know, the GDR had an active R&D system of the typical East-bloc type, with most of the research concentrated in central academy institutes rather isolated from the advanced educational system of the universities and with much of the development performed in university laboratories in the service of industrial combines, making university research institutes in many cases into little more than prolonged scientific work benches of these combines. In preparing the unification treaty, both German governments agreed to change this Soviet-type R&D system back to the western German type of organization, a process that has just begun and that may take the better part of the next decade to complete. Thus, many academy institutes will be dismantled, and many of their groups of researchers will move over or back into the universities; some will end up in new Max Planck or Fraunhofer institutes or in new national laboratories.

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The major problem with all of this—as with the whole unification process—is that enormous amounts of capital are needed to build up both the economic and the scientific base of the old East Germany to a level of productiveness and competitiveness on a par with the old West Germany. I am pretty well convinced that these demands, together with the resources needed for a comparable build-up phase for the scientific/economic systems of our eastern neighbor countries, will mean that for the next decade West Germans will have to learn to tighten their belts somewhat. I am also convinced that it will be not only necessary but very worthwhile to do so; after all, we can gain from some slimming of our waistlines.

However, one problem with all of this will be that with the right to move freely, finally, within Germany and further on, many East Germans—both researchers and other skilled personnel—will most probably move in large numbers, either temporarily or even permanently, west. This type of migration has already set in. This is probably inevitable and perhaps even advantageous, at least if we can convince them or others to move back east now and later on in order to help build up eastern Germany's productive base. I would certainly hope that many of my eastern German compatriots from the scientific R&D field would be welcome to work for a couple of years not only in western Germany but also in other Western countries, especially within Europe but also in the United States, in order to become more fully adapted to and more quickly integrated into the political and economic community of which we West Germans have since long ago become an inseparable part.

HEINZ RIESENHUBER[1]

Minister for Research and Technology, Federal Republic of Germany

The constitution of the FRG stipulates the freedom of science and research as an inalienable human right and thus as a basic element of the human community. This necessarily means that the government considers it a major task to guarantee adequate working conditions as a prerequisite for scientific research. In Germany this task is shared by the federal government and the 16 governments of the constituent states, or Länder.

During the 42 years since the foundation of the FRG a diverse research structure has evolved that, on the whole, is considered an optimum research environment and a basis for successful future-oriented science policy in Germany, even after its unification on October 3, 1990.

The German research environment includes the differentiated higher education system with its traditional research-based universities, the proven technical universities, and the practice-oriented Fachhochschulen; it includes DFG (Deutsche Forschungsgemeinschaft/German Research As

[1] Minister Rtesenhuber was unable to attend the symposium, but provided his prepared remarks for inclusion m this proceedings report.

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sociation) and MPG (Max-Planck-Gesellschaft/Max Planck Society), both of which focus on basic research, the National Research Centers with their particular research assignments, and the Fraunhofer Society, which focuses on the application of research results in industry. These institutions cover the entire research process, from the establishment of a knowledge base up to application via committed institutions. In this way the government also ensures a high level of training of R&D staff, including laboratory workers and technicians as well as basic researchers.

The strong commitment to scientific research today arises mainly from political goals: the responsibility for humans and for the ecological system in which they live and with which they increasingly interfere prompts us to strengthen the rationale of our action.

The government's commitment to scientific research is reflected by relevant figures. Regarding government funding, the FRG spends a greater share of its gross domestic product (GDP) on civilian research than does any other major industrialized nation (0.92 percent as compared with 0.42 percent in the United States, 0.44 percent in Japan, 0.86 percent in France, and 0.51 percent in the United Kingdom). The better part of these funds goes to basic research, which accounts for a substantially higher share in total research funding in Germany (19 percent) than, for example, in the United States (12 percent) or in Japan (13 percent).

German industry also has fully recognized the growing importance of research and has for many years been increasing its expenditure. Industry's share in the German R&D budget was 65 percent in 1989, compared with 56 percent 10 years earlier; only in Japan is this share higher, where industry made similar efforts in the past decade (59 percent in 1979 and 72 percent in 1989).

Regarding national R&D funding, the FRG is among the leading industrialized nations, together with Japan and the United States (2.8 to 3.0 percent of the GDP).

Research Policy Goals

The strong commitment to scientific research today arises mainly from political goals: the responsibility for humans and for the ecological system in which they live and with which they increasingly interfere prompts us to strengthen the rationale of our action.

In order to tackle these mostly global tasks, we must commit ourselves to speeding up the international coordination of research strategies.

- On the one hand, we have to secure the basic necessities of life for a permanently growing world population, reduce the exploitation of natural resources, and provide the people of the Third World, if at all possible, with an increasing share of public wealth.
- On the other hand, bearing in mind our responsibility for future generations, we must counter the overexploitation of the Earth's ecosystem and stop the destruction of the genetic heritage.

In order to tackle these mostly global tasks, we must commit ourselves to speeding up the international coordination of research strategies.

The success of research and technology policy depends on broad-based and efficient basic research, which, on the one hand, widens the knowledge base for the development of new technologies and, on the other hand, trains

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young scientists for research work at universities and in industry by familiarizing them, with topical issues and modern methods of research. It can be noted today that on the forward edge of research, the complexity of problems and the degree of specialization are increasing steadily so that often a global pooling of intellectual capacities is needed for tackling relevant topics. Furthermore, despite increasing specialization within disciplines, a high degree of interdisciplinary work is needed if we wish to arrive at long-term reliable solutions. An excellent case in point is research on global change, where virtually all disciplines must cooperate, including atmospheric chemistry and marine research, fluid physics, and research into the biological processes in major ecosystems, such as the sea or the rainforest.

Another crucial task for international research policy, in my view, is to agree on appropriate structures that are conducive to the coordination of national planning efforts in big science with a view to avoiding unnecessary duplication of investment and excessive competition.

Thus, it is a major task for research policy to strengthen the motivation of researchers as well as their creative thinking and their mobility. An important aspect is the promotion of international cooperation, which provides an optimum environment for researchers to exchange resources, views, and results. This applies also, and particularly, to the highly motivated research communities of smaller countries with fewer financial resources that wish to contribute to important research issues, including researchers in eastern Europe who are now free to exchange scientific concepts and ideas.

Another crucial task for international research policy, in my view, is to agree on appropriate structures that are conducive to the coordination of national planning efforts in big science with a view to avoiding unnecessary duplication of investment and excessive competition. This applies, above all, to the large-scale experimental facilities in astronomy and physics. In addition, it is a particular challenge for research policy to bring about international coordination between research strategies in areas that were, until recently, considered to be "little science." The urgent problems—such as the securing of the basic necessities of life for a growing world population; the organization and the handling of the ethical consequences, of such megaprojects as human genome mapping and human brain research; and the attempts to arrive at an understanding not only of the evolution of the cosmos after the big bang but also of the evolution of life, which is still going on on this Earth—call for a new readiness to engage in international cooperation, for which new global instruments have to be developed.

In contrast to the situation in big science, no inherent structure has as yet evolved in "little science" so that a new task has evolved for international science policy, which has to be developed and optimized. Initial experience has been gathered through such projects as HFSP and HUGO.

The frequently voiced fear of a brain drain (i.e., the draining off of knowledge produced with considerable national effort and resources, without an adequate quid pro quo being provided) should be countered with the elaboration of suitable mechanisms to be agreed on by the countries concerned.

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Technological Strategies

The development of new close to the market technologies must be demand oriented early on, taking into account the possibilities for implementation. The major financial burden must be shouldered by the enterprises of the respective sector. One focus of governmental action is the design of a suitable framework for R&D that ranges from the protection of intellectual property to the promotion of adequate training opportunities; to the funding of excellent basic research; and to reliable local conditions, including environmental, safety, and labor protection requirements that are the same for all countries involved and therefore do not affect competition. International harmonization is of major importance in this sector, so major collaborative efforts must be made to bring about such harmonization. This paradigm of German research policy, which is based on the principle of subsidiarity, is reflected by the decrease in government project funds for technology development and innovation in trade and industry.

Furthermore, global subjects have to be identified for the targeted and speedy development of new technologies according to goals set by society. A case in point is the sector of the resource-saving technologies. On closer inspection, virtually all resources turn out to be depletable, particularly if we consider the Earth's natural environment a resource for life. The development of new technological solutions that enable a still growing humankind to live in dignity and prosperity is a task for the community of nations, with the large industrialized nations bearing a special responsibility.

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Energy supply is one area where specific action is needed. The strategy to be pursued by the international community must first and foremost focus on the reduction of emissions that damage the environment and interfere with the global climate. Renewable sources of energy and the utilization of solar energy play an increasingly important role; assuming their responsibility for the overall system, the industrialized nations must aim to achieve rapid progress while attaching major importance as well to increasing the efficiency of energy-consuming machines and to conserving energy. The FRG has been actively involved in this sector for years; an international comparison shows that it is Germany, of all countries, that spends the largest share of its GDP on renewable energy R&D.

Another vitally important field is transport. The increases in the international commodity flow and in passenger transport, with their related risks for man and the environment (tanker accidents are a case in point), but also the undeniably favorable future prospects of a considerable efficiency increase, require major technological efforts and should be considered an international task.

Numerous countries have realized that the development of technologies for exploiting the international knowledge potential, for overcoming language barriers, and for processing information is a major task for technology policy. Great efforts are made and considerable funds provided for tackling relevant issues; cooperative activities have assumed hitherto un

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known global dimensions. The end of this development is not yet in sight; new information and communication technologies will continue to permeate all spheres of society. Solutions to specific problems will become increasingly important—a process that can be perceived as evolutionary differentiation. It is crucial that the compatibility of systems and components be guaranteed early on by the conclusion of appropriate standardization agreements. This seems to be the only way to avoid monopolization trends, which are undesirable in terms of both foreign trade policy and industrial policy.

Provision for the Future of Mankind

German science policy for years has supported preventive and anticipatory research with annually increasing funds, thus making provision also for future generations. Relevant research includes not only the above-mentioned field of environmental and climatic research but also the investigation of the basis for healthy living, of the causes of disease, and of the opportunities for curing or alleviating them. Most of these research activities are not limited to local issues and should therefore involve international cooperation and division of effort.

It is crucial that the compatibility of systems and components be guaranteed early on by the conclusion of appropriate standardization agreements. This seems to be the only way to avoid monopolization trends, which are undesirable in terms of both foreign trade policy and industrial policy.

New findings of genetic engineering—in particular, knowledge about the human genome and the potential of genetic engineering to modify genetic material—have given rise to new ethical issues that have to be discussed and settled with a great responsibility. Responsibility for the natural environment particularly for human life must not stop at national frontiers. The FRG therefore continues to tackle these issues with great interest and commitment. Joint efforts must be made to identify the potential benefits and risks of technologies even earlier and to agree on joint action.

Thus, finding a comprehensive and sustainable solution for the final disposal of radioactive wastes and other substances that are hazardous to the Earth's biosphere is an immediate goal to be pursued by all industrialized nations, fully aware of their responsibility for future generations.

Research in Unified Germany

Owing to the reunification on October 3, 1990, the territory of the FRG has become larger, and the number of people who can now live, learn, work, and do research in the free democratic German system has increased by about 25 percent as compared with the situation before unification took place. The German research environment has thus not only become larger but more diverse. In the sector of government-funded institutes (excluding academic institutions) alone more than 6,000 qualified researchers will be working in the new German Länder, and from 1992, following a phase of reorientation and reshaping, optimum working conditions will be speedily established that will soon strengthen the entire German R&D capacity.

Nevertheless, the federal government's research budget for 1992 is a solidarity budget requiring creativity and clear priorities as well as the ex

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ploitation of any synergy and saving opportunities. In view of the tremendous increase in tasks, the growth rates are rather modest.

The institutes of the former GDR's Academy of Sciences were examined and evaluated by independent experts on the Science Council who concluded that 40 of the former academy's institutes will be able to continue their work. From the academy's 19,000 staff members reported for the beginning of this year, 11,000 will remain in employment.

The long-term development of new, meaningful structures and/or the adaptation of existing ones must be the primary goal in the new German Länder. Supporting measures are as follows:

- the establishment of new research institutions
- scientific research in higher education and
- the promotion of research in enterprises and institutes.

The research environment of the FRG in its boundaries before October 3, 1990, will serve as a model. Through action in the new German Länder and beyond, the FRG hopes to continue to be a reliable partner for the international research community.

DISCUSSION

***Question*:** Professor Markl, you mentioned that 60 percent of your budget comes from the federal government and 40 percent from the Länder. That means that politicians in a sense give you your resources. Most politicians view R&D as the engine for economic development. To what extent can you allocate your funds on the basis of excellence of a proposal, and to what extent are you under political pressure to distribute the funds into local districts by politicians?

The long-term development of new, meaningful structures and/or the adaptation of existing ones must be the primary goal in the new German Länder.

Professor Markl: At the DFG we are very fortunate that we feel very little political pressure. Mind you, we spend about 2 percent of the total R&D of the country and 5 percent of the public money through the channels of the DFG, which is a small amount of the total R&D money available. But still, it is a respectable amount, so you would expect many politicians to think that they could apply pressure and drive funds in this or that direction.

I believe that one of the reasons we feel less pressure is that since the Länder and the federal government always comprises different political parties, if one group tries to push in a certain direction, we very easily find allies who say, leave the DFG alone, we will not allow your party to tell the DFG what to do. Whether this is true or whether there is just a sensible consensus among politicians that there must be a sector of the R&D funding that should be managed mainly by scientists themselves, I do not know. But up until now, at least, we have still kept the confidence of the politi

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cians in the type of work we are doing, and they have not posed more awkward questions.

Question: The German universities in the first part of this century were famous for their connection with industry, especially the chemical industry. In the United States there was no relationship between universities and industry. In the second half of the century, that relationship has been building. How would you characterize the relationship today between the research universities and German industry? Is it as strong as it was before, or even better?

Professor Markl: I think the university-industry relationship goes on quite unchanged and is even expanding. Again, after a short period in the 1960s, when some professors were accused of being the slaves of industrial research because they received too much money from the chemical industry, there has been, in the universities, agreement that receiving funds is perfectly all right if the strings attached are not too tight. This means if the work done can be published, and if the researchers are free to decide whether they want to do the work or not, they can as easily as ever receive funds from industry for projects.

This is especially true in our chemical and pharmaceutical industries, and perhaps even more so in the engineering sector. In engineering, if you go to some of the important institutes in production technology or general mechanics, you will find that 70 to 80 percent of the money is actually coming from industry contracts.

I think this will continue and will be developed even further. We have an organization for computer linguistics in Stuttgart that we founded about three years ago. This organization involves universities, Max Planck institutes, people from national laboratories, and IBM. IBM does not fund the project; instead, it adds expertise, people, new knowledge, and access to machines that otherwise might not be available. So we do not discuss so much whether the money comes from this place or that, but whether the contributions really will produce a stronger program. As far as we see it, this is a very productive involvement.

Question: To what extent do you face politics within the scientific community, big science versus little science, junior investigators versus senior investigators, some areas of research versus others? Or is the German scientific community strictly objective?

Professor Markl: It is interest driven, like every scientific community. We have these discussions continuously. For instance, there is at present a big debate on whether we will be able, with all the other exigencies we see now in the national and international scene, to fund manned space research as previously planned and agreed. The German Society of Physicists has brought out a very strong statement against German involvement, or expanded involvement, in manned space research. There is general agreement that space research is very important but that it should be unmanned. So here you have big versus little.

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In the DFG we try to keep about 50 percent of the budget for single investigators who can approach us at any time with any subject. The other 50 percent we divide among collaborative schemes, where people from all over the country agree to work together on a specific subject. Whenever one part tries to expand at the cost of the other, there is an agreement in the community to stop it, because the single investigator projects should get about 50 percent of the cake. This agreement is there.

As for big politics, how much money actually goes into increases for Max Planck or DFG as compared to increases in more industry-related research through our Ministry of Research and Technology or big programs in the national laboratories? This is very contentious, and the influence of scientists is not felt very strongly. I think this is mainly back-room power politics, where the big contenders try to push what they can.

But we haven't done too badly. We have an agreement to have a fixed 5 percent increase for six years. The government has decided that for the next four years we will assure 5 percent increases for the DFG, and we will get additional money for the new part of the country as well. So I think we haven't done too badly on that.

Question: Professor Markl said that local governments provided 40 percent of the research support at universities and the federal government 60 percent. He said as well that the 40 percent was related to educational process. My question is, does the 60 percent give you objectives that are contradictory to good educational practice?

Professor Markl: I don't think so, because it is mainly driven by the interest of the researchers. The money does not come with strings attached to be used only in those areas that the federal government is most interested in. It has hopes, but it leaves it very much to the decision process of the peer review procedures.

The government can only drive research in one or another direction when it links up with specific programs where the money does not go through autonomous bodies like the DFG but instead goes directly to the universities. But we do not, at present at least, see any influence that drives it in the wrong direction.

Question: Professor Markl said that the professors of engineering in Germany have five to 10 years industrial experience. Is that deemed desirable, important, or required?

Professor Markl: All of those. It is one of the founding principles of our technical schools, really. That's how they built up. These schools recruited their first professors from industry, and they kept doing that. The major engineering professors from electrical engineering, production technology, and so on are very proud to have been leading executives in research in some of the major industries. When they are called back to the universities, they get the professor's title and a lot of freedom to do contract work, which gives them, actually, much more freedom than they had while they were working in industry.

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Question: How much is the DFG and its funding influenced by the various and growing numbers of EC research programs?

Professor Markl: We are very lucky, compared to the British, that attribution has not yet become a used word. In England, of course, money that is given to the European Community is attributed to what the research councils get, and they actually get less. In Germany we have not experienced that, so what I find is often a complementary, sometimes even synergistic, effect between programs funded at the national level and those funded by the European Community. But on the other hand, the European Community runs most of its money through rather large, strategically focused programs, where anyone from the sciences can come with any project at any time. This is a fraction of the sums available in Germany for similar work through the DFG. So I think if there were interactive effects, we would not see them up to now. But, generally, we do not feel that our government somehow is trapped because it has to give money to the European Community. It gives additional money for research through the European Community, which is welcome from our side.

Question: I would like to know about how the government R&D budgets are really decided upon in Germany. As you know, in this country we have a lengthy and open process that takes about two years, with a lot of public participation. Is there anything remotely like that in the process in Germany?

Professor Markl: In Germany the process is very similar. But what seems most important to me is that ministers for science and technology or for education and science are rated for political effectiveness based on how well they manage to get more money out of the treasury for research. They therefore work very hard on showing that their budget has increased more than other ministers in the cabinet.

This general atmosphere exists not only within the ruling party; each of the two major parties tries to demonstrate that it is more in favor of science and technology than the other. The parties are not always in favor of the same type of research—say, nuclear energy—but there is a very strong general agreement in each that Germany should never fall in its commitment to civil spending in science and technology. Thus, the goal of 3 percent of the GNP is something like a sacred cow. Among the public, also, there will be strong debate whenever there is a danger of falling back.

For instance, we discussed cutting back the percentage of public expenditure in the total R&D. In Britain the problem was handled by cutting back the public funding to produce a lower percentage; this was declared a success. But in West Germany we convinced industrialists to increase their share so that, overall, we have reduced public participation but have more money altogether. We have the same figures for percentage changes, but they are achieved in a different way.

Question: I wonder if there isn't a very serious potential for problems, now and down the road, where people believe that international coopera

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tion somehow impairs any competitive advantage coming from public investment in scientific research and in training a skilled scientific work force. If this is a possible problem, how do you think it should be addressed by the leading voices in science?

Professor Markl: We see the problem and don't know another way to invest—maybe even more to strengthen—our competitiveness because the alternative is to fall back and say we might be investing too much where others gain. But if we don't invest and don't contribute in this game, we will not be partners. Over the long run, we will suffer because we will not be able to play on the same field as the leading nations. So even though we have these discussions, there is no proposal that by investing less in research and technology, we could do better.

Question: You have emphasized the importance of internationalizing research efforts. I'm wondering if you view this as a means for individuals in your country to receive funds from outside or if you view it as a means by which your country will put money into international research efforts— say, by teams from the United States and your own country.

Professor Markl: We do not expect that internationalization will bring additional funds from outside for our researchers. We not only pay for most of our people who go out for limited terms to work in other countries but we pay as well for most of those who come into Germany. We try to balance it a bit; if some of our postdoctorates are in U.S. laboratories for the first year, on our money, and they are very enthused about it and write to the state for funding for a second year, we might say, why don't you pay for the second year since we paid for the first, and we make an agreement on that.

But we do not make this a policy. I think we profit a lot from our people going abroad, learning, and then coming back. The money spent in that respect is good. In general, I think it would be good in these international programs for each country to pay for its own effort—at least the ones wealthy enough to do so. We should together provide funding for scientists from countries who cannot participate because they are not well enough off, as in those from developing countries.

But to enter into international programs in order to relieve funding stresses on the home front I think is a poor strategy, for if everyone pursues it, it will not work. As far as industrial sources are concerned, that is another subject. If Japanese industry pays for research in England, if they see fit and want to do it, that is a different thing. But as long as we stay in the area of public funding, I think that each country, if it can, should contribute for its participants.

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UNITED KINGDOM

SIR DAVID PHILLIPS

Chairman, U. K. Advisory Board for the Research Councils

Let me start with two general comments on the remit for today's symposium, at least as seen from a U.K. perspective. First, to quote Haldane's famous comment in 1927, "I have no doubt that in reality the future will be vastly more surprising than anything I can yet imagine." Second, there is the story of the traveler in the Cotswolds who asked the way to London and was told, "If I wanted to go to London, I wouldn't start from here."

First, then, where are we starting from in the United Kingdom? Total spending on R&D in 1989-1990 was about £11.3 billion. That is about $22 billion, and it represents around 2.2 percent of the U.K.'s gross domestic product (GDP). Figures collected by the OECD suggest that this is a proportionately smaller sum than the shares of national wealth devoted to R&D in Japan, the United States, Germany, and France. That overall message is, however, rather less informative than the insights we can gain from looking at the component elements of R&D spending.

The prospects for the 1990s remain very uncertain.

Figure 1 shows that just over half of R&D spending in the United Kingdom is by industry. That is about the same proportion as in France and the United States, but it is significantly lower than in Japan and Germany. Several influential commentators have pointed to low investment in R&D by U.K. manufacturing industry as a significant factor in its relative decline; consideration of the differences between industrial sectors seems to support this argument. Research spending in the chemical and pharmaceutical industries is relatively high, and many of our most successful companies are in that sector. Overall, U.K. industry's spending on R&D increased in the latter part of the 1980s. Data for the last year are not yet available, but I suspect that the present economic recession in the United Kingdom will have curtailed that growth in research spending. The prospects for the 1990s remain very uncertain.

The other source of private sector support for research is what we term the "charities", which in this country are more usually referred to as "nonprofit foundations." In the United Kingdom these charities provide about 2 percent of research funding. The bulk of this—more than two-thirds— is support for biomedical research, where the charities now spend almost as much as the government-sponsored Medical Research Council. U.K. charities also are significant players in the funding of social science research.

For government-financed R&D, the biggest single block is defense research at 20 percent. Spending on this has traditionally been high in the

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United Kingdom, albeit not quite so high as in the United States. However, unlike in the United States, the boundary between defense and other R&D sectors has been kept fairly clear in the United Kingdom: very little defense-related research is undertaken in our universities, and, except for aerospace, there has been remarkably little interaction between technological innovations in the defense and civil sectors of British industry. Even before the end of the Cold War and before the tantalizing prospect of a peace dividend, the U.K. government had been planning to reduce its spending on defense research. The driving force for this was the need to release resources—both cash and trained manpower—to boost civil R&D. This reduction started, very slowly, in 1988 and was expected to accelerate rapidly in the mid 1990s. It may well be, however, that events in the Persian Gulf will lead to some reconsideration of this policy.

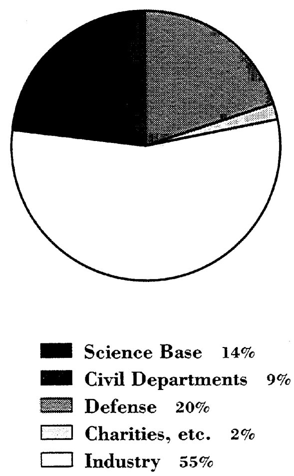

FIGURE 1
UK Expenditure on R&D
Total 1989-90 £11.3 Billion 2.2% of GDP

In contrast to the position on defense, spending by U.K. government departments on civil research outside the science base has traditionally been low in comparison to the level in other major countries. Nevertheless, the last few years has seen a reduction in this element of research funding, and the government is planning further cuts over the next two years. In general, ministries' spending on research in support of policy development and their own regulatory' and procurement activities is not being reduced. The cutbacks are largely in government support for research of potential benefit to industry (in its broadest sense). The sectors mainly affected are agriculture and energy, although manufacturing will also receive less. Most of the reductions are in support of applied research and reflect the government's view that industry itself should be responsible for "near-market" research. The surviving programs are, in contrast, very largely "far-market"—meaning strategic research that is not expected to yield a marketable product or process for at least, say, five years. As well as being part of the government's general intention of removing what it saw as the featherbedding of parts of British industry, this policy was also intended to allow some redirection of funds to the science base.

By "science base" I mean the basic and strategic research funded by government in our universities and Research Council institutes. The terms "academic" and "academically related" research also are used to describe, roughly, the same territory. This is the area of the research enterprise about which I know most and about which most of my remarks this morning will be addressed.

Spending on the U.K. science base has increased over the last decade by about 8 percent in real terms. But that increase has not kept pace with the growth in U.K. GDP, and the government's present spending plans for the next three years involve reductions that will largely eliminate it. The best international comparisons in this area are probably those that emerged from a study, jointly funded by the Advisory Board for the Research Councils (ABRC) and the U.S. National Science Foundation, conducted at the University of Sussex. That study found that the United Kingdom spent

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.significantly less on academic and related research than other major countries, although as a proportion of GDP, we did appear to be spending more than the United States and Japan.

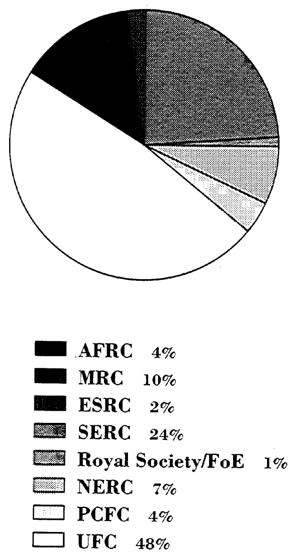

FIGURE 2
UK Science Base Funding
Total 1989-90 £l.7 Billion 0.3% of GDP

Science Base Spending

Figure 2 shows how our science base spending breaks down among funding agencies and it illustrates very well the dual-support system that is at the heart of our funding arrangements. About half of the government's support for academic research flows in unhypothecated grants through the Universities Funding Council (UFC) and the Polytechnics and Colleges Funding Council (PCFC). The other half flows through the five Research Councils: the Agricultural and Food Research Council (AFRC), the Economic and Social Research Council (ESRC), the Medical Research Council (MRC), the Natural Environment Research Council (NERC), and the Science and Engineering Research (SERC). The proportion flowing through the Research Council route has increased during the last five years, and this is giving rise to a number of difficulties at present.

To understand these difficulties, you need first to understand that our dual-support system is dual in two different ways. First, it is dual in that some research is wholly financed from UFC monies, whereas other projects and programs are sponsored by the Research Councils. Secondly, it is dual because the Research Councils cover only part of the cost of the programs they support; the rest of the cost is met by universities from their UFC grants. The consequence of the increase in Research Council spending in recent years has therefore been twofold: (1) a stretching of the limited university resources available to underpin Research Council projects and programs, and (2) a squeeze on the funds available for wholly UFC financed research. This makes the managerial problem facing universities increasingly difficult, especially when one takes into account the increasing diversity of university research funding, with some industrial and charitable paymasters covering only the marginal costs of the research they sponsor.

The difficulties that scientists at the bench have experienced as a result of this change in the balance of funding have led to greatly increased pressure on the government for additional funding for the science base. But the arguments that researchers present are almost entirely in terms of constraints on the total sums available. Very few of them realize that some, at least, of the resource problems they face are a consequence of changes in the way in which those totals are deployed. Contacts in other countries tell me that this sort of naïveté about management and financial considerations is not unique to the U.K. scientific community.

My conclusion is that part of the policy agenda for the 1990s must be to find means of increasing scientists' understanding of the ways in which their work is funded. Without this understanding they will not be well placed either to argue for a reasonable share of taxpayers' money or to ensure that

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the resources they do receive are managed efficiently. In the United Kingdom we intend to help this process along by unscrambling part of our dual-support system so that from late next year (1992) the Research Councils will pay a much larger part of the costs of the projects they sponsor in universities. From that time the Research Councils will provide the full direct costs of the research they support, together with a contribution to properly identified indirect costs, leaving only academic salaries and premises costs to the responsibility of the universities.

All of this will put even greater financial leverage in the hands of the Research Councils, and I should therefore say something about how their budgets are determined, particularly as this is where the ABRC, which I chair, most comes into the picture. At this time of year, the Research Councils know their budgets for 1991-1992; they have been given indicative allocations for the following year years, 1992-1993 and 1993-1994; and they are putting forward their plans for the three years 1992-1995.

These "Forward Look" plans have to satisfy a number of criteria. In brief, these criteria are as follows. First, the Research Councils must plan to live within the indicative budget allocations they have been given, and within these budgets they must support the science and activities they judge to be of highest priority. That being so, if they ask for more money—as they invariably do—the extra activities that they want to support must be of lower priority than anything in their planned program. There is, however, one loophole in these rules. Some new opportunities may arise that are of higher priority than some part of the established program but that cannot be taken up quickly because it is difficult to run down existing activities fast enough to release resources for redeployment to the new venture. In these circumstances a Research Council may ask for money to cover frictional effects.

The ABRC then judges the relative importance of the councils' bids for extra money, against the background of an assessment of their existing programs, and gives proposals to the government for revision of the planned Science Budget totals. That happens in early May. In November the government tells us what the budget for the next financial year will be and gives revised indicative figures for the following two years. The ABRC then advises on how these total resources should be allocated among the Research Councils, looking again at the Forward Look plans they submitted earlier in the year. (I have emphasized this process because I believe that we must all learn how to manage research within steady or only slowly growing resources, in which new programs will increasingly require the discontinuation of old ones.)

After that excursion into the detail of our funding arrangements, let me turn back to some of the broader organizational issues we face in the United Kingdom. These concern coordination, and I am sure they will have their counterparts in other countries. First, in the United Kingdom we need mechanisms to promote coordination among our five Research Councils.

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These are needed for a variety of reasons:

- to ensure complementarity of the programs they support at the boundaries of their responsibilities, particularly in the biological sciences;
- to facilitate interdisciplinary programs that need the involvement of more than one council;
- to consider the impact of each council's policies on the others (e.g., decisions about the funding of major facilities or of postgraduate training programs can have quite wide implications); and
- to harmonize administrative procedures so as to aid central policy-making and to minimize the bureaucracy with which researchers have to grapple.

The ABRC is our main mechanism for this. Since last year the board has been taking a more active role than hitherto in stimulating cooperation among the Research Councils.

We also need means for ensuring effective and ready communication among the Research Councils and the higher education Funding Councils, the UFC and PCFC. I have to confess that this is not working well at present. The answer, I suspect, is that both sides have to become better at communicating with individual universities and polytechnics, and better at ensuring that coordination is pursued actively at a local level. The balance of policymaking has become rather too top-down in recent decades. Research might be managed better if some of the responsibility were more clearly seen to reside at the local level, and if that responsibility were more firmly grasped by institutional managers.

Science Budget Spending

So much for that sort of organizational issue. Let me turn now to the different modes by which we support research. Figure 3 shows the breakdown of the Research Councils' spending last year. It is quite a varied and balanced portfolio. The biggest element, 31 percent in total, is spending on research grants to scientists in universities and polytechnics. These are normally for periods of three or five years and, as I have already said, at present cover only part of the costs involved. All of these grants are subject to competitive peer-review assessments. At present, of those grant applications that are graded alpha by the peer-review process, about 60 percent are funded.

The chart subdivides the research grants spending into "Responsive" and "Pro-Active." This is a somewhat artificial division, but it is an important issue in the U.K. policy debate. In a very real sense, all of the research grants are responsive in that all of them are responses to detailed applications submitted by researchers. But as well as inviting applications generally across all subject areas, the U.K. Research Councils also, from time to time, issue specific invitations for applications in particular research fields. These are fields that they, in consultation with the relevant parts of the research community, have judged as meriting special attention, usually be

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cause there are emerging scientific opportunities that it is believed deserve greater attention from U.K. scientists. Examples in recent years include low-dimensional solids, plant molecular biology, and AIDS. The invitations for applications in these sorts of programs vary quite a lot in the extent to which they specify in detail the subfields in which it is hoped research might be pursued. Thus, there is quite a spectrum of support from the completely unfettered "responsive" mode through to what we term "directed" programs such as that on AIDS (where the areas in which more research was wanted, and the balance between those areas, was specified in detail from the center).

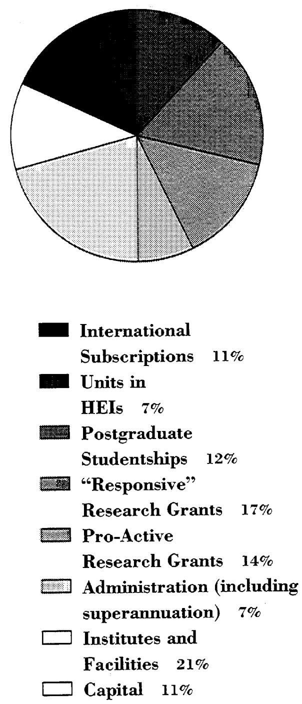

FIGURE 3
Spending by UK Research Councils
Total 1989-90 £881 Million

The "Pro-Active" category on this chart includes all those research grants that resulted from particular invitations from Research Councils, however detailed. In effect, these "pro-active" grants are part of a system in which resources are earmarked for particular research fields in advance of receiving grant applications for peer review. This does not, however, mean that poorly rated applications have an easy route through to a grant. In practice, the announcement of these earmarked programs generates a large volume of grant applications, and the competition between high-quality proposals is intense. These sorts of arrangements, which I know have their counterparts in other countries, are part of the process of selectivity in research support—a process that is becoming increasingly necessary.

Before discussing that yet further, however, I want to comment on our other modes of supporting research. Progressing around the chart from "Pro-Active" grants, we have "Units in Higher Educational Institutions." These are located in universities and polytechnics, but they are involved fulltime in programs of research negotiated with Research Councils and are financed directly by the councils. Most of them are supported by the MRC, but their numbers have been increased in the last few years by the establishment of 20 Interdisciplinary Research Centres, mostly sponsored by the other councils.

Further along the spectrum of support, we have a number of research institutes—rather fewer than other European countries and mainly involved in biological sciences. The chart shows that 21 percent of our expenditure goes to these institutes. This percentage, however, also includes our spending on large scientific facilities, such as supercomputers, a synchrotron radiation source, research ships, and so forth. Most of the activity at these facilities is by or on behalf of university scientists, but we have yet to disentangle fully the costs of that from the costs of the other in-house, institute-type research at these facilities.

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Questions about the balance between these different modes of supporting research were a key issue in the United Kingdom during the 1980s and, I believe, will continue to attract attention in the 1990s. Each of the modes has it strengths and its weaknesses. Research institutes have the capacity to concentrate effort in identified fields, to organize continuing programs of research in those fields, to focus on the relevance of research to applications, and to mobilize scientists across a range of disciplines. But they tend to be inflexible and can become moribund. University-based research, on the other hand, is characterized by its flexibility and its capacity for innovation— much helped by the continuing flow of bright young graduates who are involved. But these very strengths make it difficult to organize large, long-term, focused research programs there.

In the United Kingdom we have taken the view that the increasing pace and breadth of scientific advance puts a premium on flexibility and innovation. So, during the 1980s, we shifted the balance of support from institutes to university research grants. The proportion spent on the latter has already increased from 25 percent to 31 percent, and some further shift may be necessary. We have also looked at ways in which the strengths of the institute and university approaches can be better brought together. I have already mentioned our increased spending on centers and units, which are sort of halfway houses. Additionally, as well as cutting back on institutes' spending, we have encouraged them to develop better links with universities and in some cases to relocate alongside university campuses. I expect that we shall need to take further steps of this sort over the next decade. At the very least, we shall need to keep the balance between the different modes of supporting research under careful scrutiny.

Increasingly, we shall need to be selective to steer the bulk of our research effort into a more limited range of fields. The real issue is how, and on what basis, we do this.

The scientific and financial pressures that require that scrutiny also will, I believe, cause us to focus more than we yet have on selectivity in, and concentration of, research support. The United Kingdom undertakes about 5 percent of the world's research. Within that we cannot sensibly expect to be supporting high-quality work at the frontiers of knowledge in every field. Increasingly, we shah need to be selective—to steer the bulk of our research effort into a more limited range of fields. The real issue is how, and on what basis, we do this. Personally, I am convinced that the primary focus must be on excellence. The key criterion for selecting research priorities must, I believe, be the quality of the proposed research and of the scientists involved. In my view, if we do not back our top scientific talent to the hilt, we might as well go home. The other significant criteria in priority judgments are potential exploitability and applicability. They too are important and will certainly feature large in government minds. But, in my view, those factors should clearly take second place, behind research excellence.

A second aspect of selectivity about which I feel strongly is that our decisions about subject fields should not be irrevocable. We must retain some limited capacity in all fields, if only to understand properly what the research leaders elsewhere are achieving, and we must retain the flexibility both to shift resources from our selected fields into others in the light of scientific advances and to take account of inevitable changes in U.K. scientific strengths.

Linked with, but separable from, decisions about selectivity, are policy questions about the concentration of research resources. Both scientific and financial pressures point toward increased concentration, but how far should we go? Increasingly, the next scientific advance in many fields seems

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to require a bigger critical mass of research effort: bigger research teams, now often including scientists drawn from different disciplines, and more sophisticated research equipment. Financial pressures inevitably mean that these larger clusters of research resources are going to be focused in an increasingly limited number of locations. We need mechanisms to ensure that location decisions are made other than arbitrarily by happenstance. But we also need mechanisms to ensure that, as well as the main concentrations of research effort and resources, we also maintain a rather broader spread of research expertise—not least as a seedbed for future developments. Getting the balance right will be a difficult job in a number of ways.

The focus really needs to be on mechanisms for improving the two-way flow of information between academic researchers and industry so that industry can take up and exploit research findings more readily, and so that researchers have a clearer perception of the root problems industry wants tackled.

In the present distribution of Research Council grants to U.K. universities, about 75 percent of grants go to only 20 institutions. That might suggest that the U.K. research effort is already quite heavily concentrated. However, as is often the case, these statistics disguise more than they reveal. In the first place, most scientists in the apparently weaker universities do not recognize the situation and believe that they have an equal call on resources with their counterparts in the "top 20." To some extent they are right to believe so, for much of the research in the universities receiving the most in Research Council grants is not in itself very concentrated but is instead spread around in penny-packets. The U.K. policy agenda for the 1990s therefore also has to include questions about the following: first, the extent to which we should recognize more overtly institutional differentiation in research functions and the implications of that for funding arrangements, and, second, the extent to which we should proactively be encouraging relocation of particular research activities and interests between the "top 20" research universities.

Industry and International Links

Let me finish by touching briefly on links with industry and the international dimension. My first point about links with industry is the need to recognize that many industrialists place the output of trained scientific personnel above the generation of new knowledge as the key output of the science base. I appreciate that this view is somewhat sector dependent— for instance, in the United Kingdom this view is held more strongly in the chemical sector than among electronics companies. But it is a factor that many senior academic scientists do not fully appreciate and to which they therefore may give inadequate attention in future planning.

My second point is that we have put a lot of emphasis in recent years on building better links between academia and industry in the United Kingdom. Simplistically, this can mean an increase in the amount of applied research that universities and Research Council institutes undertake for industry; we have indeed seen a welcome increase in such commissions. But, more fundamentally, the focus really needs to be on mechanisms for improving the two-way flow of information between academic researchers and industry so that industry can take up and exploit research findings more

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readily, and so that researchers have a clearer perception of the root problems industry wants tackled.

An increasing proportion of our research budgets is likely to be directed to international activities.

Regarding the international dimension, my most important comment concerns the increasing need for international collaboration. In some ways this is but the extreme case of the pressures toward selectivity and concentration I discussed earlier. Few single countries can afford the investments required to produce ever-bigger particle accelerators or more sophisticated radiation sources, and increasing attention is being given to global concerns, such as climate change, which inherently require multinational inputs. Thus, an increasing proportion of our research budgets is likely to be directed to international activities. You will have seen from my earlier slide that about 11 percent of the U.K. Science Budget is spent already on formal international subscriptions. If more informal international collaborations were included, that figure would probably be half as large again. That is fine, both in terms of the importance we all attach to fostering international links and of the major scientific advances that have undoubtedly been facilitated by these international efforts. But the downside is that international spending is too often a preemptive charge on national research budgets. It cannot be varied much or quickly at the margin, and when times are hard—as next year will be in the United Kingdom—that places awkward constraints on domestic science budgets.

SIR MICHAEL ATIYAH

President, the Royal Society

The Royal Society is not a body concerned with the management of and decision allocations in science as a whole in the United Kingdom. It gets 1 percent of the total government funding of fundamental research, and this is used mainly for the support of research scholarships. Thus, we are not in the business of science management per se. However, we are, of course, like the U.S. National Academy of Sciences, involved in science policy as a whole. We represent the scientific community, and we are concerned with scientific policy questions. We try to influence those who have to make the decisions, such as the chairmen of the Research Councils and ministers, and we play a role on the public scene. Our involvement therefore is very much not managerial but is in trying to take part in the general discussion.

I think I have to start by describing the present position of the United Kingdom in more detail. Perhaps the most significant indicator of funding trends is in percentages of the GDP. The main point one can draw from data covering 1981 to 1988 is that, whereas in all other countries the percentage has gone up in the period, in the United Kingdom the percentage has gone down significantly. When we complain in the United Kingdom to our government about these factors, it tries to argue that percentages of the GDP are not good figures to look at. My own view is that they do really

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indicate a significant difference between the situation in the United Kingdom and in other countries. The forecasts for the future are for this tendency to go on unless there is a major change in policy.

So those are the present realities. There are also significant differences concerning the allocations of research money to civil and military expenditures. In the United States, the United Kingdom, and France a large fraction goes to defense, which is quite unlike the situation in Germany. Of course, there is a general recognition of this by the U.K. government. The policy is to reduce, to some extent, the amounts going into the defense budget; if this were to continue, it would help to improve the situation for civil research.

Looking into the future is a difficult task. We have a new government in the United Kingdom, and perhaps will have more governments in the near future. Bearing in mind the changing international scene and the way the world is going, I would guess that future U.K. governments may deem that the proportion of funding going into defense in the United Kingdom is unjustifiably large. If future governments made a policy decision of that kind, we might have a significant improvement in U.K. science over the next decade. That is an opportunity which might be taken, but then again it might not.

> ***Future U.K. governments may deem that the proportion of funding going into defense in the United Kingdom is unjustifiably large. If future governments made a policy decision of that kind, we might have a significant improvement in U.K. science over the next decade. That is an opportunity which might be taken, but then again it might not.***

Now, one of the major trends of the past decade, which was very definitely the result of government policy (sometimes trends are not government policy, but instead are simply facts) has been the successful attempt to reduce the percentages of research funded by the U.K. government, which has gone down from 50 percent to 36 percent over that period. This policy was based on the belief that there was too much support by the public sector of various things, including scientific research.

The attempt thus was made to shift some of the burden of scientific research into the private sector. This attempt took various forms, in addition to actual decreases in scientific budgets. There also has been a shift administratively in terms of trying to move out various organizations, such as laboratories, into the private sector or into an intermediate "agency" status.

From the point of view of university research grants, the money has been coming from a wide range of resources, including the Research Councils, the U.K. government (directly from government departments but mainly from the Research Councils), and U.K. charities. The charities fraction is the one that has been increasing most significantly. This fraction has, in the medical field, grown to be larger than contributions from many other sources, which is perhaps unique in Europe.

There is another part to the funding of the universities that we call "core funding." Core funding refers mainly to the provision of staff salaries of those involved in research in universities and the basic infrastructure that goes with that. As seen from the universities standpoint, the percentage of their core funding has gone down by approximately 10 percent in the past decade.

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Corresponding with this shift of resources, what we see coming out of a general government policy is a shift of financing away from major reliance on government sources and toward diversification. In many ways diversification of funding is a good thing. Diversification gives you some kind of stability, and the more sources you have, the healthier you are—in a sense.

On the other hand, diversification has other consequences, and one of these consequences is felt by academic staff conducting research (those who hold higher degrees, not technical assistance staff). The proportion of such staff in U.K. universities who are in permanent employment, as opposed to short-term renewable contracts, has been much reduced. Over the period in question—the last decade or so—the proportion of people on short-term contracts has doubled, from around 20 percent to 40 percent. This is a major change in the staffing of universities, which is to a great extent a consequence of the diversification of sources, for the outside sources tend to be on a shorter time scale.

This increase in short-term contract staff has both plus and minus factors. Some people view the possibility of having people on short-term contracts and then letting them go as a good thing. It keeps you from getting stuck with somebody who ceases to be productive after a certain number of years. On the other hand, many people in the scientific community feel that those who are engaged only on a short-term contract cannot afford to take the long-term view of scientific work; instead, they have to concentrate on short-term projects perhaps proposed by someone else, rather than initiated by themselves, because they have to justify themselves at the end of a short period of time to get some renewal of their funding.

Thus, there is a genuine problem here—to compare the advantages and disadvantages of having a largely mobile or short-term staff in our universities. But I think the feeling of many of our colleagues at the moment is that the present proportion of short-term staff is unduly high, and with about half the staff appointed this way, the disadvantages probably outweigh the advantages.

> ***One of the major recent trends in the United Kingdom is the rather rapid growth of what we call interdisciplinary research centers.***

Let me move on now to some other factors. One of the major recent trends in the United Kingdom is the rather rapid growth of what we call interdisciplinary research centers. These are large units, always associated with a university and sometimes with several universities, where there is a large concentration of resources, substantial expenditure, and usually some kind of interdisciplinary work involved. These research centers have many advantages—for those who believe in them. First of all, they foster research across traditional boundaries. Second, they concentrate expensive equipment in a few key places where it can be used (the argument is that you cannot afford this kind of equipment everywhere). Third, they are a means of fostering particularly exciting new areas where you want to put a lot of your resources.

Because of these kinds of arguments, there has been a very significant growth of interdisciplinary research centers in the past two years. But the

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arguments against them are also familiar: they are too elitist; they put too many resources in one place; and, perhaps more doubtfully, their establishment depends more on science policy than on science. That is, the people who know how to manage themselves on scientific committees sway the arguments, whereas those scientists who spend their time working at the bench do not spend time on committees and therefore do not get the support.

I think this is certainly a danger. When you go too far down the line in making awards very large—an all-or-nothing affair—then it becomes so important for people to take part in this process that either they are involved in the management side or they are scientists working on the ground. I think this an aspect that I myself am rather concerned about. If you have a large number of such centers, no doubt some of them will be very successful, but some of them may be of only mediocre significance.

The days when Europe could go it alone, the United States could go it alone, Japan and the Soviet Union each could go it alone are perhaps coming to an end, and even larger-scale collaborations may be the only way to go forward.

The present view, after initial enthusiasm in establishing a lot of centers, is that perhaps we should be a little bit more cautious and that the Research Councils are pulling back a little from too rapid an involvement until they see more clearly how things develop.

As for the European question, there are two major directions in European cooperation in science. The first of these is large multinational laboratories. These laboratories have been remarkably successful in scientific terms, but they do have their drawbacks: they are bureaucratically very cumbersome; they require agreement by a large number of countries; they are difficult to control; they tend to be expensive; and, again, their establishment and subsequent evolution depend very much on political questions as well as purely scientific ones.

The consequence of this is certainly major tension, particularly in the United Kingdom concerning the resources that can be spent on international collaboration of this kind and the resources that are spent inside the United Kingdom itself. The United Kingdom is perhaps different from other countries in Europe in that the money for these international subscriptions comes out of the same overall financial budget as the direct support of science in the United Kingdom. Other countries manage it in a different way, so the competition is not quite as obvious. In the United Kingdom the one overall budget funds both U.K. science and most of the foreign science as well. So at the present time, when there are a lot of constraints, many questions are being raised about what is the best use of money, and this produces tension in the scientific community.

Of course, there are many international collaborations that involve countries outside Europe. The scale of many things has now reached the point where worldwide collaboration may be the only solution for future development. The days when Europe could go it alone, the United States could go it alone, Japan and the Soviet Union each could go it alone are perhaps coming to an end, and even larger-scale collaborations may be the only way to go forward.

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On the European scale, I think it is fair to say there is not the same degree of confidence in the procedure by which the funds are allocated and in whether these are as well justified as the corresponding funds allocated within the country itself.

The second growing channel of support for science in Europe is through the European Commission. There is every reason to expect this to increase very significantly, particularly after 1992. In general, the Royal Society is in favor of this. Collaboration is viewed as desirable for cultural, economic, political, and scientific reasons, so in general terms we all are enthusiastic about this general direction.

On the other hand, I have to say that at the detailed level of mechanics, there is some concern that, partly because of the diversity of systems in different countries in Europe and partly because of the speed with which things are changing, the mechanisms for the distribution and allocation of funds at the European level are not perhaps as refined as they are within a given country.

In the United Kingdom we have developed, over a long period of time, what we think is a reasonably refined system of peer review and the methods for getting the best use out of the limited funds we have. On the European scale, because of the difficulties I have alluded to, I think it is fair to say there is not the same degree of confidence in the procedure by which the funds are allocated and in whether these are as well justified as the corresponding funds allocated within the country itself.

At the present time, the funds on the European level are not so great that they totally distort the picture. But as these funds increase and as we look ahead (and we ought to look ahead over the next decade or so), undoubtedly this is one of the major factors we have to come to grips with. Namely, if larger amounts of funds for scientific research are going to be spent in Europe on a multinational basis, in one way or the other, then the mechanisms for dealing with this will have to be refined so that they command more general assent within each country. Because of the wide range of different structures in different countries, this is not going to be an easy task.

So much for Europe, for the moment. We were also asked to comment about the national plans in various countries for the science policy over the next decade.

I am not a government official, and I am not privy to the inner secrets of what ministers decide or what their plans are. But, as far as we outsiders are aware, there is no plan in the United Kingdom. I think it is fair to say the government does not have a long-term vision for the planning of science. Everything is conducted very much on a short-term basis governed primarily by financial considerations.

For the scientists, who have to think quite often in long-term scales, this makes for great difficulties. The one item that one can deem to be a government plan is the general philosophy I mentioned before—that direct government spending in all forms should be reduced and a greater burden should be placed on the private sector. This is a philosophy that the previous government held, and it still appears to be part of the present government policy: to reduce the public sector expenditure in general and in particular for science.

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If I go back for a moment to the figures about the percentage of scientific research funded by the government and by the private sector, one will see the government was very successful in reducing its own contribution and increasing the percentage taken up by industry. One might feel therefore this was therefore a very successful policy. But if one looks at the comparative figures of other countries and bears in mind the percentages in terms of the GDP, one might argue that all that has happened in the United Kingdom is that the government has pulled out and the gap has not been filled by anybody else. Thus, it is dangerous to believe that if the government pulls out and exhorts industry to take its place, this will automatically happen; one could argue, indeed, that it has not really happened at all.

There has been some oscillation, I believe, in government thinking on what kind of scientific research it should support. There was a time when the view was that the government should support the movement of scientific research into industry and should support those kinds of research that have exploitable economic advantages. But after a certain amount of experimentation, the basic philosophy that the government should keep out of things finally won over. The government now has a policy of keeping out of near-market research and leaving that to industry, which is best fitted to undertake it.

Whatever one might think about the overall size of the science budget, one day, now or later, limits are reached. Within those limits the most important thing is how the money is divided and how rational allocations are made among different kinds of research. Those are the responsibilities of the scientific community, and they should not be handed over to the government.

The government now believes in funding basic or strategic research. Its policy is to fix cash limits and, by and large, to leave it to the scientific community to divide up the cake as it feels necessary. Of course, whatever one might think about the overall size of the science budget, one day, now or later, limits are reached. Within those limits the most important thing is how the money is divided and how rational allocations are made among different kinds of research. Those are the responsibilities of the scientific community, and they should not be handed over to the government.

Because there is no plan for science, as far as I can see, in government circles, the Royal Society decided recently to undertake what one might think of as a plan of its own. This plan is a bit ambitious. The society has set up what we call a science inquiry, which is to run for the next year or so, to address a number of issues in science over the next decade. It will be a middle-term plan, established to investigate the present situation and to see what recommendations we might make to those who have to make decisions.

This inquiry has a list of topics or headings, and they cover almost everything of concern, but I can spell them out a little for you here. The first question concerns what sort of research should be supported by public funds and what should be supported by other sources, including industry. T h e second question concerns what the organization should be of the U.K. science base—that is, science conducted within universities and research councils. We want to find the best way of organizing that with respect to the division among universities, large research centers, laboratories, and the Interdisciplinary Research Centers that I mentioned earlier. How much should scientific research be directed and how much should be left to the

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individual scientists? Obviously, these are crucial issues and will form one of the focal points of our inquiry.

A third question concerns the funding of the U.K. science base, which refers to how much funding comes from different sources and how it is channeled into the different types of research. The fourth question or topic refers to high-cost research—the large facilities needed for such fields as particle physics, astronomy, space, and so on. The most pressing problem is how to support these fields and how to decide on their scale measured against the claims of smaller scientific research. This problem certainly has to be tackled in some fundamental way.

The most pressing need is to ensure in science that we recruit and bring into the scientific community able people of the next generation, and that we give them the right training and the right opportunities to conduct their future careers, whether those be inside universities, in research centers, or out in industry.

The fifth topic refers to career structure, which is related to the figures I gave about the proportion of scientists who are on short-term contracts in universities. The most pressing need is to ensure in science that we recruit and bring into the scientific community able people of the next generation, and that we give them the right training and the right opportunities to conduct their future careers, whether those be inside universities, in research centers, or out in industry. Ensuring that the permanent career structure develops in the future in a constructive way is certainly one of our biggest problems. We know some of the difficulty already, and we are going to look at it in greater detail.

A sixth question is the European dimension I alluded to before: the increasing role of Europe and what the consequences are going to be for science in the United Kingdom—the financial consequences, in particular.

The seventh question also refers to the same thing: the division between national and multinational support for science. And the eighth and final topic concerns the division of science into different parts: what is the size of the total and how much should the United Kingdom be spending on science? For that one can, of course, make international comparisons as I did in the beginning.

We were asked not only to describe trends but to explain what our views are about what the future should be. The Royal Society view will be much clarified when this science inquiry has been finished. So if you ask me to come in a year's time, I may be able to come with a very clear blueprint. At the moment, however, I cannot do that. All I can do is give you a few thoughts on what I think the general principles are that the Royal Society believes in.

The first, and most important one, we feel, is that the training of scientific personnel is the single most important thing to bear in mind. This is not only because the future of science depends on the training of succeeding generations but also because of the practical applications in industry. Many people in industry tell us the most important thing they need from universities is the production of a trained scientific workforce at various levels. This is one of our essential tasks. Training is undertaken in universities by staff who are involved in research. The Royal Society view has been very firmly that most scientific research should be based in universi

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ties, either within departments or in research centers associated with universities. Either way, we feel that the research should be conducted in universities in close proximity to the younger generation. The distinction between education and research can be oversimplified. The important thing is to have a whole cohort of people coming up doing undergraduate work, graduate work, and postdoctoral work and then moving into scientific research, and having them all in close proximity at the same place. This is the most effective way of ensuring continuity and providing for the future.

Applied research, whether it is applied for industrial purposes or applied to a specific area such as the environment, may well best be done within large research institutes not necessarily related to universities.

The second principle is, we believe, that government support should be given to basic long-term science, with no immediate consideration of commercial or industrial payoff and that such research is best done in universities or similar establishments. Applied research, whether it is applied for industrial purposes or applied to a specific area such as the environment, may well best be done within large research institutes not necessarily related to universities.

The general question of whether research is best conducted within large institutes and laboratories or by individual scientists is one that is very pertinent at the moment in the United Kingdom. People are much concerned because of the shortage of funds. Perhaps I could digress a moment to say that one of the good things about having a constraint on resources is that it makes people think so much more. Certainly, we have had plenty of time to think within the last 10 years in the United Kingdom. I do not make that an argument for cutting funds, but if you do have to cut funds, then you are forced to think about certain fundamental issues.

The general view, I believe, in the Royal Society is that really fundamental progress in science comes from the individual scientists—the cutting edge—and that science funding should recognize this and should respond by providing funds for key scientists. Attempts to control science by overdirection, by saying "this is what we think the interesting things are that you should be working on," should be avoided, at least as far as possible. Committees, however experienced, are not the best people to make judgments. Our view is that we have to respond basically to the research needs of the scientists actually working at the bench. There are various mechanisms by which this can be done, but the fundamental need is for support of the individual scientist.

Looking ahead a little, I believe there are going to be a lot of pressures on universities. I have said that universities are the key places in which research should be done. But there is going to be a lot of pressure on the universities, in the United Kingdom in particular. For example, there is certainly a general feeling in the United Kingdom that far too low a percentage of our population goes to universities, or indeed goes on to any form of higher education. Undoubtedly, there will be an increased number of students over the next decade. Our universities are much smaller in total size than those of comparable countries. It is very likely that there will be an increasing number of students entering universities and other forms of

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higher education. This means that universities will probably have to diversify in many ways: they cannot all fulfill the same function. Perhaps we will move more toward the kind of system that exists in the United States, with a wide range of institutions of higher education—from very prestigious universities conducting a great deal of high-grade research to other universities that perform a wider range of activities.

Because of the political movement in Europe and the wide diversity of structures in different countries, I think it is inevitable that we will have some kind of convergence of the different systems in Europe.

At the same time, I think there will be a need to converge in Europe. Because of the political movement in Europe and the wide diversity of structures in different countries, I think it is inevitable that we will have some kind of convergence of the different systems in Europe. For example, in Germany it takes six or seven years to get a degree. In Britain one can do it in three years. I think convergence here means that there has to be some kind of move in both countries toward the middle. In the United Kingdom, on the one hand, we will certainly move toward less specialization in schools and toward, perhaps, longer courses in universities. In Germany, on the other hand, they will try to shorten their courses. Both of us may end up with four or five years of study being customary. I think such changes will come because there is now essentially a free flow of students. One of the most remarkable things is the increasing number of German students who come to study in the United Kingdom, for the obvious reason that they can get their degree in half the time. Once free-market education has been set up, then the institutions have to develop accordingly; they cannot retain their previous forms.

Universities are going to have to converge in some sense, and that will have consequences both for education and for research. I am sure that this is one of the big issues that will be facing us in the next decade or so.

In comparing Europe and the United States, it is very tempting to see whether we can learn from U.S. experience. The history, of course, is completely different, but the United States has the same problems between state and federal structures and with the diversity of educational institutions, so perhaps we can learn something by making comparisons.

DISCUSSION

***Question*:** With regard to the concentration of research in the United Kingdom, I am curious to know whether your research has been diffusing to more institutions, or is it becoming more concentrated in fewer institutions over the past few years?

***Sir David Phillips*:** By your standards, our universities are very small, ranging from 2,000 to about 12,000 students. Now, for an institution with only 2,000 or 3,000 students to expect to engage in research across a broad spectrum of subjects is probably a false and uneconomic hope. As for trends, I think that the concentration has been getting greater. How much further

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it will go, I don't know, but you should know that in 1987 this kind of argument led to a proposal that we should be differentiating between universities that are engaged in research across the full range of subjects and those that are expert in, say, one or two fields of research.

Universities are going to have to converge in some sense, and that will have consequences both for education and for research. I am sure that this is one of the big issues that will be facing us in the next decade or so.

We in the United Kingdom have a group of universities—of which there are about 50 in all—all of which give doctorates and all of which engage or have the ambition to engage in research at the highest and most expensive level, but these universities are of this range of sizes that I have described, and many of them are of a very uneconomic size to be engaged in expensive research across the range of activities. We have a university, for example, that is extremely good at plant sciences but not terribly distinguished in other areas. We envisaged, in 1987, that such smaller universities will be engaged in not very expensive research but rather in support of teaching. Now, that raised a great amount of debate and, I think I would have to say, anger in the university community. Nevertheless, the trend is in that direction. The mechanisms used to fund the universities through the universities' funding councils, and the forces of the Research Councils, are pushing the system in that direction.

In parallel with the universities, is a system of higher education institutions known as the polytechnics, invented in the 1960s, partly I believe as a government response to the expense of maintaining universities in which all the staff had the right to spend 30 percent of their time doing research— whether they did or not, incidentally, but they had a right to engage in research. The polytechnics are constrained not to receive public money in support of doing basic research and are pushed toward a close relationship with industry.

The greatest expansion in U.K. higher education over the last 10 years has been in the polytechnic sector. Polytechnics are, on the average, larger than universities, and they produce now' the greater number of graduates: 50 percent or more. But they are not funded through a funding council automatically with a large block grant to support research. They get the support from industry, the Research Councils, and wherever else they can find it. So we do have a diverse system.

Question**:** Could you address how the abolition of tenure has affected the morale of the universities and what long-term effects it might have there?

Sir Michael Atiyah**:** First of all, one has to recognize a little bit of history in this. The problem with British universities was that there was a very, very rapid expansion of the system in the 1960s, which led to an enormous influx of new faculty. In the British system at that time people got tenure immediately on first appointment after their Ph.D. This caused an enormous problem, which we still have today. It was that problem that had to be tackled—to remove tenure in that sense. The effect on morale can be exaggerated. Although tenure has been abolished in the legalistic sense, in practical terms people are not in immediate danger of losing their jobs. There will be a difference between people who are appointed with the expecta

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tion of being kept on, and who are normally kept on except in unusual situations, and those who are appointed on limited grants.

***Question*:** Dr. Atiyah, you mentioned that work at interdisciplinary centers is often mediocre. That might often be true, but can one not also look at it as evidence that the scientific community has lost the ability to communicate across disciplines and that they have specialized so much that these mediocre studies reflect merely bad communications?

***Sir Michael Atiyah*:** Of course, interdisciplinary activities are very important. I totally agree with you that, on the whole, within universities people are traditionally stuck within traditional disciplines, and we want to break those down. It is difficult in a university sometimes to bring this about, and therefore it is very good to have centers that bring together people from different areas to work together. That is a very good reason for having these centers.

However, the decision of which areas to cover may be dictated by political considerations, or considerations of strategy and policy, and not necessarily by the status on the ground. One can therefore make mistakes, for one might end up saying there should be some interdisciplinary activity in this area for general reasons of strategy or because some committee thinks so, but once it is set up and has become a large organization, it may not produce fundamentally good science.

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Soviet Union

YURIY A. OSIPYAN

Vice-President, Academy of Sciences of the U.S.S.R.

The world is very interested in what is going on in the Soviet Union right now. It is hard to say whether the movement is from east to west or from west to east; it is not easy to distinguish.

It seems to me that it is best to begin by explaining briefly—and roughly— what is going on in my country. First, I would like to characterize the general situation for scientific R&D in the Soviet Union. I am not going to provide figures for current expenditures; I think my colleague, Dr. Ezhkov, who is vice-chairman of a state committee for science and technology, can provide more precise data on this matter. Instead, I would like to speak about the big transitions in my country and what they mean for us: for scientists and for people involved in science and technology. I should start by considering the situation about five years ago, before the Gorbachev reforms began.

First, I think the main feature of science and technology in the Soviet Union has been the Academy of Sciences of the Soviet Union. The Academy of Sciences is a unique organization—sort of a combination of a scientific society and a ministry for fundamental research. I think this is more or less similar to the situation in West Germany, where there are very powerful research organizations such as the Max Planck Society, that have many laboratories and institutions oriented toward research without any teaching duties. In the Academy of Sciences we have about the same number of people as we had about five years ago: 350,000. There are 60,000 Ph.Ds working for the Academy of Sciences, and the Academy comprises about 500 research institutes and research laboratories.

It is impossible, of course, to discuss the subject, but we can easily conclude that the Academy is a little bit overstaffed. However, the Academy has a high reputation in basic or fundamental research, and it has a lot of first-class scientific organizations that compare very well with the best Western organizations.

Second, I should point out that Soviet universities do not play so important a role in research as the Academy of Sciences. If you try to compare the university situation in the Soviet Union to that of the Western world, it is impossible. We have very few excellent universities with a very high scientific reputation like Moscow State University, Leningrad State University, or Kiev. There are very few—only enough to count on one hand.

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The provincial universities in the Soviet Union are very poor, both in the staff's qualifications and in facilities.

A third aspect I would like to mention is that we have a number of very good research organizations doing basic research in industry. A good example is the Atomic Commission of the Soviet Union. I should stress that these organizations are doing mainly fundamental research in such areas as elementary particle physics and high energy physics. We also have good organizations in the Ministry of Electronics, including a research center conducting microelectronics research. In chemistry I could mention the Karpov Institute.

Now I would like to explain our applied research organizations and the system of management in applied research. For a very long time, since just after World War II, we developed a very inflexible system of managing applied research in the Soviet Union. It was a very administrative system. For example, there was recently a special decision made by the Politburo of the Communist Party; the details of this general decision were filled in by a special governmental body under the Council of Ministers. This very detailed plan dictated what we had to do, where we had to do it, and who was obliged to do this and to do that—taking into account every necessary detail. This sort of detail is very characteristic of an administrative system.

We have declared movement to a market economy and to market-type relationships among science and technology, research, development, manufacturing, trade, and so on. But it is not enough to declare it; it is necessary to build a new system.

In this way we did all that was accomplished in atomic energy and in space research. The system worked rather well, and there was no problem with money. A very large amount of money from the state's budget was allocated for space research, atomic research, and defense industries, with the result that in atomic energy, in space research, in some aspects of the defense industry, and in special fields of chemistry and biology, we were in a rather good position for a long time.

Then, about five years ago, Gorbachev came into power and, with so-called perestroika, started restructuring. The first three years was a very happy time for us. Indeed, we were in euphoria. The first acts of the Gorbachev government were very attractive, both in foreign policy and in the reconstruction of the social and political atmosphere in my country. People got freedom to a large degree.

But in the economy—what has happened in the economy? We have destroyed the administrative systems, but we have created nothing to take their place. This is very characteristic of the present moment. We have declared movement to a market economy and to market-type relationships among science and technology, research, development, manufacturing, trade, and so on. But it is not enough to declare it; it is necessary to build a new system. There is a lot of talk about Gorbachev being right, wrong, or whatever. But as scientists, you can understand clearly that for a big and heterogenous system like the Soviet system, it is not so easy to have a straight line of transformation.

We are facing many problems now, including ethnic problems, many economic problems, and many other kinds of problems as well. For in

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stance, we were very happy about transforming to democracy. But what does democracy mean now for the Soviet Union? I can say that we now have a very high degree of democracy; maybe we have a little more than necessary. For instance, even in the Academy of Sciences and in other scientific institutes, we have to elect everybody, including the director. I remember the old joke about passengers getting on an airplane and the flight attendant opening a general meeting to elect the pilot. I think that is an appropriate metaphor of our present situation.

What we have now is the whole system of administrative management destroyed.

I do not want to dwell on the political aspect of our life, but there are a lot of rumors about what has happened: we have turned to the right—from democracy to dictatorship and so on. The people want to live an ordered life. But, nowadays, practically everything is destroyed—industry, agriculture, all aspects of the economy. Of course, there are many possible ways out of the situation, but I think it is a special problem—not my field, of course, for I am a physicist. In any case, I would like to say that Mr. Gorbachev himself has great respect for the scientific community and scientists, and he invites them to participate in all stages of decisionmaking. But there are so many different views now, it is not so easy to come to a conclusion.

Now I would like to explain a little about applied research and technology transfer. What we have now is the whole system of administrative management destroyed. Members of the scientific community who penetrate to the top level still can get guarantees for basic fundamental research— enough money to be in a stable position. But for people from applied research areas—you have to understand that it is not so easy to guarantee subsidies for activities as big as applied research is in my country. We are facing very great difficulties in supporting applied research of a scale necessary.

Of course, in applied research we also find such situations as overstaffing. But the main problem is not the efficiency of people or the efficiency of institutes or laboratories; the problem is the cuts in money allocated. The government has now decided to support this big area with subsidies from a special fund for the coming two or three years—to support laboratories and institutes doing applied research and making technology transfers to industry.

What we need now is a completely different kind of action in the fields of fundamental research and applied research.

I think everybody knows that Soviet industry for a very long time was absolutely uninterested in accepting new technology. We could do it only under pressure, by special directives from the top level of government. Now we are trying to move to a market economy, and all manufacturers and factories, as well as some other organizations, have decided not to pay for R&D. They have no motivation to pay. They want only to continue their old-fashioned production, and they have no motivation at all to produce new products, especially with high-tech methods.

This is the present situation. What we need now is a completely different kind of action in the fields of fundamental research and applied research. This past summer a very important act was signed by President Gorbachev concerning the Academy of Sciences. The act made the Academy of Sciences of the Soviet Union a private, self-ruling organization,

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independent of the government, which I believe is an extremely important decision for us.

Living conditions and research conditions in the Soviet Union are much worse than those in the West.

Now we are free, practically and formally, from any obligation to respond to directives from above. I have worked for the Academy of Sciences for over 30 years, and I remember very well many directives from above to do this, or that, in chemistry, biology, genetics and so on, and to do some kind of defense research. The Academy was obliged to a very large degree to do many things for the defense industry. Now we are free to make our own decisions. If we need some additional money, we can ask industry to pay and set up a contract to establish a special relationship. But we have got 1.5 billion rubles this year for so-called basic financing.

What, then, is the system? In the law signed by Gorbachev this summer were three major points. First, the Academy of Sciences is now an independent, self-governing organization. Second, nobody from above— party, government, or other political organization—can try to press the Academy by directives. Third, a new foundation has been established, so we now have a national or all-union foundation for fundamental research. This year the foundation has 3.2 billion rubles to distribute among academies, universities, and others in the scientific community so that everybody, including individuals, small groups, large groups, institutes, and laboratories can apply for money in a system very similar to that of the National Science Foundation.

Thus, we have two parallel systems. The first is the budgeting of the Academy of Sciences and the academies of the national republics, without any preconditions, for fundamental research. The money is distributed, not to the projects, but directly to institutes and Academy divisions. The second system is along the lines of the National Science Foundation of the United States—that is, it concerns grants and referees. It seems to us that we are very lucky to have a well-balanced system, and we will develop it carefully along these lines during the coming three to five years.

So the system of allocating money for fundamental research is in good shape, but, of course, we have another critical problem, and that is brain drain. Living conditions and research conditions in the Soviet Union are much worse than those in the West. For example, the President of the Soviet Union makes 4,000 rubles a month or 48,000 rubles per year. The black market ratio is 25 rubles to a dollar, so you can work out the numbers. The director of a big institute with 1,000 employees has a monthly salary of about 1,000 rubles—12,000 per year. Because people have freedom now, they can travel and they can apply for positions in the United States and in western Europe. With conditions as they are, many have the desire to leave.

But that is not the only reason for the brain drain; I think a more important reason concerns research conditions. An experiment that takes about one month to do in the United States takes about one year in the Soviet Union, on average, for there are the problems of computing, of experimental facilities, of service, and of getting materials in the Soviet Union.

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I am not going into the political, social, and ethnic problems we have to solve. But I must say that this brain drain away from the Soviet Union to the Western world is a very dramatic process, and I believe it is much more important in the Soviet Union than in eastern Germany. Not only can we lose our scientific potential but we can lose our best people, and this drain can have a dramatic effect on the general atmosphere of the country. At present we still have choices about which way we will go, but if we lose our best people, we may lose the ability to go in the right direction.

As for applied research and technology transfer, of the many issues I could discuss, I address just two. The first is the special need to form a link between the Western world and our defense industry. Our defense industry is very capable and very much able to be integrated in the market economy because of its relatively high technological level. I think it is especially important to discuss ways in which we can do this. The people from the defense industry were put into a box for a long time, and they also want to be free now. They have a taste of freedom already, and they are, on average, very good people who could be very useful in the course of the main stream.

Not only can we lose our scientific potential but we can lose our best people, and this drain can have a dramatic effect on the general atmosphere of the country. At present we still have choices about which way we will go, but if we lose our best people, we may lose the ability to go in the right direction.

Second, I suggest for discussion the possibility of establishing not only offices of Western companies in Moscow and Leningrad but research organizations as well—research laboratories and institutions owned by Western companies and employing Russian people. For instance, IBM has good divisions in Europe; if such companies as IBM and IT&T were to establish scientific institutes in Moscow, they would provide the opportunity to employ very good people and would provide the chance to retrain many people doing applied research.

VLADIMIR V. EZHKOV

Deputy Chairman, U.S.S.R. State Committee on Science and Technology

I would like to make some comments on the problems of the Soviet Union's scientific and technical policies. First, I would like to give you some numbers concerning the outlays of the Soviet government for science. This year alone science expenditures from all sources will total about 68 billion rubles. Approximately 28 billion of that will come straight from the state budget, 1.5 billion of which will go to the Academy of Sciences and 12.5 billion of which is proposed to go to the development of military science (this figure is somewhat lower than last year's figure for military science and technology). About 6 billion rubles will go to the U.S.S.R. State Committee on Science and Technology for several priority sectors in civilian R&D. And, for the first time, there is a new article in our state budget this year: 8 billion rubles will go toward the conversion of military research and design institutions to civilian use.

The first priority for the money that the State Committee on Science and Technology receives is state-funded research projects. In 1988 there were 14 such specific research programs identified, and four more were added

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this year. As for the specific content of these programs, it pretty much follows the sort of things one would expect to be developed in most of the countries of the world. In choosing the specific directions of these programs, one criterion we followed was that they should answer in some manner to the global problems of mankind. We view these programs as a basis for potential international cooperation, which would allow us all to develop even more research in these areas and to conserve research brain power, thus avoiding redundancy around the world.

Of course, some of these state programs are very specific to our country. For example, there is a program on highly efficient food production, which is a question that has probably been resolved in many countries of the world but for which we need a program. I want to underline the definite social emphasis in the development of these programs.

One thing that we have noticed in our country is that pure science has been torn away from the human factor —from peoples' needs. These programs about which I speak go in a new direction for us—they are socially oriented. Socially oriented science is something that has existed in other countries but not so much in our country. It is qualitatively new for us.

One problem that exists is a sort of scientific monopolism that has developed in our country, which at times impedes the selection of the best people for a given project.

I do not have the time, of course, to go into detail on all of these programs, but I do want to mention that the selection of the projects was done on a competitive basis. Today, under the umbrella of these programs, we are working on something along the lines of 1,500 individual research projects that were selected from among 11,000 entrants into the competition. Among the majority that were not chosen, there were very many that were of very good quality; these were not rejected because they were bad-quality projects but simply because of the lack of funding.

I do not want you to get the idea from my talk that everything being done under the aegis of the state science programs is going perfectly well. One problem that exists is a sort of scientific monopolism that has developed in our country, which at times impedes the selection of the best people for a given project. Sometimes unfortunate things happen, as when the same people get money for specific projects that would have gotten money from some other source anyway. One way in which I see we can achieve the proper decisions might be through the invitation of the international community to participate in these projects. I think that this is a field in which there are broad opportunities for collaboration.

A third item that I would like to touch upon is the legislative support for scientific and technical progress in the country. This morning, Mr. Pandolfi of the European Community mentioned that there is a series of legislation supporting scientific research within the European Community. Unfortunately, I could not name for you a parallel item of legislation in the Soviet Union—one that outlines the competence and the authority of a particular scientific institution or particular organs and so forth for scientific research. Unfortunately, until now, the entire process of directing sci

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entific research was done through the government or through such organizations as the Politburo.

As we strive toward the achievement of a legally based social system in our country, we realize that we need a legislative foundation for scientific and technical progress.

Now, as we strive toward the achievement of a legally based social system in our country, we realize that we need a legislative foundation for scientific and technical progress. As a result, at this point there is a great deal of draft legislation in various stages of development. Some of it is still in the project phase; some of it has been introduced already in the Supreme Soviet.

The one piece of draft legislation that has made it to the Supreme Soviet is the draft law on inventions. This draft law guarantees the author's full rights to intellectual property: either a process or an invention created by an individual. It would be hard to overestimate the impact of such a law because its absence has a profound negative effect on the development of international scientific cooperation.

Another direction for possible collaboration with the Soviet scientific and technical community might be in assisting in the development of an appropriate legislative base, because the only way that we can enter the world scientific community is through legal mechanisms.

DISCUSSION

***Question*:** Perhaps you could take another minute to say something both about the Russian Academy of Science and the emerging academies of other republics and about the cooperative sector in scientific research, the private sector.

***Academician Osipyan*:** First of all, I would like to say that we have academies in all national republics except the Russian republic. The Academy of Sciences of the Soviet Union draws 95 percent of its members from the Russian republic; 99 percent of the Academy's laboratories and institutions are in the Russian republic. Practically, it acts as the Academy of Sciences of Russia. But, nevertheless, the Russian republic should have its own academy, in addition to the Academy of Sciences.

The only way that we can enter the world scientific community is through legal mechanisms.

I think there are two reasons it should. First, there are so many eminent scientists who have no chance to enter the Academy because its size is very much limited; there has been a struggle to create additional places for the election of more candidates. The second reason is purely administrative; the Russian government would like to have its own academy to manage or manipulate.

***Dr. Ezhkov*:** Let me say a word or two about scientific cooperatives. They have begun to function very efficiently. I don't have the exact figure, but, roughly speaking, I know that the entire volume of scientific works published or created by the cooperative sector last year equaled the volume

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of works published within the official institutions of higher education: universities, colleges, and institutes.

But such a tumultuous growth of scientific cooperatives has raised certain problems. One of the biggest problems is that the workers of a scientific research institute may work on their own projects, using the physical plant, equipment, and materials of that institute. Using the brain power of the institute, of members of the institute who are not members of their cooperative, they may come up with research results at the expense of the institute but in the name of the cooperative, thus diminishing the institute as an institution. This particular problem is not yet regulated by legislation. It is not against the law.

***Question*:** I am interested in the 18 special programs that you have launched. You represent them as being the basis for international cooperation. Do you have any specific mechanisms, plans, or procedures in place for connecting those with international activities of any sort? In other words, how are you going to exploit the international cooperation in those programs?

***Academician Osipyan*:** To manage international cooperation you need hard currency. Under the current system, if you have a budget for a state program, you get a very small additional part paid in hard currency from the state budget. It is the only means of organizing international cooperation. A program I work with, for example, is funded with 30 million rubles per year, including just $100,000 in hard currency. We spent practically all that money sending people to participate in international conferences.

Another example is a high energy physics program. This is traditionally big science, with a very high level of international cooperation. But we have to be very sharp at creating opportunities. For instance, we have spent our rubles with Soviet industry to produce superconducting wire, and we are going to send this wire to Dallas. In return, we hope to get back some hard currency to use for international cooperation.

***Question*:** I am interested particularly in the 1,500 projects selected from 11,000 applications. You mentioned that they came from many sources; where primarily are these grant requests coming from? And has there been great pressure to improve that ratio?

***Dr. Ezhkov*:** We do not discriminate between proposals from the state sector or the cooperative sector. A large number of the projects that we fund are Academy of Sciences institutions. But this also includes cooperatives and so forth.

The current projects, the ones that are ongoing, are not stagnant. They are being reviewed constantly by scientific committees and so forth. Academician Osipyan, in fact, had one such committee. So they are constantly in a state of flux as to who is actually in the project.

As for future competition, I personally feel it would be wrong to limit participation. I think we ought to disseminate information about them more widely and invite as many applications as possible. Of course, that complicates the actual decisionmaking process, but this is only an administrative question.

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JAPAN

JIRO KONDO

President, Science Council of Japan

Japan is now spending about 3 percent of its GNP on R&D; 80 percent of the money comes from the private sector and 20 percent from government. Of the money spent, 10 percent goes to the universities, and another 10 percent goes to government-established institutions.

> ***Because the number of public universities has now increased to 99, the government budget has been diluted in order to allocate to each new university. Therefore, we have the feeling that the university situation in Japan is becoming very bad. We must admit to ourselves the need to establish some centers of excellence among our universities.***

These figures indicate, as it is sometimes said, that Japan is spending its money mostly on applied science, and is spending only a very small amount of money on basic science. However, the situation is now changing. One example of this change is that the big steel industries recently established a laboratory for applied biology—for biotechnology. I do not think that microbiology can make steel, but this is the situation, and it shows that when a big industry has the money, it may choose to directly invest the money in basic science. Not all of them do, but the Japanese attitude toward science is now changing.

We established the oldest university in Japan, the University of Tokyo, in 1878 in order to build a focal point for the introduction of Western civilization. When we opened our country in the middle of the last century, we were very much surprised. It was about a century after the Industrial Revolution, and we were surprised at the progress of science and technology in the Western world. Therefore, we needed some point for introducing this progress into our country, so Tokyo University was established.

For a long time Japan had only seven big national universities. But today, we have 460 institutions of higher education, a number that has increased by about 10 times since before the Second World War. This indicates obviously that, after the war, development of higher education in Japan progressed very rapidly, and this is one reason why Japan's economy has expanded so quickly.

The number is now leveling off because the size of the population has become somewhat stable. In the future, because of the decreasing birth rate, we will have some difficulty getting good students at the university level. Furthermore, because the number of public universities has now increased to 99 (whereas before the war, as I said before, we had only seven), the government budget has been diluted in order to allocate to each new university. Therefore, we have the feeling that the university situation in Japan is becoming very bad. We must admit to ourselves the need to establish some centers of excellence among our universities.

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How we can cope with this situation? It is rather difficult in Japanese universities to get funds from the private sector, for most universities are government establishments. All professors are government employees, and they are not permitted to receive money from the private sector. They cannot use such money as their own salary, to support their family. Therefore, university professors are not very aggressive about getting funds from the private sector. However, in some particular places that we call centers of excellence—for example, at the University of Tokyo we recently established a research center for advanced science and technology—we can introduce funding from industries. These we call crown professorships. We can attract universities in order to do some particular research, and we can obtain and use private money.

It is rather difficult in Japanese universities to get funds from the private sector, for most universities are government establishments.

The Ministry of Education has allocated funds to some particular places called institutes for common use. Common use means the university professors can use the facility. The KEK laboratory at Tsukuba is one example. Also, we are planning to build an astronomical observatory in Mauna Keya with a telescope 7.5 meters in diameter, called the Japanese National Large Telescope. It is not possible to distribute such a facility among colleges or universities, but by accumulating a large amount of funds and then setting up the facility in a particular place, we can establish a new center of excellence. Other ministries, such as agriculture, forest and fisheries, would like to establish other institutes as centers of excellence.

In the future, maybe up to the year 2010, what will be some of the main subjects for Japanese scientists? It is very hard to predict the progress of science. However, I think one important trend is research on the environment. I believe that global environmental issues will continue for a long time. Next year, we will have in Brazil a world congress on environment and development. Since the Persian Gulf war, we have been faced with widespread damage to the environment in the Middle East region. We need environmental research on these problems, and we also need to find a way to cope with global warming—a very big issue.

I have been appointed as director-general of a new organization, called RITE (Research Institute for Innovative Technology for the Earth). This institute was established last July; as yet we do not have any laboratories, but they will be located near the city of Kyoto. An example of an idea being explored at RITE is the development of a process that would remove carbon dioxide from exhaust gases and convert it into methanol by adding hydrogen.

We also have another program that involves introducing sunlight by means of optical fibers and using the photosynthesis of microorganisms that we think can absorb carbon dioxide. We have already discovered useful marine microorganisms that can absorb a large amount of carbon dioxide. Another research program will look for a new generation of refrigerant to substitute for CFCs.

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If the environment is one direction for future research, energy is another. We are very much interested in the international thermonuclear experimental reactors (ITER), and we will collaborate with the main industrialized countries to build them. Another issue that we are very much concerned about is how to transfer our technology to the developing countries.

MAKOTO KIKUCHI

Executive Technical Advisor, Sony Corporation; Professor of Electronics, Tokai University

The other speakers at this symposium have given you a bird's-eye view of science and technology policy. I, however, because of my background, cannot give you a bird's-eye view; I can give you only a worm's-eye view that is based on my understanding through my own experience in 40 years of working on semiconductor devices and electronics.

The Electronics Revolution

I think it is very important to identify or recognize the historical position of electronic technology right now. Modern electronic technology started from the invention of the transistor in 1947 and in only 20 years created a revolution. The revolution changed almost everything because it involved a new concept, quite different from the concept of vacuum tubes. In recent years, however, the change has slowed down, and we are coming into a pattern of steady evolution.

Therefore, we now have two different tasks. The first is how to contribute to this steady evolution. The second is how to prepare for the next possible breakthrough. Over the next 10 to 15 years, I think three areas will provide important foundation stones for new electronic technologies. These are further progress in very large scale integration (VLSI), optoelectronics (the use of lasers in electronic circuits), and software.

If we break down just the first one, the progress of VLSI, we can identify three different fields. The first is higher capacity: how we can put more and more transistors or elements on one chip. This will be influenced by improved silicon technology and computer-assisted design (CAD) and simulation. A second way to improve VLSI is by developing higher-speed devices, perhaps through new types of semiconductor compounds, such as gallium arsenide. The third avenue for improvement is higher reliability with lower cost; this is related to the further progress in process technologies.

> ***We now have two different tasks. The first is how to contribute to this steady evolution. The second is how to prepare for the next possible breakthrough.***

To prepare for future breakthroughs, we must meet some challenges. I believe two are vitally important. The first is to come up with brand new ideas for devices—new concepts. The second is to develop some new or unknown material. For example, when I graduated from university in 1948, semiconductors were an unknown kind of material; now they are really

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well known. If we want to talk about future breakthroughs, we must look for unknown materials and try to understand them.

Next Generation Technology

In Japan the next generation of basic technology is being addressed by some programs sponsored by the Ministry for International Trade and Industry (MITI). Topics include superconductive materials and devices, which started in 1988, photoreactive materials, and so on. I would like to mention something here about the mechanism of setting up projects related to MITI, because I feel there is often some overreaction or some misunderstanding among my American and European friends about how these things go.

The present is a very interesting time in the history of science and technology because feedback from technology to science is taking place.

As an example, I will talk about some of the interesting tasks now being tackled by Japanese scientists and engineers. A symposium on future electronic devices was sponsored by an association that is not purely government, but is, instead, between government and private industry. This symposium was sponsored as well by the Japan Industry Technological Association, another half-government association, and by the Agency of Industrial Science and Technology, again belonging to MITI. That was the ninth symposium held in 1990, for which I gave the keynote address. That organization also sponsored a workshop on future electronic devices in 1989, covering advanced crystal growth, characterization of microstructure, and other fine process technology.

Now I would like to mention my own views. I think the present is a very interesting time in the history of science and technology because feedback from technology to science is taking place. We have such experience — feedback from technology to science—in the history of science. For example, the technology of the telescope opened a new field in astronomy; likewise, the development of the microscope opened a new field in biology. That was feedback from technology to science. In the field of electronics, process technology is now giving tremendous feedback to the physics of new material and structures. One new technology being used in experiments performed in many universities and laboratories is the making of crystals in atomic dimensions by stacking atoms. As you remember, in 1955 Bell Laboratories developed solid-state diffusion, for the first time in history producing control on the order of one micron. But now, with the new technology, you can control on the order of angstroms—you can really control the stacking of atoms.

This makes it possible for us to produce superstructures or superlattices. In this way we are creating semiconductor lasers, high-speed transistors, and MQW devices, and we are trying many other things as well. Moreover, we are now facing an interesting step in the physics of integration. More and more transistors are now put on the same chip, so you can understand that the distance between electrodes is becoming more and more reduced. Indeed, the distance between electrodes has become submicron in these days.

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Submicron distances have affected the fundamental current equation for semiconductors. This equation will not hold anymore, for it is based on many collisions over greater distances. This was formerly the ordinary condition, but now electrons can jump directly into the different electrodes, which are closely spaced.

The fundamental mechanism is changing, and the wave nature of electrons is now coming into practice. An example is the scanning tunneling microscope, which lets us see each atom. So, in this way, we are now doing research on so-called nano-devices or mesoscopic devices. It is a fundamental idea, and that is why we are trying to work with it: to take a first half-step into the new physics.

In another area altogether, many of my friends in Japan hope to learn from biosystems. There are many different kinds of expressions, and there are many different kinds of challenges. But the fundamental point of view is that there is a great deal to learn from biosystems. They depend essentially on the nature of biology, but we can transfer fundamental mechanisms to electronic systems. This is the basis for biochips and neurodevices.

These projects are supported fully or partly by the government through three different channels. In many cases MITI does not directly give financial support to someone or to some company. There are classifications of national support, but I am concerned with big-scale R&D-type projects. In these cases, as I mentioned before, we have an intermediate step called an association—between MITI and the working research group. The head of the association comes from MITI—which can be a problem, but if the association can match the technological challenge, it can do some good. It depends on the particular case.

The second source or means of support is the Ministry of Education. In this case the ministry supports a project by directly supporting an individual professor at the university. The third and final method of support is the Agency of Science and Technology, which is more biased toward so-called fundamental research and gives more freedom to the group leader. In most cases, the group leaders are from the university.

The amount of support also depends on the particular situation. In some cases the project is support 100 percent by the government. Such was the case for Next Generation Industrial Technology, begun by MITI in 1981. Another example is the International Human Frontier project, which is very fundamental work actually done in the RIKEN Institute of Chemical Science. The project invites very prominent foreign scientists to head the effort. Other projects, however, are supported at 70 percent or lower, depending on the circumstances. You should also understand that this support by the government is not a large portion of the budget. Here is an example: at Sony's research center, we are talking about optical memory related to next generation basic technology. We have accepted 15 million yen per year for five years. Another area is superstructure devices; for 10 years we have about 15 million yen.

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Basic Research in Japan

There is a lot of discussion that we Japanese are very strong in applied research but very poor in fundamental research. When my friends discuss this, I raise an objection to the idea. I do not believe that fundamental research and applied research are two distinct concepts. I see them instead as opposite ends of a continuous spectrum. That is my principle; even in presiding at my research center at Sony for 15 years, I treated everything on that spectrum.

> ***Right after the war, Japan had an imbalance toward the applied research side of the spectrum because we were very poor. But as our income grew, we began to extend the tail of the applied research toward the fundamental side of the spectrum. It goes slowly, and takes a long time, but I believe it is happening.***

An example of this can be seen in the case of the CCD that is used in the video cameras now being sold. CCD projects started in Sony in 1970. The first product came out in 1980, so it took 10 years to complete. In the early days of the CCD projects, we suffered from defects in the final picture, which resulted from crystal defects formed during the oxidation process. Because of this, I pulled the project away from the applied end of the spectrum to the fundamental research end. I let the physicists work on that end for 2 1/2 years to check the fundamental nature of this defect. After that, we could get good results, so I put the project back to the applied research side and returned it to the semiconductor group in Sony.

Therefore, I think we should treat Japan's situation in terms of that continuous spectrum. Right after the war, Japan had an imbalance toward the applied research side of the spectrum because we were very poor. But as our income grew, we began to extend the tail of the applied research toward the fundamental side of the spectrum. It goes slowly, and takes a long time, but I believe it is happening.

DISCUSSION

***Question*:** It turns out that 80 percent of all R&D in Japan is privately financed. I wonder whether you could tell us something about what it is that Japan is doing to provide private industry with the incentive to support such a large fraction of all R&D spending.

***Dr. Kondo*:** MITI is in charge of the development of Japanese industry. Let me give one example: chips for electronic devices. I think now most people feel that large memory chips are manufactured in Japan. But in the beginning the risk was very high, and, therefore, private industries could not afford to proceed by themselves. MITI organized a kind of association, and in this association the risk was taken by the government. When such an association is successful at good quality production, then MITI pulls back and lets them go.

I can give another, but opposite, example: production of large aircraft in Japan. We have manufactured aircraft successfully, but because the risk is so great, private companies are very much afraid to step in. The government is also very much afraid of the risk. So when it came to building the

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next generation of passenger jets, we decided that it might be safer to collaborate with Boeing. This is another example. One is more successful, the other one not successful.

I think that sometimes Japan is criticized for "buying brains" outside of our country. However, we do this because Japanese universities are not so cooperative with industry. Faculty have not been permitted to accept outside funds. But the situation is now changing.

***Question*:** Japanese firms show great interest in supporting foreign research and apparently only a modest interest in supporting research in the academic institutions at home. Does this indicate some continuing lack of confidence in Japanese research capabilities?

***Dr. Kondo*:** I think that sometimes Japan is criticized for "buying brains" outside of our country. However, we do this because Japanese universities are not so cooperative with industry. As I said before, faculty have not been permitted to accept outside funds. But the situation is now changing. I believe that, in the future, Japanese industry will distribute funds not only outside our country but also inside our country.

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UNITED STATES

D. ALLAN BROMLEY

Assistant to the President for Science and Technology; Director of the Office of Science and Technology Policy

As part of this symposium, we have been asked to look at the future of the research policies within each of our countries. In taking on this assignment, I am ever mindful of the Chinese proverb "prediction is a difficult art —particularly when applied to the future." I am also sure that the only absolutely valid prediction I can make is that I will miss many important developments entirely. Who would have predicted a year ago, for example, that the Gramm-Rudman budget law would be a thing of the past, that the international scene would have changed as dramatically as it has, and that the United States would be at war?

But the long-term future is an important consideration of the Office of Science and Technology Policy (OSTP). In my confirmation hearings I stated that a major strength of many of our friendly competitors lies in their ability to maintain a longer-range perspective in business, in academic institutions, and in government than we do. We in the United States need to develop a longer-range strategic vision of science and technology and of their present and potential contributions to economic growth, the quality of our lives, and national security.

We in the United States need to develop a longer-range strategic vision of science and technology and of their present and potential contributions to economic growth, the quality of our lives, and national security.

I have been very fortunate in that regard, because the Bush administration is committed to making the investments necessary to ensure the vitality of the United States through the 1990s and into the twenty-first century. In particular, the administration is strongly committed to increasing support of R&D, because we believe that investments in R&D can be expected to pay themselves back many times over. This is why the Bush administration proposed to increase federal funding for R&D by 13 percent— to over $75 billion—in the budget submitted to Congress three weeks ago.

As you well know, divining the long-term future of federal science and technology policy from a single year's budget document is something like trying to figure out the plot of a movie from a single still photograph. Nevertheless, if the still has all of the movie's characters in it, perhaps the plot can be explained. So let me start by talking about the budget and about some of the thinking that went into it. Then I shall discuss some of the long-term planning that is entering into the formulation of the administration's science and technology policy.

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Basic Research

One of the most important areas of emphasis in the Fiscal Year 1992 budget is basic research. Basic research accounts for less than 10 percent of all the R&D done in the United States. But basic research, and particularly the large fraction of basic research done by individual investigators in universities and colleges, is the wellspring from which new knowledge and technical advances flow, not only in the United States but around the world.

Recognizing the many essential contributions of basic research to our national future, the Fiscal Year 1992 budget proposes actions in several federal agencies designed to strengthen the individual and small group investigator component of the scientific enterprise. At the National Science Foundation (NSF) the budget proposes an 18 percent increase, which would get the NSF back on the doubling track established by President Reagan and supported by President Bush.

In the United States the challenge increasingly is to find ways to exploit more effectively and efficiently the results of basic research, whether it is done here or elsewhere.

At the National Institutes of Health (NIH), the budget proposes an increase of 6 percent—to almost $9 billion. Because of the way this increase is structured, it would allow for an increase of 9 percent in NIH's funding for research project grants awarded to individual investigators.

Together, NSF and NIH support over half of the federally funded basic research done in the United States and over 75 percent of the federally funded basic research done in universities. By focusing special attention on these agencies, the administration plans to strengthen the individual investigator and small group research that remains the heart and backbone of American science and technology.

Yet it should be remembered that we will never fully satisfy the needs of university researchers for funds; nor should we. Competition remains an indispensable part of a system based on excellence. The challenge is to balance competition with the needs of the nation and with the many opportunities that now exist within science.

Technology Development

I have been focusing on basic research thus far, but, clearly, basic research cannot be the only component of a nation's R&D enterprise. Many nations have R&D enterprises of great value that include very little basic research. Indeed, in the United States the challenge increasingly is to find ways to exploit more effectively and efficiently the results of basic research, whether it is done here or elsewhere.

Our international trading partners have forged very strong links between government and industry. They have put public and private funds into targeted programs that reduce the risk of technology development. These funds lower the cost to each participant and make it easier to compete. If the United States is to compete in such a marketplace, we cannot force each individual company to reinvent the technological wheel. Rather, the government must act as a catalyst, with federal funding if appropriate, to combine the very real strengths apparent in each component of our R&D enterprise.

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Our challenge is to involve these [federal] laboratories in a much-discussed but all-too-infrequently realized partnership with universities and industry so that the laboratories can play a more effective role in supporting U.S. economic competitiveness in the international marketplace.

In this country, in addition to our university researchers and those researchers in industry, we have an enormous national resource in the professional talent, know-how, and science and technology resident in the 726 federal laboratories. Most of these laboratories were established in the immediate post-World War H period, with very specific missions and objectives, many of which were satisfied years ago. Many of these federal laboratories now lack clearly defined objectives, although some have been able to keep their programs in close touch with national needs. Our challenge is to involve these [federal] laboratories in a much-discussed but all-too-in-frequently realized partnership with universities and industry so that the laboratories can play a more effective role in supporting U.S. economic competitiveness in the international marketplace.

Competitiveness and the power of partnerships are leading considerations in one of the presidential initiatives in the FY 1992 budget: high-performance computing and communications. The President has proposed a 30 percent increase—to a total of $638 million—for an interagency effort designed to extend U.S. leadership in all advanced areas of high-performance computing and networking. The program underlying this initiative has been put together by the Committee on Physical, Mathematical and Engineering Sciences under the Federal Coordinating Council for Science, Engineering and Technology (FCCSET), which is the Cabinet-level group in the federal government responsible for coordinating and implementing federal science and technology policy.

Part of this program consists of basic research at the nation's universities designed to develop the hardware, software, networks, and human resources needed to ensure American leadership in all advanced areas of high-performance computing and networking. An additional and very important component of the program consists of applied research and the development of generic, precompetitive technologies that will form the basis for tomorrow's computer and communications industries. This work involves both the national laboratories and the computer and communications industries, and it promises to provide an excellent example of what can be accomplished in the kind of partnerships I have just mentioned.

The budget includes increased funding for a number of other areas of technology development, including energy technologies, biotechnology, advanced manufacturing and materials, and aeronautics. In fact, the budget itself goes so far as to state that it is providing increased funding "for all major civilian applied research and development areas." This is a very important indication of future directions in federal R&D. In addition to supporting a strong program of basic research, the federal government intends to support the technologies that will be crucial to meet national needs.

The Organization of Applied R&D

However, an important factor in that support is the way in which the federal government structures its support. The technology initiatives cited

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above tend to be most effective when pursued through collaborative, cost-shared efforts among government, industry, and universities. In the past, as I have just noted, there has been much discussion of partnerships but not much action. More recently, however, all sectors of the R&D enterprise have become aware of the problem and have demonstrated their willingness to take action.

This is a process frequently defined as "technology transfer." I have become convinced, however, that the only effective transfer occurs when the technologies are carried in the minds of trained individuals moving from one organization to another. As a result, I believe that substantially increased mobility among our research personnel—both basic and applied and both short and long term—is essential.

Equally important, I believe that potential users must be more involved in the launching of laboratory programs than is now the case. I am convinced that groups of knowledgeable industrial and university scientists, meeting with laboratory management and senior scientists and engineers, can add a very important new dimension to the selection of program emphases and priorities—at the outset—with the laboratories. In so doing, this process will lead to significantly improved coupling throughout the research programs and in the use of their outputs.

The only effective transfer occurs when the technologies are carried in the minds of trained individuals moving from one organization to another. As a result, I believe that substantially increased mobility among our research personnel both basic and applied and both short and long term—is essential.

Another good example of a partnership among government, industry, and universities is SEMATECH. Increases in productivity brought about through SEMATECH's R&D directly benefit the computer industry and will lead the way to new generations of technology. These increases in productivity also have important indirect benefits to other companies through the provision of more powerful, cheaper, and more reliable computing power. This is the kind of external return that offers a powerful argument for partnerships involving more than just industrial researchers.

Another partnership example is a new venture involving the Department of Energy, Ford, General Motors, Chrysler, and the Electric Power Research Institute (EPRI) on R&D on batteries for electric vehicles. We are within a factor of two of having batteries with the lifetime, energy density, and charging characteristics required for truly viable electric vehicles. By leveraging the knowledge and expertise of the private sector with governmental and university inputs, great progress can be made.

In parallel with the efforts to find more effective ways of organizing technology development, the administration is acting to improve coordination among the federal agencies that support this work. Part of this coordination work is being done through FCCSET. Following its reorganization and revitalization last year, FCCSET has initiated and extended a number of activities in high-priority, crosscutting areas of science and technology. Over the last year, FCCSET has conducted such analyses in the areas of education and human resources, global change, and high-performance computing and communications, and it plans to call for new areas to be added to this list over the next year.

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In addition, the National Critical Technologies Panel, formed under the auspices of OSTP, has been examining technologies important to the future economic health and national security of the United States. The Critical Technologies Institute, which OSTP is in the process of establishing as directed by Congress, will assist in the development of strategies that will follow up on the panel's work in these critical areas.

Finally, the President's Council of Advisors on Science and Technology (PCAST) has been meeting monthly with the President and with senior members of the White House staff for much of the last year. PCAST has helped to bring the private sector's perspective to the federal science and technology policy process at the highest level, and the deliberations of this group are having an important influence on federal science and technology policy.

It is vitally important for us to recognize at all times that the federal government is only one of the players in the research enterprise. It does have a powerful influence on that enterprise, but it is limited in many of the things that it can do. It is important that those limitations, just as much as the opportunities be recognized.

Conclusion

These, then, are some of the institutions that will be shaping federal science and technology policy over the next few years. But, of course, the policy itself is in a state of constant flux, for the world is changing with unprecedented speed, and an unchanging policy will quickly become obsolete.

Of course, any policy will have to be reevaluated and changed in the light of changing external conditions. It is vitally important for us to recognize at all times that the federal government is only one of the players in the research enterprise. It does have a powerful influence on that enterprise, but it is limited in many of the things that it can do. It is important that those limitations, just as much as the opportunities be recognized.

In the long run, however, I believe that we have established a mechanism, in this administration, that has the potential of working with many organizations to coordinate and integrate the activities of the federal government in a way that has not been possible previously. Rather than taking forward the programs of a whole series of heterogeneous agencies, which after all is one of the great strengths of our enterprise, in this coordinating activity, we put together federal programs instead. By doing so, and by being able to take forward to the rest of the administration and to the President such items as the federal program on global change, the federal program on high-performance computing, the federal program on education in science and mathematics, we have been able to convince all of those involved that these are indeed very important areas—areas deserving of special support.

At a time when we, probably unique among the developed nations, are very certainly playing a zero-sum game in constant dollars, I think all of us here should take real encouragement from the fact that the budget reflects the increases I have mentioned, for that means that other programs with strong constituencies have necessarily been cut back to provide the funds that have been moved into the support of science and technology.

I have every confidence that this will continue in the years ahead. The real problem we now face is that, although the President requests and pro

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poses, it is Congress that disposes and appropriates. I must say with all candor that the scientific and engineering communities do not constitute a singularly effective constituency. This is a challenge that all of us must face in the years ahead.

FRANK PRESS

President, National Academy of Sciences

In my remarks today I would like to single out several issues that I think will be important in the years ahead. Let me start with current trends. By that, I mean things that are already in place and trends that might take us to the end of the decade. I would like to tell you about a few factors that influence my own thoughts on these matters.

If one uses the index of citations to each nation's literature in the world's scientific literature—new data from the Institute for Science Information— normalized for the size of the country, this is what one concludes: the United States leads by a large amount according to this indicator of scientific productivity, and it is the only country in recent years with a positive slope. We are getting better.

In the second ranking are the United Kingdom and Germany. Japan and Italy are in the bottom of the group. I would like to ask David Phillips and Michael Atiyah how Great Britain does so well in the light of tight science budgets. You are well up there in the world scientific literature. You are producing; you are very creative. Maybe Prime Minister Thatcher was correct in her statement that there is enough money to go around, as long as we give it to the best people. That question actually is one that we are facing in this country.

Another factor that impresses me is that the Bush administration proposal for science funding is really the best in as long as anybody can remember. And it comes at a time of record deficits. One might argue with the way the administration is allocating the budget, but one cannot argue with its commitment to science and its recognition that science is one of the best investments in the nation's future. Allan Bromley is to be congratulated in shepherding that budget through the administration. He is also lucky that he has an Office of Management and Budget (OMB) filled with science buffs. They like science, and they believe it is one of the best investments we can make. That is a very powerful team, OMB and OSTP working together.

Despite the skepticism of a senator or a congressman or congresswoman, I believe that in Congress there is general support for investments in science. Every congressperson wants an R&D establishment in his or her district. They recognize the connection between economic development and a strong research university R&D center in their community. So there is support across our government, I believe, in science budgets and in investments in science.

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I believe that the research universities will remain the primary vehicle for fundamental research in the United States. They have delivered on the investment made in them in the years since 1950. There are no alternatives in our country.

If the United States is supported so well in absolute terms—by international comparisons of science funding or by the output measurement I have suggested—if we occupy that position, why is there such a great deal of stress in the American scientific community? The growth in science budgets, as magnificent as they have been, have not kept up with the growth in the number of scientists at work in our research laboratories and, mostly, in our university research laboratories. We cannot say in this country what Professor Markl said about Germany this morning: it is very difficult to be a good German scientist and not be supported. There are some very good American scientists who have lost a great deal of their support.

This raises key questions in our country that I think will be debated in the years ahead. Are we training too many scientists who want to do academic research? Is it realistic to think of continually increasing scientific budgets? How much is enough in the support of science? The issue has polarized the scientific community into two groups. One group I call the plateau school. This group, in the present climate of deficits and despite the great Bush budget for science, believes that it is unrealistic to expect to have significant growth in the years ahead at the same rate and that we should be concentrating on setting priorities and on better allocation of science funds.

The second group supports growth. I call it the doubling school. They believe that growth can be persuasively argued in terms that the public and politicians can understand, that increased funding of science is not that expensive compared to other national priorities, and that science will founder unless it continues to grow.

My own view is that the outcome will be somewhere in the middle. We will see continuing budgets, good budgets, for science. But there will be a great deal of thought given to allocation, to setting priorities, and to seeing that the funds are well spent.

Let me talk about some trends in the infrastructure of science, starting with the research universities. I believe that the research universities will remain the primary vehicle for fundamental research in the United States. They have delivered on the investment made in them in the years since 1950. There are no alternatives in our country; the research universities have been good, and they have the potential for continuing to be highly productive in scientific research.

Wrongly or rightly, our research universities are under a siege of criticism from many quarters: Congress, governors, faculty criticizing their own administrations, parents of students criticizing the escalating costs of education, and so on. There is a perception that their rising costs are out of control and that they need tough management. Then there will be demographic changes as a wave of retirements takes place in the next few years, necessitating that new faculty be found.

Thus, because of these pressures, there will be many changes in the management of science in the research universities and in the way they allocate their own internal resources. There will be pressures to cap the esca

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lation in their costs, their tuition, the growth in their overhead, and so on. But these pressures can have some positive effects. I think we may see a redefinition of departments and disciplines as new faculty and newly trained scientists come in and as the administrators wrestle with the pressures that I have described. We may see some reduced scope; universities cannot do everything for everybody. Perhaps they will cut back fields that have been bypassed by the progress of science and reallocate those resources to the more lively fields. As a matter of fact, I visit a lot of universities each year, and these kinds of trends are already happening. They are not advertised—they are happening without fanfare—but these kinds of internal soul searching and changes are gradually taking place.

I think we may see a redefinition of departments and disciplines as new faculty and newly trained scientists come in and as the administrators wrestle with the pressures.

Here are some words about the industrial laboratories and what is ahead for them. We have some great and effective industrial laboratories in the United States, especially in the pharmaceutical, chemical, electronic, and biotechnology fields. By great and effective, I mean they do good research and their management knows how to use the products of that research. We also have some great laboratories that are ineffective. Some of our companies with the highest R&D budgets in the country have very good laboratories, but you would not know it from the products they turn out. This is because their management is not trained properly; they do not know how to use their very able scientists and engineers and their research centers to develop new ways of doing things and new products.

I believe that this may change in time. I think that those companies that do it well will be role models for the others, and I believe as well that the effective use of R&D by Japanese companies may be a role model for American companies.

As for our national laboratories, the personnel there and the political supporters of these laboratories are in search of new missions as the sponsoring agencies change their priorities.

As for our national laboratories, the personnel there and the political supporters of these laboratories are in search of new missions as the sponsoring agencies change their priorities. The Defense Department is reducing its budget in the years ahead, and the same is in store for the other national laboratories. Many of them are looking for new work in the areas of the environment, energy resources, and precommercial R&D.

Can they bring this off? Can the culture of these national laboratories, accustomed to single customers, change so that they are competitive in these areas that I have mentioned? I believe these laboratories will survive because no regional congressional group will permit them to be disbanded. We do not know how to do that in this country. But can we make them effective in addressing the new national problems? That will be the issue we will have to face.

Let me talk about the national response to trends in the research enterprise. Explosive developments in almost every field of science will keep science and technology very high in the public interest. It will keep its priority high. Every week one can read of a major new discovery in the newspapers, and the public follows this with great interest. All of the leading newspapers now have science sections. This past week Amgen released a

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remarkable new product, maybe the most important biotech product yet on an agent that enhances the white cells' effectiveness. During the previous week, I was traveling during the meeting of the American Association for the Advancement of Science (AAAS), and in every city I visited I found on the front page of the newspaper what was happening that day at the AAAS meeting. I think the public knows a lot, that science has a high priority, and that science and technology will be in the limelight.

But that limelight also presents us with problems. The large science budgets that we are enjoying makes science very, very visible. Increasingly, we will be asked as a community, with so much invested in science and with our world leadership role, why is our record of commercial exploitation so disappointing? Anybody who has testified before Congress must have been asked that question many times.

Looking ahead, I think American industry will shift a major fraction of its fundamental research to research universities and will reserve targeted research more related to products for their own industrial laboratories.

I recently heard a new slant from a Japanese friend, who very frankly said that we Americans may be putting too many resources into basic science, with the mistaken notion that technological innovation follows a linear model: research to development to prototype to product.

Well, I do not know anybody in this country who believes that innovation exclusively follows that linear model. On the other hand, let us not forget that the transistor came out of solid state physics and spawned the computer information revolution, that biotechnology came out of molecular biology, and that all of the emerging technologies that Dr. Kikuchi mentioned in his paper require some scientific breakthroughs before they reach fruition. So when it comes to the innovation process, especially in the years ahead with the new technologies, we can make a good case for the support of science.

But why have we not done so well in economic exploitation? There are so many important factors that go into innovation: management skills, the investment policies of management, such tax policies as the capital gains tax or the lack thereof, the macroenvironment, and regulatory policies of government. If this nation has failed to exploit its own scientific successes fully, it is not because it has not been successful in science; it has not done well in these other factors that influence our ability to reap commercial success from scientific success.

Looking ahead, I make a prediction that some of you may argue with, but at least it will make a good discussion. I think American industry will shift a major fraction of its fundamental research to research universities and will reserve targeted research more related to products for their own industrial laboratories.

Why do I say this? A growing number of American companies have formed new kinds of relationships with university departments that go beyond simply sending money. These new relationships respect the open nature of the university; their only restriction is exclusive licensing if something useful develops. This is very important. There is a two-way intellec

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tual flow of people and ideas, with the industry contacts being the intellectual peers of their university scientist counterparts.

There is a lot of feedback from technology to science that results from this kind of relationship. The industrial scientists who maintain this relationship know on a timely basis about the research in the universities where they serve as patrons. They know the graduate students, and they know the thesis topics. These industrial scientists go and spend time, months at a time, at the universities, and the university people sometimes spend an equal amount of time in the industrial laboratories. This is a new concept that seems to be very successful. I think that the more that American industries not doing it learn about it, the more they will swing in this direction.

Also, university research is cheap, and that is because a great fraction of it is done by low-cost labor: the postdoctorate and graduate students. This is a very efficient means of technology transfer, because it is not simply money being sent down but it is people working together, going back and forth. It leverages a much larger government investment in the research university.

If the relationship between science and technology activity and economic success is as close as we all think, there may be some pressures and some unfortunate directions taken. There may be a new kind of protectionism, replacing the military security sort with economic protectionism, that could lead, in one way or another, to closing off scientific communication. We must guard against that.

Despite these future trends, no matter what happens, the industrial contribution to universities will always be a small fraction of the federal contribution. On the other hand, that small contribution, as I said, leverages a great federal investment. Some members of Congress are worried about this. On the other hand, this is as it should be, because the government return on their investment is in the form of industrial growth, growth in the tax base, and growth in jobs.

I believe there will be more spin-offs from American universities—not only in biotechnology but in materials, software, and many additional areas. Can the national laboratories participate in these trends? This requires the cultural change that I alluded to before, which has occurred already in the American universities. Today, the relationship is a good one, whereas 20 years ago industrial representatives were not very popular on American campuses.

Finally, some concerns about the future. If the relationship between science and technology activity and economic success is as close as we all think in this room, there may be some pressures and some unfortunate directions taken. There may be a new kind of protectionism, replacing the military security sort with economic protectionism, that could lead, in one way or another, to closing off scientific communication. We must guard against that.

As I said before, big money attracts political attention. So we have to be concerned about pressure to allocate resources on political grounds rather than on the basis of quality of work. There may be oversight initiatives, close monitoring of universities because of the big money spent there, and issues of fraud and conflict of interest leading to inspectors running all over the place. We have to guard against that. There may be a tendency to allocate resources not to the best places but to the lower bidders; we see some signs of that happening already.

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I think these are problems we can handle in the years ahead. If we are not sensitive to them, we might be disappointed—we might be surprised and shocked. But, on the whole, I am rather optimistic about the way things are going in our country. We have a lot of problems, which I have described, but the connection between the welfare of our people and the economic success of our country generally is recognized, and I think we will do well in the years ahead.

DISCUSSION

***Professor Roger Geiger*:** I think I agree very much with the view that Frank Press just gave of the American research universities. That is the part of the research system I am prepared to talk about.

I think a major trend of the past decade is the decrease in the percentage of federal funding of university research. The federal government paid for about 70 percent of university research in 1970, and 67 percent in 1980; at the end of the decade of the 1980s, that percentage fell below 60 percent. Thus, it is now approximately where it was in 1960.

This low percentage is not because federal investment decreased; it actually increased by about 50 percent in real terms during the 1980s. Rather, other sources increased at a more rapid rate. One of the most important of these has been the increase in industrial funding. I found your comments very interesting, because the industrial contribution to university research has approximately doubled in the last 15 years. It has reached a level of perhaps 10 percent, counting direct and indirect contributions. Many people doubt that it can go beyond that.

Your faith that it will, I think, is a daring position to take in some ways. But it may be a very reasonable one as well, because the limits of this are not yet apparent, and the interactions that have occurred to date seem to be breeding more interreactions rather than reaching any particular limits. So, I think the reasons you give for why this partnership may be extended further are quite convincing, and I believe the point you made that the culture of universities has changed dramatically over the last decade is certainly a particularly significant reason.

***Question*:** I agree with the comments, just made by Frank Press, that if you look at the growth rates of supportive academic R&D in the 1980s, the federal government rate has been only at about 9 percent per year, and industry has been about 17 percent per year, so those ratios have gotten to where the federal government supports about 60 percent. But as for total support for academic research, that grew at about 10.5 percent per year during the 1980s, during a time when inflation was only 5 to 5.5 percent. As a matter of fact, per capita expenditures on academic doctorals grew during the 1980s very significantly.

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There is a long time lag in building up science and scientists, and one has to bear that in mind in trying to assess where the future is going to lie. I think it is dangerous to be complacent, because by the time you discover that things are bad, it is too late to change.

Thus, there is the curious phenomenon that in the very year when per capita support of people in the physical sciences in academia was at a minimum, the survey showed there was greatest satisfaction with support. Today, where that support is 64 percent higher in constant dollars, the satisfaction has dropped. I think that, as scientists and engineers, that is a phenomenon that deserves examination and explanation. I do not know what the explanation is, but it is curious.

***Dr. Frank Press*:** I think those figures have to be disaggregated to see where the money is coming from. Is there defense money in there; is that counted? Is there NASA money in there? Are the big accelerators included? Because when using the NSF's own data in scientific indicators, you will see that the average grant size does not seem to follow the trend you have mentioned. So one has to understand this information in a better way to see what is really happening.

***Sir Michael Atiyah*:** Could I just try to respond to the question that Frank asked about the health of British science? First, I would like to say how very pleased I was to learn that he thought British science was still in a very healthy state.

Not everybody puts full faith in citation indices, but even if one takes these at face value, I think one might make the following point. The health of science in a country at a given time depends not only on the funding of institutions at the moment, but it depends on its past. It takes a long time to build up a scientific tradition, to train scientists and so on.

So the point may be that you may look very healthy at a particular moment, but 10 years later your situation might be quite different. I think there is a long time lag in building up science and scientists, and one has to bear that in mind in trying to assess where the future is going to lie. I think it is dangerous to be complacent, because by the time you discover that things are bad, it is too late to change.

***Question*:** I attended a recent meeting sponsored by the National Academy of Engineering on industry-university interactions. One of the things that struck me during the course of the day was that several of the academic presenters and a couple of the people in the audience were very much interested in developing models for and expanding services of universities that would be of value to companies.

The corporate speakers seemed to be presenting the view that they do not look to universities as their primary source for new technologies—not necessarily basic research, but new technologies. It seems to me in my observations that corporate support for university research usually is in areas where there is some perception that something useful is going to come out of it. So I would guess that a lot of the support is not uniform across fields in science and engineering but that it is very heavy in biologically oriented areas, particularly in microbiology and where there is a medical application that is available; that it is very heavy in the computer and computer soft

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ware area; and that it is not as heavy in some other areas—certainly not as heavy in basic engineering research.

To look to industry to drastically increase its support of universities seems to me to be saying in a sense that, over a period of time, university research is going to change—it is going to change in response to the sources of funds that come in, which is always what happens when sources of funds change, and it will become more directed into areas that are of interest for industrial application. Now, there is nothing wrong with that, except that we then have to question what happens to the basic research capability of the university. Are we developing then within the universities the same kind of shorter-term perspective that we are saying our industries have suffered from?

The universities in this country have been the long-term research generator—the place where somebody could follow a research idea for 20 years, and where some of these major breakthroughs that you mentioned before came about.

Is not the discussion deriving from the fact that federal support for basic academic research has not been keeping up with need? So we are looking around for another source of funds, other than the first principles, and we are saying that the other source would, in fact, be a good thing.

***Dr. Frank Press*:** I said it was a tentative prediction of how things might go. I have in mind about a dozen American companies that have relationships with universities of the kind that I described. The fields are absolutely forefront. The university people would love to work in these fields, no matter who supported them.

A model that immediately comes to mind is the relationship between MIT and AT&T, IBM, and ITC. It is a great model. MIT is mostly supported by the federal government. The industries put up their own money for this joint project, and people from the industrial laboratories spend months at MIT and the other way around, with graduate students going to the industrial laboratories and so on. It is a terrific model.

There are some others that I might speak of—Monsanto and Washington University, for example. It is a unique model; if I had time I would describe it to you. There are only about a dozen of these models, but they are so good I think other companies might learn about them and try to replicate them.

***Mr. Erich Block*:** Let me just remind you that over the last decade, roughly speaking, the percentage of funding from industry to universities has doubled. You can say that is from a small percentage, which is true also, but it has doubled nevertheless. That is one kind of indicator.

Second, there are some universities where the funding from industry is a very high percentage of their total research funding—much higher than the average. The third point I wanted to make is highly field dependent. There are certain industry sectors where greater university funding is more prevalent; and there are other industry sectors where it is not so. A lot of it has to do with tradition and also with the fact that some of these industry

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sectors have not yet realized that basic research is a very important ingredient to their competitiveness.

I think we will see a trend in that direction. It will never be 90 percent of the total research funding of a university; that comes from industry. But you should not underestimate what has happened and what the trend is.

GENERAL DISCUSSION

***Professor Alan Beyerchen*:** A major transition that has occurred, naturally, is the unification of Germany: something that was not foreseen by anyone—German, American, or otherwise—that I know of in 1989.

I am very concerned at this point about the manner of the West German restructuring of East German scientific institutions, and I am concerned as well about the reports coming out of East Germany that indicate that certainly people in the eastern provinces of Germany realize that there was a great deal of overstaffing and so on. But there was a lot of partisan activity going on. Professor Markl indicated that the nature of the environment for science policy has become very politicized in the past 15 years or so. The fact that there is a CDU government in charge of Germany sets the tones of everything being done in eastern Germany. If there were an SPD government, perhaps the tone would be different.

I wonder if perhaps this is not an historical opportunity for scientists in the federal republic to step in and work for a more nonpartisan way of setting policy for the eastern provinces—more nonpartisan than what is happening in general in those provinces.

I have a second general comment on the talks, those of this morning in particular, but also the ones this afternoon. This morning we heard a fair amount of talk about the human capital involved and the mobility of human capital, from the various members representing the European Community in particular, but also from people who were talking about training the young in the universities and preparing the next generation.

One word that seemed to be left out of this entire discussion was "women." In this country we have a number of major initiatives from the National Science Foundation, the AAAS, and all sorts of other organizations to encourage the flow of women into the mainstream of science. What we see is literally a human energy shortfall. I wonder if the other speakers this morning might want to address that particular question—Professor Markl, in particular, who said there is no real shortage in Germany. Does this mean that women are not being recruited as actively as they are in the United States? If they are, in what ways?

***Professor Hubert Markl*:** I want to combine my answer to your comments and questions with a comment I wanted to make on Academician Osipyan's presentation.

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This change of the East German scientific system comes as a great hardship to the people who are involved there, and we realize that. If it is the perception from the outside that the hardship comes from a kind of partisan treatment of the situation, I think that perception is wrong.

The major agent, presently, in this process is the Wissenschaftsrat, the science council, which is really very nonpartisan as to the people involved. There was from the very beginning a conviction, which has even strengthened, of all parties and even between politics and the scientists that the faster the restructuring goes and the more it goes in the direction of building up the research base of the universities again, the better it will actually be for the people involved.

We live in an open world. It is clear that talented scientists move much more quickly and freely than does money. So what we all have to face is that there is no strategy to keep talent where it is.

This is not easy for those who are now the objects of this handling to accept, because they were, in fact, rather comfortable and well financed, without any job insecurity, and with very little pressure to show in productivity what they did in the academic system. The East German Academy was a rather sheltered, prestigious body that did not have to worry too much about where the funds came from for its work. Once you were in, you could be pretty sure you were in for life, unless you aged with the political system. That, of course, could give you trouble.

Now, the situation cannot continue like this, and it will not. What actually is happening is that we have tried to help all the different groups assembled there to get as fast as possible into the closest productive contact with the system that makes the money available for them now. So, many of the groups will end up in Max Planck groups, in Hanover institutes, or in some of our national laboratories. But most of them really will come into closer contact with the universities, an idea they do not like, for they will have to teach—to face the red in the eye of the student every day. I have heard a number of comments to this effect. Of course this is not true for everyone; I know that Academician Osipyan is continuously in contact with his students. But there are many people who are not, so this is the basic thing.

The problem that I see with the situation as you described it, regarding the connection between science and the economy, is as follows. In East Germany, since unification, we have clearly seen the following process. West German investors immediately went into the services and commercial sectors, and established everything from very small to very big supermarkets— everything very fast. This provided a number of jobs. Repair shops then blossomed everywhere, as did investment in those industries that have to be very close to the market to be served, say, for instance, furniture.

But all of these investors and industries do not employ researchers. Where you do find employment for researchers—in the big chemical industry, or the big engineering sector, the investment is very slow and very difficult to arrange. What really happens is that the average person hitting a big company—say one of our company industries—has to justify in front of his stockholders whether he or she invests wherever the value added to the product is best. If that is judged to be Australia, the investors will put

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the next department of research of Hoechst in Australia or Spain rather than in Leipzig, even though it is German.

Not disregarding that, labor is much cheaper in East Germany, and real estate is very, very cheap. The eternal factors seems to be very simple and easy. But this is not how it is decided where to invest in research. I can tell you where the West German industrialists invest in new research activities. They invest in Munich, where the rents are staggering and where it is very difficult to find a square meter in town that is less than most Tokyo values. But that is where they put their money. They do not go where it is cheap to set up a new building and where there are cheap but qualified scientists.

We live in an open world. It is clear that talented scientists move much more quickly and freely than does money. So what we all have to face is that there is no strategy to keep talent where it is. Thus, when you say, "Please come set up a research department in Moscow and work with these people because they are cheap; for this will hold them back in Russia." I believe it just will not work.

The only way which we have discovered to retain talent is to have the government invest and then to attract more money from outside in very qualified research universities. Research universities provide something that keeps people in their home communities and gives them support, because it is the young people from the region who are educated there, and education provides chances for the future for them.

> ***The only way which we have discovered to retain talent [in eastern Germany] is to have the government invest and then to attract more money from outside in very qualified research universities. Research universities provide something that keeps people in their home communities and gives them support, because it is the young people from the region who are educated there, and education provides chances for the future for them.***

So what we are going to do—and that is why we are trying to move these people out of the Academy and into the universities—to build up the R&D and science and technology structure of East Germany to make it productive, first by putting a lot of money into the universities and then by letting conglomerate around active research universities small and large business, making it attractive for other investment as well.

This is the only way it has worked in our country, and I see it in other countries as well. That is why I am so much in agreement. If you talk about industrial policy and regional policy, the only way we could affect the system of investment in Germany, at least, was by providing this type of attractiveness and not tax benefits.

In Berlin you can see it very clearly. Investors will undertake any type of research, as long as the government pays for it. But when the subsidies are cut, they suddenly take off. They do not worry about whether that research is productive or not. If you want to make productive investment, you have to leave it to the industrialists to decide where they want to go, and you have to attract them by the boundary conditions, so to speak. And research universities are an exceedingly important condition for development.

The former East Bloc countries, such as Poland and. Hungary are having similar problems and unless they somehow try to tie in with this experience of western Europe, they will not have the development they want. I think they will try to do so.

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> ***We [Russians] have to take into account the two ways possible: (1) western European or British, American, German, and French based on individual activity and individual responsibility, and (2) let's say, Asian, Japanese, Taiwanese, South Korean. I do not know what the Russian way will be, but this is the very time to decide. Perhaps we will combine the two.***

In the long run, for the Japanese, the Taiwanese, the Singaporese, the South Korean, or for any of these examples, there is no way to build up their country from attracting venture capital from outside. You have to earn your money in your own country in a free world market with products that are competitive, and from that you can build up your society. There is no other way.

As for women researchers, women have much better chances now in Germany to get funds and to get jobs. But it will take some time before these policies, which have really only evolved over the last five years or so, really show in the numbers.

***Academician Yuriy Osipyan*:** In general, I agree with what Hubert Markl said. But we [Russians] have to take into account the two ways possible: (1) western European or British, American, German, and French based on individual activity and individual responsibility, and (2) let's say, Asian, Japanese, Taiwanese, South Korean.

I do not know what the Russian way will be, but this is the very time to decide. Perhaps we will combine the two. I have only to say that for us, personally—for the Russians—it would not be best to move this unsuccessful research group to the university. Maybe there will be a new research group—there will be a little shift with the good people based on individual responsibility.

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APPENDIXES

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SYMPOSIUM AGENDA

FEBRUARY 26, 1991

8: 15 a.m.	**Welcome and Opening Remarks**
	James D. Ebert, Chairman, Government-University-Industry Research Roundtable
8:30 a.m.	**Morning Session**
	Session Chair: Robert M. White, President, National Academy of Engineering
8:45 a.m	**The European Community**
	Filippo Pandolfi, Vice-President for Science, Research, and Development, Telecommunications Industry and Innovation, and the Joint Research Center, The Commission of the European Communities
	Paolo Fasella, Director General of the Directorate for Research, Science, and Development and the Joint Research Center, The Commission of the European Communities
	Discussion
9:45 a.m.	**Germany**
	Hubert Markl, President, Deutsche Forschungsgemeinschaft (DFG)
	Discussion
11:15 a.m.	**United Kingdom**
	Sir David Phillips, Chairman, Advisory Board for the Research Councils
	Sir Michael Atiyah, President, The Royal Society
	Discussion
1:45 p.m.	**Afternoon Session**
	Session Chair: Erich Bloch, Former Director, U.S. National Science Foundation
2:00 p.m.	**Soviet Union**
	Yuriy A. Osipyan, Vice-President, Academy of Sciences of the U.S.S.R.
	Vladimir V. Ezhkov, Deputy Chairman, U.S.S.R. State Committee on Science and Technology
	Discussion

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3:00 p.m.	**Japan**
	Jiro Kondo, President, Science Council of Japan
	Makoto Kikuchi, Executive Technical Advisor, Sony Corporation; Professor of Electronics, Tokai University
	Discussion
4:30 p.m.	**United States**
	D. Allan Bromley, Assistant to the President for Science and Technology; Director of the Office of Science and Technology Policy
	Frank Press, President, National Academy of Sciences
	Discussion
5:45 p.m.	**Adjourn**

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PANELIST BIOGRAPHIES

Michael Atiyah is President of the Royal Society. He was recently appointed Master of Trinity College, Cambridge University, and Director of the new Isaac Newton Institute for Mathematical Sciences. Prior to his current positions at Cambridge, Sir Michael was on the faculty of Oxford University, where he was appointed Savilian Professor of Geometry, Royal Society Research Professor, and Fellow of St. Catherine's College. From 1969 to 1972 he was Professor of Mathematics at the Institute for Advanced Study in Princeton. Sir Michael obtained B.A. and Ph.D. degrees in mathematics from Trinity College, Cambridge. His awards include the Fields Medal in 1966, a Royal Medal in 1968, and the Copley Medal in 1988. He is a Foreign Associate of the U.S. National Academy of Sciences. Sir Michael was knighted in 1983.

Erich Bloch is a Distinguished Fellow at the Council on Competitiveness in Washington, D.C. From 1984 to 1990 he served as Director of the U.S. National Science Foundation (NSF). Prior to his NSF appointment, Mr. Bloch was corporate Vice-President for Technical Personnel Development at the IBM Corporation. During his career at IBM, he was the engineering manager of IBM's STRETCH supercomputer system and, in 1962, headed development of the Solid Logic Technology program, which provided IBM with microelectronic technology for its System/360 computer. From 1981 to 1984 Mr. Bloch served as Chairman of the Semi-conductor Research Cooperative. In 1985 he was awarded the National Medal of Technology by President Reagan. He is the recipient of the 1989 IEEE United States Activities Award for Distinguished Public Service and the 1990 IEEE Founders Medal. Mr. Bloch is currently serving as Chairman of the Working Group on the Academic Research Enterprise, Government-University-Industry Research Roundtable. He is a member of the U.S. National Academy of Engineering.

D. Allan Bromley is Assistant to the President for Science and Technology and Director of the Office of Science and Technology Policy (OSTP) in the Executive Office of the President. He is currently on leave from his former position as Henry Ford II Professor of Physics at Yale University, where he was the founder and Director of the A. W. Wright Nuclear Structure Laboratory. Prior to his current appointment, Dr. Bromley served as a member of the White House Science Council throughout the Reagan Administration and as a member of the National Science Board (1988-1989). Dr.

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Bromley has served as President of the American Association for the Advancement of Science and the International Union of Pure and Applied Physics. During his scientific career, he has carried out pioneering studies on the structure and dynamics of nuclei and has published over 450 papers in science and technology. Dr. Bromley is a member of the U.S. National Academy of Sciences.

James D. Ebert is Vice-President of the U.S. National Academy of Sciences. He served as Chairman of the Government-University-Industry Research Roundtable from 1987-1991. Dr. Ebert is currently Director of the Chesapeake Bay Institute, The Johns Hopkins University. From 1978 to 1987, he served as President of the Carnegie Institution of Washington. Prior to that position, Dr. Ebert served as President and Director of the Marine Biological Laboratory at Woods Hole from 1970 to 1978, while also concurrently heading the Carnegie Institution's Embryology Department for six of those years. Earlier in his career, he served on the faculties of the Massachusetts Institute of Technology, Indiana University, and Johns Hopkins University. He is a graduate of Washington and Jefferson College and obtained his Ph.D. from The Johns Hopkins University. Dr. Ebert has been a visiting professor and lecturer at many universities throughout the world, and he is especially recognized for his promotion of scientific interactions with Japan and China. He is the author of more than 175 scientific publications.

Vladimir V. Ezhkov was Deputy Chairman of the U.S.S.R. State Committee on Science and Technology and Head of the International Relations Complex. Prior to his appointment as Deputy Chairman in 1987, Dr. Ezhkov's work for the U.S.S.R. State Committee included research related to studies of the earth's natural resources using space technology (remote sensing) and to problems of computer processing of images. Dr. Ezhkov was a member of the former State Commission of the Foreign Economic Relations of the U.S.S.R. Council of Ministers. He was Chairman of the Commissions and Subcommissions on cooperation in the field of science and technology with Finland, China, Austria, Vietnam, Canada, and the European Communities. He was a director and member of the Executive Committee of the American-Soviet Trade and Economic Council. Dr. Ezhkov was educated at the Moscow Institute of Physics and Technology, where he received a Ph.D. in physics and mathematics.

Paolo Fasella is Director General of the Directorate for Research, Science, and Development and the Joint Research Center, the Commission of the European Communities. Prior to assuming this position, Professor Fasella was Director of the Snam Progetti-Asssoreni, Basic Research Laboratory, Montarotondo, Rome. He holds a Professorship of Biological Chemistry, University of Rome. Professor Fasella has served as President of the

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European Molecular Biology Conference, Member of the European Research and Development Committee (CERD) of the European Communities, and President of the International Union of Biological Sciences. From the University of Rome, Professor Fasella received a *Laurea in medicina* (medical degree), a *Libera Docenza* (Ph.D.) in biological chemistry and *a Libera Docenza* (Ph.D.) in applied biochemistry. Professor Fasella is the author of more than 200 papers on protein structure and functions, neuroproteins, biological catalysis, and biotechnology, as well as articles on scientific research policy and bioethics.

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Hubert S. Markl is Professor of Biology, Universität Konstanz. He has served as President of the Deutsche Forschungsgemeinschaft (DFG) (German Research Association) and Vice-President of the Alexander von Humboldt Foundation. Professor Markl's previous university appointments include assistant professorships at Universität Munchen and Universität Frankfurt a. M.; Research Fellowships (1965-1966) at Harvard University and Rockefeller University; Dozent, Universität Frankfurt a. M.; and Professor of Zoology, TH Darmstadt. Professor Markl's university degrees

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include Dr. rer. nat. in Zoology, Universität Munchen (1962) and Habilitation in Zoology, Universität Frankfurt a. M. (1967). His research includes studies in behavioral ecology, sensory physiology, and social behavior and evolution in animals. His honors include the Lorenz Oken-Medal of the Gesellschaft Deutscher Naturforscher und Ärzte; the Karl Vossler-Prize of the Bavarian Minister of Culture; the Arthur Burkhardt-Prize of the Arthur Burkhardt-Stiftung für Wissenschaftsförderung; and the Verdienstkreuz I. Klasse des Verdienstordens der Bundesrepublik Deutschland.

Yuriy A. Osipyan was Vice-President of the U.S.S.R. Academy of Sciences. Academician Osipyan has been Director of the Solid-State Physics Institute, U.S.S.R. Academy of Sciences, since 1973. He was elected to the Congress of People's Deputies in 1989 and was a member of the Supreme Soviet's Science, Education, Culture, and Upbringing Committee. He is best known for his research in the fields of semiconductors and superconductivity and is recognized for his discoveries pertaining to the impact of light on semiconductors. In addition to his scientific responsibilities, Academician Osipyan has remained active in academia as a professor, department chairman, and dean at the Moscow Physical Technical Institute. Academician Osipyan graduated from the Moscow Steel and Alloys Institute and has received a doctorate in physical and mathematical sciences. He served as President of the International Union of Pure and Applied Physics.

Filippo Pandolfi is Vice-President for Science, Research, and Development, Telecommunications, Industry and Innovation, and the Joint Research Center, The Commission of the European Communities. From 1968 to 1988 Vice-President Pandolfi was a member of the Italian Parliament (Christian Democrat), where he served as Minister of Finance, Minister of the Treasury, Minister of Industry, and Minister of Agriculture. From 1979 to 1980 he was Chairman of the Interim Committee of the International Monetary Fund. Vice-President Pandolfi holds a university degree in philosophy.

David Phillips is Chairman, U.K. Advisory Board for the Research Councils, which advises the U.K. Secretary of State for Education and Science on government funding of basic and strategic civil research. He is also a member of the Advisory Council on Science and Technology, which reports to the Prime Minister. Sir David is formerly Professor of Molecular Biophysics at the University of Oxford, where he supervised a laboratory for the detailed study of protein structure and function. He obtained his B.Sc. and Ph.D. in crystallography from University College, Cardiff. Honors awarded him include the Krebs Medal of the FEBS, the Ciba Medal of the Biochemical Society, the Royal Medal of the Royal Society, the Prix Charles Leopold Mayer of the French Academy of Sciences, and the Wolf

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Prize for Chemistry. Sir David was elected a Fellow of the Royal Society in 1967 and served as Vice-President and Biological Secretary from 1976 to 1983. He is a Foreign Associate of the U.S. National Academy of Sciences. Sir David was knighted in 1979 and was created a Knight Commander of the Order of the British Empire in 1989.

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Robert M. White is President of the U.S. National Academy of Engineering (NAE). Before assuming the NAE presidency in 1983, Dr. White served as President, University Corporation for Atmospheric Research; Administrative Officer, National Research Council; Executive Officer, National Academy of Sciences; and President, Joint Oceanographic Institutions, Inc. From 1963 to 1977 he served within the U.S. Department of Commerce as Administrator, National Oceanic and Atmospheric Administration (1970-1977); Administrator, Environmental Science Services Administration (1965-1970); and Chief, United States Weather Service (1963-1965). Dr. White holds a B.A. degree from Harvard University and M.S. and Sc.D. degrees from the Massachusetts Institute of Technology.

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