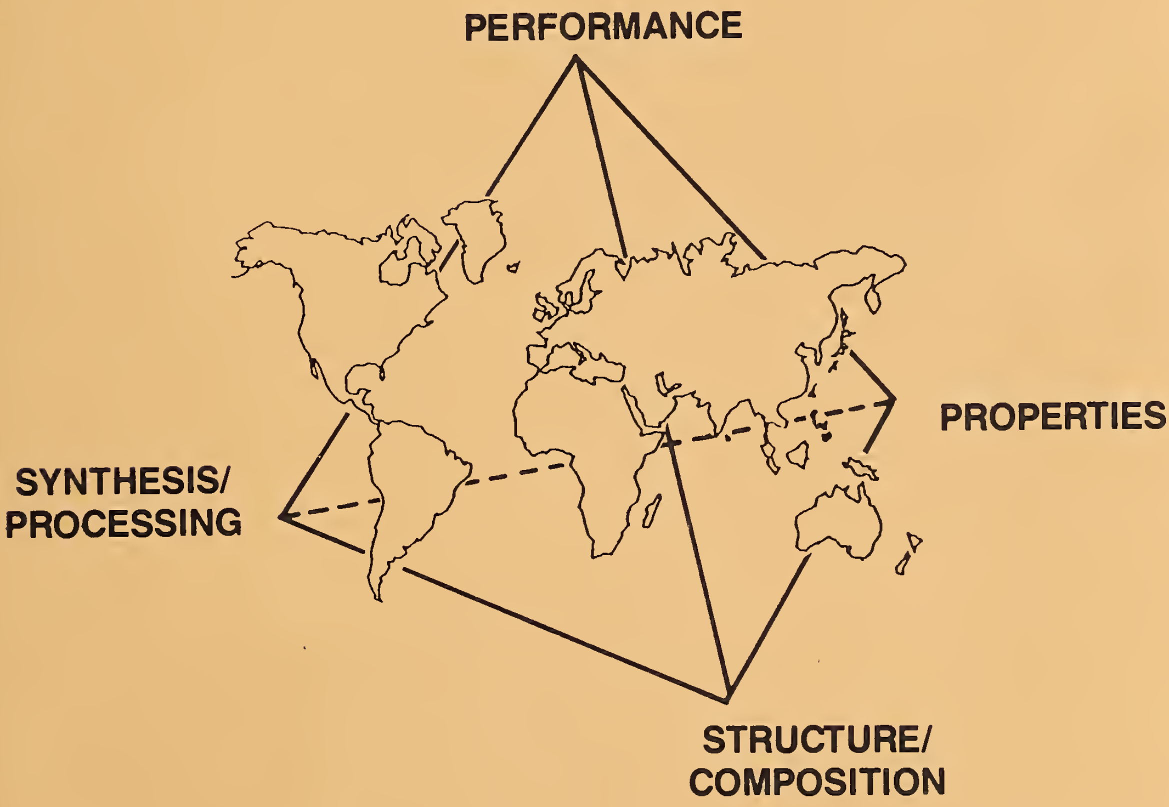
INTERNATIONAL COOPERATION AND COMPETITION IN MATERIALS SCIENCE AND ENGINEERING



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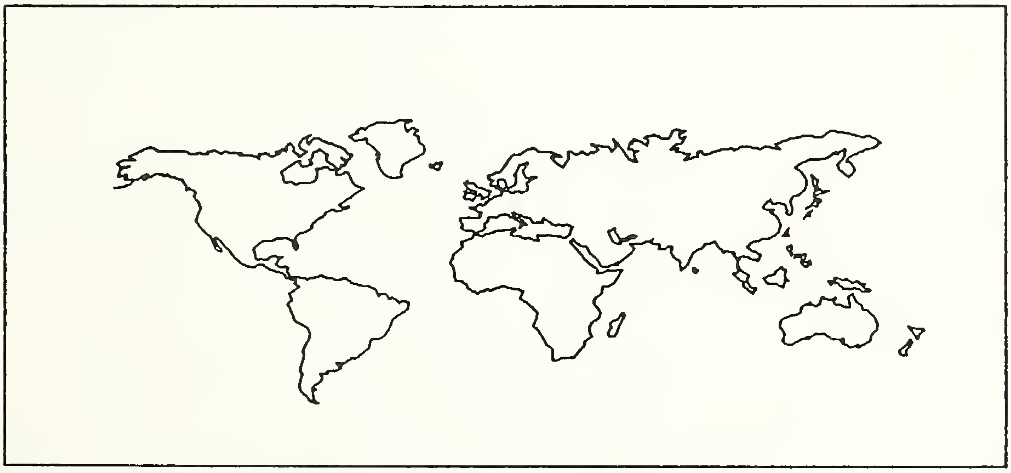
INTERNATIONAL COOPERATION AND COMPETITION
IN
MATERIALS SCIENCE AND ENGINEERING

Materials Science and Engineering, an enabling technology viewed the world over as paramount to industrial advancement, deals with the synthesis and processing, structure and composition, properties, and performance of materials and with the interrelationships among these elements.



FOREWORD

In 1986, the National Research Council (NRC) commissioned a Committee on Materials Science and Engineering (COMMSE) to conduct a comprehensive study of this field, to define its progress, assess needs and opportunities and provide policy guidance at the national level. A Summary Report of COMMSE was published in 1989, and was based primarily on informational inputs generated by five separate panels, each charged to investigate a different aspect of Materials Science and Engineering (MSE). The background information provided by Panel 3 of COMMSE has now been organized into this Supplementary Report on International Cooperation and Competition in Materials Science and Engineering, and published by the National Institute of Standards and Technology (NIST) as a public service.

This report deals with many facets of MSE, as practiced in other countries, and in the United States. It surveys national policies and programs for science and technology (S&T) and MSE, elaborates on administrative structures to carry out R&D, and provides comparisons between the United States and the major industrial nations of the world. Much of the content revolves around the theme of industrial competitiveness as influenced by cooperative R&D. In assembling this extensive resource document, a complete review function was not carried out by NRC, COMMSE, and NIST, thus the report does not necessarily reflect a consensus of involved organizations. It, however, carries the approval of the Panel 3 membership, so that this rich store of information could be made available to the general science and engineering communities, and others concerned with the broader implications of worldwide MSE.

Samuel Schneider
Editor

Washington, DC
June 1989

PREFACE

This report of Panel 3 of the National Research Council Study on Materials Science and Engineering (MSE) is the result of the efforts of many. The Panel and their affiliations are listed in the following section. Their involvement as participants in the planning, authors of sections, editors and critics has contributed the breadth of backgrounds and understanding of the international scene necessary to give credibility to this report. Others, not formal members of the panel, are to be thanked and praised for their efforts in assisting with the preparation of case studies: Paul Weisz, University of Pennsylvania, for the zeolites, Robert Spear, Alcoa, for the lightweight structural materials (composites for aircraft), and Richard Fleming, E.I. du Pont de Nemours & Co., Inc., for the composites in automobiles. Their technical expertises were invaluable in organizing these documents.

The panel wishes to acknowledge the cooperation of the science attachés of the embassies in Washington, DC of all nations surveyed for their assistance in gathering information about MSE activities in their nations, and for helping us to identify those to whom our questionnaire about MSE organization should be sent.

We also acknowledge those who responded to our request and filled out panel questionnaires, giving us the valuable insights into how MSE was organized and faring in their countries.

All materials were typed in final form by Susan Roth of the National Institute of Standards and Technology (formerly the National Bureau of Standards), and her tireless efforts cannot be praised too highly. Most important of all to the success of this document was Samuel Schneider. He threw himself into the job of staff for the panel and through authorship and editorship of major sections of the report (including the remarkable country by country summaries) left his strong imprint on the final document. All final conclusions and language have been approved by the panel and the report is certainly theirs, but it should also be recognized as Sam Schneider's labor of love.

For the Panel,

Lyle H. Schwartz
Chairman

Washington, DC
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1. OVERVIEW AND SUMMARY

BACKGROUND

In 1986 the National Research Council (NRC) commissioned a comprehensive study of the field of Materials Science and Engineering (MSE), to define its progress and assess needs and opportunities. It was intended that the study present an authoritative and unified view on the role of MSE in its broadest sense-defining research directions and setting priorities and policy at the national level. To carry out the assessment, the NRC established a Committee on Materials Science and Engineering (COMMSE), comprised of five separate panels, each charged with the responsibility to investigate a different aspect of MSE. One panel addressed the issue of International Cooperation and Competition in MSE and the results of its work is reported here.

The selection of this topical area for study and assessment is timely and appropriate in view of the competitive pressures being experienced the world over. Indeed, the decline of the U.S. position in industrial world markets vis-à-vis many of our trading partners has taken center stage in the political debate of the late 1980's. Quoting from Global Competition, The New Reality [The Young Commission-The Report of the President's Commission on Industrial Competitiveness, 1985], "Since 1960 our productivity has been dismal--outstripped by almost all our trading partners." "For this entire century--until 1971, this Nation ran a positive balance of trade. Today, our merchandise trade deficit is at record levels." "In industry after industry, U.S. firms are losing market share." The origin of these negative trends are many and complex, but the technological issues--particularly those related to Materials Science and Engineering, are paramount to industrial advancement. MSE in the U.S., viewed as an enabling technology, will suffer as the economic and technological bases are diminished and must flourish if the technological base is to do so.

With this background, this COMMSE study panel focused on the subject of international cooperation and competition with the charge to develop a quantitative assessment of MSE activities abroad; determine the differences and similarities between the ways materials research and development is carried out in the major countries; identify the formative process and implementation strategy for national policy in MSE and compare with U.S. practices; and, assess the role of MSE in international industrial competition. The study covered several countries: the traditional overseas trading partners of the U.S., the U.K., France, West Germany, and Canada; Japan as a major competitor and strategic ally; Korea as an example of the newly industrialized countries (N.I.C.), or the "new Japans"; China as another N.I.C. under a different political system; and, the U.S.S.R., the principal strategic competitor of the U.S. The task of this panel was done in the context of the national debate on how to maintain our competitiveness in manufacturing, and the observations, conclusions, and recommendations are inevitably impacted by this context.

Data gathering and analyses consisted of four components. (1) A questionnaire was constructed and distributed to all the nations studied, with the exception of the U.S.S.R. The focus of the questions was on national goals, strategy and implementation in science and technology in general, and on MSE in particular. Responses from leaders in MSE were tabulated and incorporated into country-by-country profiles. (2) Statistical information about MSE activities, planned programs, and areas of focus was sought and obtained from the embassies of the nations studied. With the aid of the science attaches of major countries extensive documentation was gathered from various sources, including the open literature. (3) The competitiveness of the U.S. in science and technology (S&T) and MSE was assessed through the development of a competitive profile scheme in which the U.S. position was rated against that of other nations. The position of foreign nations was determined from information obtained from sources identified in (1-2) above and from assessment by panel membership. (4) To instill an element of currency of the impact of foreign MSE on U.S. industrial technologies, case studies were developed for representative industrial sectors: (a) Primary Metals (steel making); (b) Information/Communication (manufacture of VLSI and magnetic storage); (c) Transportation (composites in commercial aircraft, ceramics in heat engines, and engineering plastics); and (c) Energy (zeolites as catalysts).

This volume deals with many facets of MSE, as practiced in other countries and in the U.S. Its theme involves the inter-related elements of cooperation and competition. Cooperation is required to provide the combined technical and financial resources to ensure an international technical base for free trade and national productivity growth. Industrial competitiveness provides the impetus for technical advance and new markets and is the essence of business strategy and success. In collecting and analyzing the information it was often difficult, or impossible to delineate the characteristics, trends, or policies of MSE from those pertinent to general S&T. While explicit characteristics of MSE are emphasized when possible, much of the study involved broader based considerations, in which MSE was an integral part.

The following sections summarize the principal findings of the NRC Panel on International Cooperation and Competition in Materials Science and Engineering, starting first with the major conclusions and recommendations derived from the study.*

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* Note that money figures and currency designations cited in the Overview and Summary section, and in the Report proper are those listed in the original reference documents. Because of varying exchange rates, no attempt has been made to convert local currencies to constant or current dollars.

CONCLUSIONS AND RECOMMENDATIONS

For the past 40 years the U.S. has been the world industrial leader, due to its dominant position in science and technology. During the past decade this position has been rapidly eroding as Western Europe and Japan have assumed an aggressive role in technology development, both for domestic and export markets. In many areas, including materials, these nations now are fully competitive, and in some cases, surpassing the U.S. Their re-emergence in MSE benefits the field as a whole, but the U.S. can and must regain the competitive edge. Without it an essential factor in maintaining our economic well-being will lost. Foremost among the observations contained in this study, is the strong commitment to industrial growth by all major competitor nations, stimulated by coordinated R&D in which MSE is a featured element. Indeed, of all industrial areas in which growth is anticipated for the next decade, MSE ranks along with biotechnologies and computers/information as targeted by all nations sampled.

As demonstrated by the case studies, with the exception of materials producing industries, MSE is rarely the driver in industrial advancement, but it is critical in areas of changing technology. In all of these critical areas, competition now exists, with our major trading partners catching or exceeding our capabilities in the production of many materials and materials systems-i.e., in the development of manufacturing technology. The principal drivers in these competitive markets are specific industrial businesses, not governments, but in the general case coordinated government sponsored R&D efforts can have a significant impact on industrial capabilities to compete. Notable examples in our own history illustrates this impact; focused Federal funding on aerospace related R&D by DOD and NASA and carried out in universities, government laboratories, and industry, have been highly influential in the development of a national eminence in commercial aircraft manufacturing. Moreover, leadership in science doesn't guarantee leadership in engineering or technology, and cooperative mechanisms, fostered by government involvement more and more are being used the world over as a prime vehicle to enhance industrial competitiveness.

The complexity of modern manufacturing has led inevitably to interdependence among industries. This trend is on the up-swing, taking the form of joint ventures, licensing and outsourcing of manufacturing via long-term contractual agreements, and increasingly, cooperation in the long-term research and development of technologies for improved manufacturing capability. In Japan, such cooperation is most advanced, mediated by government funding and often carried out in government laboratories in collaboration with industry. In the U.S., the earliest examples of such industrial cooperation in pre-competitive research may be seen in the funding efforts of such industry sponsored research granting organizations as the Electric Power Research Institute (EPRI), the Gas Research Institute (GRI), and the Semiconductor Research Corporation (SRC), in R&D laboratories such as the Microelectronic and Computer Corporation (MCC), and in numerous industry/university centers. Noticeably lacking in the U.S. and found to a greater degree in all countries studied is a national agency charged with stimulating and assisting industry and, where appropriate, with ensuring that cooperative activities are coordinated and that their impact on industrial development is optimized.

The recognition of MSE as a subject for focused national support is common to all nations, but the organizational structure and funding mechanisms are as varied as are the cultures and governments of those nations. There are, however, some important features to be noted in comparing the U.S. with Japan, and to a lesser degree, West Germany (countries which have been enormously successful in recent years in converting innovative concepts into technological advantage): (1) Education has been focused strongly on engineering rather than science; (2) Coordinated planning of targeted industrial development is stimulated by a government whose policies and expenditures are aimed at fostering the competitiveness of private industries; and (3) National laboratories are specifically charged with service to industry as a significant component in the complex process of transforming innovation to practice and product. These laboratories have almost no counterpart in the U.S., since with the exception of the National Institute of Standards and Technology (formerly the National Bureau of Standards), this country's national laboratories are not charged with the mission of service to the commercial sector.

These observations lead to the following guiding recommendation:

The government of the U.S. must assume a pro-active role in assuring a proper and more favorable environment for technological development by private industry in a cooperative framework involving both the private and public sectors.

This recommendation is consistent with the sentiments and recommendations of The Young Commission. It also leads to several explicit recommendations with particular impact on MSE:

(1) The government should assure the presence of a network of laboratories in which pre-competitive research on materials can be accomplished. This assurance might take one of several forms: further relaxation of regulations and laws inhibiting industrial cooperative research and development; development and funding of new laboratories and/or changing the mission of existing ones by giving them the mandate to support industry where and when appropriate.

(2) The government should recognize the separate paths of technology development characterizing defense and nondefense technology, and devote focused attention and allocate financial support of the nondefense sector in collaboration with private industry and universities.

(3) The government should acknowledge the role played by MSE as an enabling technology required for the success of other industrial technologies and coordinate the already extensive funding of MSE to achieve maximum impact. Funding should be increased where appropriate to assure development of this important field, and transfer of the technology to private industry. This coordinative role should include, but not be limited to: maintenance of accurate information about MSE markets, R&D funding levels, topical coverage and manpower allocation in MSE in the U.S. and in major competing nations; and ensurance of translation of select technical information from those major contributors to new technology including those advanced in commercial applications (Japan, Korea) and those which are not (U.S.S.R., China).

PERSPECTIVE ON SCIENCE AND TECHNOLOGY

Science and technology is a cornerstone of the whole of the economic system as it provides the requisite technical change through the generation of new knowledge and the application of this knowledge for commercial advantage. Virtually every nation now views S&T as the essential ingredient in fulfilling national goals and aspirations. Pro-activism in S&T by government is a characteristic evident in the major countries, worldwide, though the degree of involvement, styles of approach and ultimate success achieved, vary significantly. Two main facts about the S&T enterprise are clear- it is vast in terms of people and money with about 4.3 million persons engaged in R&D and more than $400 billion spent annually; and it is global with over thirty countries having yearly R&D expenditures exceeding the multi-million dollar range. The distribution of worldwide R&D activities is roughly equal between the industrialized Western nations and the U.S.S.R. with approximately a 35% share each. Within the Western countries the U.S. accounts for about 18% of the world effort and Japan 8%. In terms of national economies the (total) R&D/GNP ratio of the U.S. is now very similar to its major trading partners. The relative rankings dramatically change if only nondefense R&D is considered; here the U.S. level is well below that of West Germany and Japan, slightly below France, but still above the U.K. In absolute levels of expenditures however, the U.S. invests more in R&D than Japan, West Germany and France combined. Even so, Japan and West Germany, with less than one-half the R&D activity of the U.S., have almost equal exports, much less than one-half imports, and an overall positive trade balance. Conversely the U.S. has experienced during the 1980's an alarming yearly trade deficit and today, even with a devalued dollar, the trend of serious trade imbalances is continuing.

Science and technology are not static entities; they drive technical change and in turn, are driven by technical change. Problem complexity has increased with the innovation to commercialization time shorten. Organized multi-participant R&D and centralized research management, fostered by government in a cooperative framework is a dominant operating theme of many of U.S. competitors. Most nations, with the exception of the U.S., have an upper-level ministry devoted to industrial affairs and advancement in which collaborative R&D between the public and private sectors is integral to their mission. The rising pre-eminence and importance of civilian oriented industrial R&D is a fact recognized the world around. Industry is now the major provider of R&D funds in most Western nations; it is also the dominant performer of government sponsored research, from basic to development and manufacturing. Countries that have directly enhanced industrial R&D have seen rewards in the market place; Japan is a good example, with Korea on the horizon.

NATIONAL MSE PROFILES

MSE government sponsored R&D in all nations, because of its multi-functional impact, is diffused throughout an array of national bureaucracies and programs. While there are substantial materials efforts, and there may be materials organizational units, no single upper echelon agency in any of the major countries has the sole mission of "materials" or MSE. Nonetheless its role as a critical and enabling technology is recognized, and indeed materials technology has been identified as an "targeted industry" by competitor nations. Oversight, accountability and tracking for MSE R&D, however, is almost always as a subset of a larger technological effort connected to an agency's mission like energy, defense or industry. Accordingly, MSE statistics are seldom tabulated on a routine basis, though estimates of U.S. government MSE funding are available (about $1.1 billion in 1988). While comparable data for other countries probably do not exist in an organized fashion, information on special programs is available, like the European Communities' EURAM program (European Research on Advanced Materials) or Japan's Mew Materials for Future Industries. These materials enhancement programs are appearing on the research slate of competitors with increasing frequency.

CANADA - Canada ranks seventh in the world in GNP, and sixth in trade after the U.S., West Germany, the U.K., France, and Japan. Since 1984 Canada has achieved one of the highest economic growth and job creation rates among the Western nations, due in part to its spectacular growth in manufacturing. Industry is now a leading component of the nation's economy and employs about a third of its work force. Government concentrates its research on areas to improve its industrial trading position through support of basic research, in tandem with providing inducements (e.g., R&D tax credits, capital gains exemptions, etc.) to industry for developmental efforts. Industry has, however, relied on technology importation for its technical edge, a strategy no doubt influenced by the degree of foreign ownership or heavy investment in Canadian businesses.

In Canadian view, their traditional industries and markets no longer can be counted upon to fully sustain the nation's economic growth and new advanced technologies must be fostered through cooperative R&D efforts. A comprehensive federal S&T policy has been under development which focuses on strategies for increased R&D expenditures by the private sector to complement federal and provincial state initiatives. New technologies for Canadian market niche development have been identified by The Ministry of State for Science and Technology (MOSST), the government organization most responsible for science policy and coordination. The three specified by the MOSST led study as strategically important are: information technology, biotechnology, and advanced industrial materials. Current federally sponsored R&D provides a key network of activities, as for instance in the area of advanced industrial materials where government R&D amounted to about CD $29.7 million for the 1985-1986 period.

The organizational setting for these R&D programs is pluralistic and coordinated, and is built around the federal state system of government where policy and programs must have accord between the federal and provincial governments. The ultimate authority for all federal policy on S&T resides in the cabinet of the elected Prime Minister. Line departments, such as the Department of Regional Industrial Expansion (DRIE), the Energy, Mines and Resources, the National Research Council (NRC), and the Natural Sciences and Engineering Research Council (NSERC) have the ultimate charter for implementing federal S&T policy. Each manages the part of Canada's S&T research budget (about $2.9 billion in 1982-83) within its own jurisdiction. The NRC is among the top agencies in funding R&D (about $361 million in 1982-83); its charter includes industrial expansion and regional development. NRC operates its own laboratories; gives direct financial support to the universities and industry for specific R&D projects; and sponsors coordinating research activities. The NSERC underwrites university research supplementing provincial state funding. It distributes its funds ($227 million in 1982-83) through peer-reviewed project grants to the universities. MSE projects primarily focus on the metals side, but other materials, like advanced ceramics, composites, and polymers are increasingly being pursued. More industrially oriented R&D is administrated under a separate grants program designed to foster direct collaboration between industry and university researchers.

CHINA - Modern day S&T in China started in 1949 with the formation of the Communist style of government and its progress ever since has been tempered by the political scene. Initial ties with the U.S.S.R. led to the installation of the centralized, highly structured Soviet type S&T system. In 1975, the government put forth a new set of economic goals. These were described as the "four modernizations", targeted to raise the economic power of China by the year 2000 to a rank much above its self-proclaimed status as a third world, less than developed country. The four modernization elements were agriculture, industry, defense, and science and technology. Within this context, a key strategy was the massive importation of Western technology, including whole manufacturing plants and the simultaneous buildup of S&T. Budgets were increased, new institutes formed, science education expanded, and interaction with the Western S&T activities encouraged on all fronts, including a significant outreach program for additional education of their already well trained, up-to-date students from the better Chinese institutions. The plan, now in place, identified

27 "spheres" for comprehensive research, eight of which were designated as of special prominence: Agriculture; Energy; Materials; Computer Science and Technology; Lasers; Space; High Energy Physics; and Genetic Engineering.

The organizational structure of R&D follows government divisional lines with additional special entities for Party oversight and control. The primary executive body is the State Council, and under it are an assortment of ministries, agencies, and commissions, such as the State Scientific and Technology Commission (SSTC) which plans and coordinates civilian R&D policy and programs. Its activities are roughly divided among four sectors: The Chinese Academy of Sciences (CAS); the universities; the industrial sector; and other ministerial sectors (e.g., agriculture). Military research is handled separately by the National Defense and Technology Commission.

Whatever the institutional framework, the major organizational mode of R&D in China is the research institute--one or a set of small laboratories having a narrowly defined research focus such silicate chemistry, or transformer research or chemical metallurgy, etc. Their size varies with need, from 100 to 1000 persons, the average being less than 500. Technical staff constitute about half of the total with senior people amounting to no more than 20 or so for the average size institute.

Another major organization exerting influence on S&T is the China Association for Science and Technology (CAST). This national group is funded by government and acts as the umbrella representative for more than a 100 of the nation's learned (professional) societies. Although formed in 1958, the current liberal government approach to intellectuals, has allowed CAST to provide a more or less unencumbered forum for free scientific exchange and open policy advice to government.

FEDERAL REPUBLIC OF GERMANY (FRG) - The distinctive feature of industrial and economic policy, planning, and programs in West Germany is its broad based consensus-building process. This process combines elements of decentralized decision making and regional implementation, with sectoral autonomy a keyword and representation by major interest groups a guiding premise. These characteristics also typify the S&T system in FRG and set it apart from the approaches used by the rest of Europe. Materials science and engineering has been a long-standing theme of many of FRG's R&D programs. The lead organization for S&T policy is the Ministry of Research and Technology (BFMT). The BFMT receives about 60 percent of all federal R&D funds (about DM 7.0 billion in 1984). About half of these funds go directly to industry on a cost-shared basis, usually 50-50. The remainder is used to support major national research centers, educational institutions, and private research organizations, many of which have an industrial focus.

A significant fraction of research funding is channeled to a series of quasi-independent research institutes or laboratories through major nongovernmental research associations or societies, like the (MPG) Max Planck Society (basic research), the (FhG) Fraunhofer Society for Applied Research (industrial research), and the (DFG) The German Research Society (education). The research institutes of these societies, are usually small, highly focused, and autocratically administered. The FhG, for example, consists of 34 separate institutes and employs about 4,000 people, one third of whom are scientists and engineers. Its institutes cover nine important industrial areas: microelectronics; information technology; automation; production technologies; materials and component behavior; process engineering; power and construction engineering; environmental research; and technological economic studies and technical information. The materials and component behavior area ranks first in terms of staff allocation (approximately 500 personnel) and second in budget (behind microelectronics, each with about DM 53 million in 1985).

In 1985, the BFMT inaugurated a new 10-year materials research program having an annual budget of about DM 100 million. The BFMT has assigned the Nuclear Science Research Center at Julich to manage the new program, which encompasses the following areas: high-performance structural ceramics; powder metallurgy; high-temperature metals and special materials; high-performance polymers; and advanced composites. About 30 institutes, representing the FhG, the MPG, and Germany's large research centers, cooperatively participate with numerous industrial companies in this program.

FRANCE - France has developed a modern and highly diversified industrial enterprise which generates about one-third of its GNP and employs about one-third of its workforce. It is now a major producer and exporter of steel, chemicals, motor vehicles, nuclear power, aircraft, electronics, telecommunication products, and weapons. The latter five product areas have been featured items on the government's agenda for industrial advancement. National planning and policymaking in France for all areas, including S&T, is unified. It is highly centralized within a governmental system structured for maximum coordination and control of programs. In 1988, the government R&D budget was about FF 90 billion; combined with industry expenditures, total R&D amounted to approximately $24 billion. Of this, about $1 billion was for MSE R&D.

Organizationally and operationally, the R&D system in France is enmeshed in an inter-ministerial structure, each covering different mission spheres like defense, industry, education, etc. The Ministry of Research and Technology was formed in 1981 to focus government R&D on national industrial technology programs, as well as provide oversight and management of the nationalized industries. Within the ministerial system, the government operates a host of research establishments and laboratories. By far the most extensive and important agency for R&D is the Centre National de la Recherche Scientifique (CNRS). Operational in 1945, CNRS is attached to the Ministry of Education and is organized much along the lines of the traditional academic disciplines, supporting primarily basic research in chemistry, physics, earth, atmospheric and ocean sciences, life sciences, engineering, social sciences, mathematics, and humanities. CNRS, however, does not have a research directorate for MSE. In the last few years, cross-cut programs have been established in communication science and new materials. In 1988, CNRS had a budget of about FF 9.0 billion, about 16% of the total civilian R&D expenditures, and employed almost 10,000 scientists, and 15,000 support staff in 1350 laboratories or universities, other government agencies, and industry.

As a complement to their internal research efforts, the French have sought to extend their S&T base through international cooperative programs. These for the most part are geared toward industrial development and involve multi-nation participation under the auspices of the EC. The two most notable are ESPRIT (European Strategic Program for Research in Information Technology) and EUREKA (European Research Coordinating Agency), the latter being the French response to the U.S. SDI program, but oriented for technology, not defense. Both programs require participation by industry on a funding and research conduction basis.

JAPAN - The Japanese S&T and MSE establishment is a highly structured enterprise that has been instrumental in many past technological successes. It is comprised, however, of conventional organizational elements and implementation/strategy instruments not too dissimilar from those used throughout the world. What is atypical to Japan is its systems approach--its long-term and consistent policy, stimulated and coordinated by government but coupled to an effective communication link between the public and private sectors, including a multi-level advisory/committee arrangement. In an orchestrated division of activities and responsibilities, the government acts as the catalyst and industry takes the lead role as a funder and performer of R&D.

Within government, the highest policy making body for S&T is the Office of the Prime Minister. Two advisory councils, the Science and Technology Council, and the Science Council, provide guidance on S&T and on pure science matters. The membership on these councils are made up by leading spokespersons in government and out; chairmanship resides with the Prime Minister of Japan. These councils establish national goals and provide broad directions for S&T and MSE, and in general, have great impact on Japan's federal S&T yearly budget (about ¥1700 billion in FY 87). The Ministry of Trade and Industry (MITI), the Ministry of Education, Science and Culture (ME), and the Science and Technology Agency (STA) essentially share government operational responsibilities for S&T and MSE, including planning, funding, and oversight.

STA is located within the Prime Minister's Office. It receives about 26% of government R&D funds for major national projects like the space and the reactor programs. The agency also has the charge to stimulate basic research within industry and through its Japan Research Development Corporation (JRDC) support new technology developments (Exploratory Research for Advanced Technology-ERATO) using start-up companies as one implementation mechanism. Attached to STA are six research institutes, two of which, NIRIM (National Institute for Research in Inorganic Materials), and NRIM (National Research Institute for Metals) are the principal laboratories most related to MSE. Although under

STA, they often perform R&D in cooperation with MITI, the industrial oriented ministry.

ME accounts for about 47% (FY 1987) of government research funds, the total of which are provided to the universities and national centers for scientific research.

MITI is the central government organization having industrial development as its primary charter. It receives only about 13% of government R&D funds, relying on cooperative mechanisms with industry to leverage considerably more R&D. MITI formulates industrial technology plans, determines and provides for subsidies and/or funding and selects participating industrial R&D groups/associations to work with MITI's 16 national labs on a long term basis. The national labs fall under the jurisdiction of one of MITI's operational arms, AIST (Agency of Industrial Technology and Science), which in FY 1987 had a budget of ¥122 billion. A sister agency, JITA (Japan Industrial Technology Association) functions as the licensing agency of AIST and provides regular information on foreign technology developments.

Typical of MITI's procedural mode is their program on advanced materials (R&D Project on Basic Technology for Future Industries). This program, under the auspices of AIST, targets three general research areas, biotechnology, electronics, devices, and advanced materials. In the general case, AIST forms a non-government advisory committee for each major project area and an industrial association is created to work cooperatively with all other members of the organization and MITI's national labs.

To complement Japan's already complex cooperative venue, a new dimension has recently been added. In October of 1985, the Diet established the Japan Key Technology Center to be run under the joint oversight of MITI and the Minister of Posts and

Telecommunications (MPT). The Key-TEC program (estimated to be about ¥31 billion) is viewed as a part of a needed effort to boost science through support of long-range advanced applied and fundamental research on key, but very new advanced technologies. The focus of the programs is to be about ten years out in front of current knowledge and is not supposed to result so much in prototype products as in generic information upon which products can be based later. Because of the advanced technology mission of Key-TEC, one could describe the program as a Japanese civilian analog of the DOD's DARPA.

KOREA - The rapid industrial development of Korea matches or even surpasses that of Japan, and for many of the same reasons. Industrial developments proceed rapidly, owing to a strong government that has placed S&T in a favored position and rewards corporations and organizations most successful in promoting international trade.

The Korean Advanced Institute of Science and Technology (KAIST) is the largest government supporter of materials science and engineering. Overall, materials research in Korea is divided into two major categories: conventional materials improvement and import reduction, and technology development (advanced materials). The former category is supported in the main by industry, whereas research in the latter category is financed almost exclusively by the government in a public-private cooperative mode. In 1985, there were about 29 advanced materials projects under way in Korea, including efforts in metals, polymers, composites, and fine ceramics. There are about 3,000 Ph.D.'s working in science and technology, with about 10 percent of those involved in materials science and engineering.

UNITED KINGDOM - The organization of the R&D system in the U.K. is extremely pluralistic and decentralized, and in many respects resembles the U.S. system in that S&T policy and planning is carried out by several government departments. While new programs have been established in the U.K. and new approaches (collaborative research) are being tried, the elemental organization of R&D has remained fairly static over the years. On the whole, there is no primary coordinating group within government for its $6.1 billion/year R&D program, and individual departments maintain an autonomous operation.

Research and Development (ACARD) is the main body influencing coordination of applied R&D between government and external groups. It, however, has no management function nor does it allocate resources; it does provide the primary pipeline conduit for industry access to top government department heads.

The majority of all university research funds come from the government's budget and are administered by the Department of Education and Science. In 1983, the Department spent about $1 billion on university research, a sum which included major funds for four major research laboratories operated by the Councils. Defense R&D consumes more than 50% of the U.K.'s research dollar (pound). The Ministry of Defense provides this support primarily to industry via contracts and for operation of its own set of laboratories. The Ministry funds little (<2% of its budget) for basic type research at the universities.

The principal government agencies for civilian R&D are the Department of Trade and Industry and the Department of Education and Science, with some added activity by the Department of Energy. Support for industry is provided by Trade and Industry in two ways; by direct investment (e.g., loans, pre-production guarantees) in firms through its National Research Development Corporation, and by direct R&D contracts, usually on a cost shared basis. In 1983, 61% of its funds were spent this way in an effort to increase technological innovation by industry. The balance of the Department's resources go to support programs in other government departments and in its own laboratories. Today, there is a general redirection of the U.K.'s national research establishments to R&D more akin to market oriented needs. Research organizations, like the National Engineering Laboratory, the National Physical Laboratory, and Harwell, work with industry on a contract basis. Harwell, for example, essentially operates as an independent laboratory serving industry in a self-sufficient fiscal mode.

On the whole, industry contributes less of its own money on R&D than the government spends, a practice just the opposite to that in most other Western nations. British industry is a mixture of public and private firms. Several important industries that are publicly owned include steel, railroads, coal mining, shipbuilding, certain utilities, and most civil aviation. These receive significant attention by the government, as do the more high technology areas. To aid industry, a major new five-year, $500 million (Alvey) program was established by the government in 1983 to bolster the U.K.'s competitive position in microelectronics. The program follows a consortia model involving cooperative R&D between industrial companies, government laboratories, and the universities. Costs are shared between industry and government on about a 50:50 basis. A follow-on Alvey ($1.58 billion) multi-year program is now under consideration. Initiation of another major collaborative type program aimed at developing high technology products has been approved. This multimillion "Link program" will make funding available for selected university projects, provided that the costs are equally shared with industrial sponsors. It is anticipated that up to $735M will be spent by government and industry over the next 5 years. Initial projects will cover molecular electronics, semiconductor materials, industrial measurement systems, genetic engineering, and nanotechnology. It is presumed that the basis for the projected R&D on materials technology under the Link program had its origin with the submission in 1985 to the Department of Trade and Industry of the "Collyear" Report. The Collyear committee proposed a five-year, £120 million program "For the Wider Application of New and Improved Materials and Processes".

UNITED STATES - In the U.S., S&T in general, and MSE in particular, in government affairs, are pluralistic and decentralized. The organizational framework for MSE is similar to the practices followed by many nations. Unlike many of its prime competitors however, the U.S. does not have a major department having the responsibility to foster industrial advancement, and to coordinate and integrate the spectrum of materials R&D upon which industry depends. MITI in Japan, for instance, is a strong force in their industrial affairs and MSE; nothing comparable exists in the U.S. Accordingly, the R&D directions in science and technology, and in materials taken by the U.S. government is the sum of all the directions of the parts making up the R&D system. Coordination and control is agency-to-agency specific and national priorities emerge from individual agencies perceptions of national needs and opportunities, guided by the framework set by cabinet level policy and directions.

For its overall planning, government relies on formal and informal advisory groups and organizations at all levels within government and out. In the main, however, industry and the universities provide S&T policy advice to the government essentially only through informal communication links. During the 1970's, the Office of Science and Technology Policy (OSTP) and the Office of Technology Assessment (OTA) were created to advise the President and the Congress, respectively, on R&D issues as a whole, including materials considerations. In 1982, a science council, reporting to OSTP was established to improve coordination of the national research effort. OSTP also chairs a coordinating Committee on Materials (COMAT), made up of representatives of government agencies engaged in materials R&D.

The Office of Management and Budget (OMB) provides further oversight through its budget review and approval process. The General Accounting Office (GAO), an analytical arm of Congress complementing OTA, furnishes additional assessments and advice. The Academies of Sciences and of Engineering constitute major independent private advisory sources for the whole of government.

Through this advisory and review process, new programs addressing the competitive issue, such as the recently established high temperature ceramic superconductor initiative, and the Sematech cooperative, are planned and implemented by Executive orders or enactment of new legislation. In 1980, the National Materials and Minerals Policy, Research and Development Act was passed; it required coordination by the President of the government's minerals and materials activities. This was followed by the passage of the National Critical Materials Act of 1984, which called for (1) the establishment of a National Critical Materials Council, and (2) the establishment of a national Federal program for advanced materials research and technology, and the stimulation of innovation and technology utilization in the basic and advanced materials industries. Implementation of the law by the Executive Branch, is still in the early stages. In associated legislation, Congress addressed the issue of industrial research and enacted the Cooperative Research Act of 1984. This law, and proposed legislation modifying the Clayton Act, provide a more favorable environment (less antitrust penalties) for cooperative R&D between businesses. Moreover, it is not obvious what additional steps will be taken in the U.S. since so much is already in motion. This is particularly true since no single format is appropriate to address all MSE needs.

Government provides about one-half of the $130+ billion currently devoted to all types of research in the U.S.; industry provides the balance. Definitive statistics on industrial funding of R&D in MSE are not available, but may be as much as ten times the

$1.1 billion spent by government. Government sponsored R&D is carried out by contract mechanisms in industrial laboratories, in university laboratories, and in independent laboratories, or university research centers; and by direct Congressional appropriations in the government's own departmental laboratories and in Federally funded R&D laboratories, principally the National Laboratories, and the NSF sponsored research centers. By far, the major fraction of the total Federal R&D funds go to defense related research, but for materials R&D, the DOE sponsors slightly less than half the work. The balance is provided principally by DOD, NASA, and NSF, with smaller efforts at DOC (NBS) and DOI (BOM). The specific research programs on materials are diverse, and cover the majority of the materials classes and types, but usually in the context of broad efforts like engine or VLSI development. Industry performs the bulk (about 73%) of all R&D conducted in the U.S. It spends the majority of its own R&D funds within its own laboratories and the rest at independent research centers and the universities. Corporate R&D expenditures are often reported and analyzed as a percentage of sales and as such, R&D, particularly that of a long-term nature, may suffer from the vagaries of the near term economic climate.

U.S.S.R. - The structure and operation of S&T within the Soviet Union is intimately linked and woven into the machinery of government, a single party system. It is the most highly structured, and centrally controlled system in the world. Planning is a top down arrangement where the party policy is articulated into S&T goals, generally through one of the government's five-year plans.

Operationally, S&T starts with the Central Committee. Next in line is the Supreme Soviet and its functional body, the Council of Ministers, made up by the heads of the major ministries (like defense, industry, education, etc.), and the State Planning Committee (Gosplan), State Bank, and the like. The real power of decision rests with the Presidium, chaired by the head of the Communist Party. This body proposes and approves S&T plans formulated by the Gosplan through a coordination process involving the Academy of Sciences, the State Committee for Science and Technology, and the various ministries. Within this organizational complex, the Academy of Sciences carries the most influence, and at one time guided R&D within the ministries. Today, the Academy is the science side of Soviet S&T and the ministries the technology side. Higher science education is handled by both the Academy and by the Ministry of Higher and Secondary Education. The Academy and other educational institutions, as well as all the ministries, operate an array of research establishments of varying size and sophistication, involving well over one million workers. Soviet science on the whole is highly rated, and in some cases enviable, to be watched and built upon, as for example, Japanese advancement of the published U.S.S.R. materials and processing developments in the areas of low temperature diamond film deposition and electrodeposition of fibers for metal-matrix composites. Soviet product design and manufacturing technology is inefficient and more often that not, characterized by reverse-engineering of Western made goods, a practice leading to a five to ten year 'to the market' lag between the East and the West.

Overall, the S&T 'plan' (put forth by Gosplan) over any time frame is developed as an integral part of the National Economic Plan. It is detailed in almost every respect; it identifies the problems to be worked on, which research groups will do the work, and defines achievements expected. The subsection of the Economic Plan dealing with specialized branches of industry, targets such items as the introduction of a new technology, automation, investments, and production goals, etc. More and more, the industrial ministries are being allowed increased autonomy in their R&D, but still are subject to oversight by the Academy (and the Party). There is, however, no official tie between any major research grouping; thus many of the innovative basic ideas (including materials) generated by the Academy research institutes are not developed within the country because the ministries conduct about 90% of all engineering R&D, and generally do not interest themselves in Academy business (and vice versa). While there is superficial coordination, there is no incentive for collaboration and Soviet industry opts for adaption of Western technology rather than developing their own. As a consequence of this division, MSE is treated as materials science on one hand, and materials engineering on the other, with the former generally excellent, and the latter duplicative. The impact of U.S.S.R's new policy directions, "glastnost" (openness) and "perestroika" (restructuring) on their S&T and MSE remains to be seen.

COOPERATION

Cooperative research entails the joining of resources, technical and financial, to pursue areas of collective interest in furtherance of specific individual needs. Recent times have seen the methodical creation and buildup of a plethora of new technical linkages among businesses and research organizations throughout the world, outstripping past efforts. These take many forms, and joint ventures, multinational corporations, national and international consortia and an array of new types of collective industrial research associations now abound. However, both the concept and conduct of cooperative R&D involving private corporations are more common in Europe and Japan than in the U.S. This difference derives partly from the smaller domestic or regional markets, hence smaller resources for R&D in other countries, and partly from distinct philosophical convictions regarding competitive behavior. Whatever the reasons, cooperative industrial R&D abroad plays a more active and pivotal role in national affairs than in the U.S. More and more other nations rely heavily on government orchestrated technology development programs in which collaborative arrangements between government, universities and industry is integral to their strategic approach.

In many of the European countries there is an extensive network of industry-specific collective associations with independent laboratory facilities, usually operating with a government subsidy along with some formal basis for industry funding. In addition to these strictly national efforts, R&D conducted under the auspices of the European Communities (EC) represents one of the most extensive collaborative efforts in existence. It involves over a million workers, major research laboratory centers and a multi-billion dollar budget. The EC programs in recent times have focused on cooperative R&D requiring direct participation and funding by private firms. Example programs relevant to MSE include ESPRIT (European Strategic Program for Research and Development in Information Technology), BRITE (Basic Research in Industrial Technologies for Europe) and EURAM (European Research in Advanced Materials).

Japan probably has the most prolific system of cooperative research programs and organizations. Major categories consists of at least 18 government centers, 600 local centers and (many) semi-public groupings. The industry-specific cooperative R&D efforts are primarily funded by MITI and conducted through (more than 50) research associations as authorized by Japan's Industrial Technology Law. Advanced Materials for Future Industries is a featured item on MITI's collaborative R&D venue.

A distinct feature of U.S. cooperative R&D activities is its diversity, but not its cohesive approach. Individual researchers, universities, private corporations, and all levels of government participate in different degrees and at different times to meet specific, but individual needs. While the U.S. has no direct counterpart cooperative system or organizational framework, nor national policy in place comparable to its competitors, movement in this direction is evident. Antitrust laws have been modified and industrial consortia (e.g. MCC, SRC and the new Sematech) are on the rise. Executive orders are in place to promote better utilization of the National Laboratories by industry though the issue of intellectual property and data rights needs resolution. New NSF sponsored Engineering Research Centers are being set up (modeled in part after the successful NSF Materials Research Centers). State initiated technology incubator programs are appearing with regularity. Still lacking however are the government fostered national laboratories for applied industrial research, seen so effective in Japan through its MITI's labs and in West Germany by the Fraunhofer Institutes.

IMPACT OF FOREIGN MSE ON INDUSTRIAL TECHNOLOGIES

International competition affects various industries in differing ways and at rates and to degrees which depend upon diverse but inter-related political, economic and technical factors. No single set of parameters can fully describe the impact of foreign MSE on U.S. industrial technology. Nor is a comprehensive and exhaustive analysis required to establish the status and trends vis-à-vis competitors to learn the lessons that are to be learned.

Characteristic Trends

Case Studies

Manufacturing of Steel: The U.S. steel industry, despite recent cuts in production is still a major economic factor. It is the fourth largest industry in the U.S. employing in excess of 160,000 people. In the countries surveyed (Japan, West Germany, Canada) the steel industry is considered vital, not only for its direct effect on the economy, but also on related industries.

Currently the U.S. lags others in the implementation of the newer economical processes, like continuous casting. While opportunities for future continued industrial competitiveness are present, the U.S. may be unable to take advantage because of its diminished R&D base, as compared to other countries. In competitor nations there is more cooperative research based on identified long-term research goals along with commensurate research funding. The U.S. has only begun this process. It appears that the best, and possibly the only way long-term research can be carried out in the future in the U.S. is on an organized collaborative basis with the government acting as a catalyst and partial funder.

VLSI: The international market in semiconductor devices (primarily Si-based) is expected to exceed $50 billion by 1990. It is generally expected that a tenfold decrease in feature size must take place over the next decade in order to accommodate needs for increased device density and speed with reduced power requirements. The race between Japan, the U.S., and other nations to develop effective means for surface processing on this 0.1-0.3 μm length scale will play an important role in determining the future configuration of the electronics industry world wide.

The success of the Japanese effort thus far in VLSI processing is attributed to the organization of their resources toward the technical goals required for commercial success. As a nation, they have made a commitment to develop new processing technologies and to apply them to semiconductor structures conceived for future applications. MITI has identified projects for continued effort that require ten years or more of R&D to accomplish commercialization. The system they use integrates the efforts of national laboratories, universities, and most importantly, industries, into an effective and creative organization for developing new processing technology. Critical to achieving such a result is an organization with decision-making capacity and long-term stability of resources.

Magnetic Recording Media: Magnet recording media is a classic example of materials as an enabling technology. The actual value of the magnetic particles in a tape or disk medium may be only 10%, and the medium may be only 10% of the value of drive--yet it is certain that the goal of high density storage cannot be reached without the achievement of high coercivity in particles of ever decreasing and even more uniform size.

In this area there is not a coordinated government policy to chart the direction of Japanese industrial choice--rather the driving force comes from individual companies with support by the government. It is important to note the degree of cooperation between companies in Japan as for example, the creation of a world wide standard for the new 8-mm consumer machines and tape. This standard was developed and agreed upon in 12 months. In recent years the Japanese government has played a more direct role in the recording industry through a MITI focus on perpendicular recording including in a coordinated research program involving the efforts of 12 universities, 15 industrial laboratories, and at least two government research laboratories.

Conversely the U.S. is ill-prepared to compete in magnetic technologies. There are only two universities in the U.S. that offer magnetic engineering and there is only a feeble research effort in magnetooptics.

Composites in Commercial Aircraft: Commercial aircraft will increasingly be constructed from organic matrix composites (OMC) rather than metals, but this conversion will be slowed by safety and financial risk questions. It is estimated that by the year 2000 about one-fourth of the structure of commercial aircraft will be composites. Aluminum is the metal most at risk in the shift to composites; however, the impact on the aluminum industry would be only about 1 % of total volume.

The materials manufacturing system supporting OMC has a broad base of U.S.-Europe-Japan corporations and most of the major suppliers are international companies which can function effectively across the free world. The basic technologies appear to be diffused with no one country having a strong lead. The possibility of establishing a unique scientific advantage in OMC is deemed extremely difficult due to the diffuse nature of both the OMC and commercial aircraft businesses. It is on the engineering questions of quality design and manufacturing of composites upon which the competitive lead will depend. It is in these areas where a coordinated national effort to ensure leadership is required. Barring this, one may readily envision a situation in which increasingly large fractions of U.S. commercial aircraft are manufactured in those countries in which quality assurance, fabrication control, and design capability of composites can be optimized.

<u>Ceramics in Heat Engines:</u> A survey of worldwide activities in this field indicates that several countries, including the U.S., Japan, Germany (FRG), Sweden, and the U.K. have been active in this field, and several others are beginning to become active. Pioneering work had been carried out by the U.K. in the 1960's. Experimentation using some of the processes developed in the U.K. started in the U.S. shortly thereafter, aimed at gas turbine applications. The U.S. work, initially funded by industry, expanded greatly in the 1970's when various government agencies provided more substantial funding. By the late 1970's the U.S. was believed to have a general leadership position in some aspects while the U.K. led the science and other countries, particularly Germany and Sweden, excelled in specific areas.

Subsequently, Japan adopted the development of structural ceramics for heat engines as a part of its national technological development in ceramics and made huge strides. Currently, Japan appears to have become the world leader in terms of the capability of producing ceramic engine components (and other ceramics) commercially such as ceramic diesel engine prechambers and ceramic turbocharger rotors. These are appearing in autos marketed in Japan, but it should be noted that much additional technological and manufacturing progress is needed before ceramic components attain a major role in heat engines. Improvements are needed in product reliability and reproducibility, as well as cost reduction. Indeed, newer analyses of the potential advantages of ceramic engines do not present as bright a near term future as had driven the initial R&D effort. Nonetheless Japan is sufficiently far ahead that only a concerted coordinated effort by all sectors in the U.S. would allow this country to compete for a major share of the market. This appears to be occurring, but in a piece-meal fashion with the independent formation of numerous industrial trade associations and ceramic research consortia.

This assessment illustrates four major points with regard to U.S. national R&D policy. First, careful analysis of the international technological opportunity is necessary before the commitment of resources for particular targets. Second, is the insufficient or ineffective government planning and coordination so that resources are utilized efficiently. Wide fluctuations in level of effort on a 2-3 year cycle are fundamentally and inexorably incompatible with good technological development. Third, is the insufficient attention to national personnel questions which have long time constants. Fourth, in the chain of science-engineering-manufacturing, the U.S. and Europe (which started ahead) may be competitive in the earlier stages, but both have lost the lead in manufacturing to Japan.

Engineering Plastics: As in the case of aircraft, materials substitution is a major trend in automotive manufacture. The inevitability of replacement of the metal auto skin by some form of reinforced plastic is unquestioned; however, the rate of substitution is slowed by several factors, both technical and other. Increasing liability and warranty requirements generate the need for more extensive and expensive test evaluation. The most pressing technical need is the reduction of cure temperature for paints and/or increase of high temperature tolerance by the structural plastics--both factors need consideration to assure continued utilization of enormous capital investments in paint ovens.

The influences of governments throughout the world on this materials substitution issue have been indirect, through legislated technical requirements--the most notable of which include emissions limits on hydrocarbons, crash worthy bumpers, less hazardous windows, and fuel economy. One thing present in Japan and Europe and missing in the U.S. is formal and visible interlocking of materials producers and users.

Catalysts: The U.S. has developed and maintained a clear lead in this area, both scientifically and technologically. Zeolite cracking catalysts with sales of about 700 tons per year in the U.S. can be shown to produce a savings in gasoline yield equivalent to over $2 billion/year (based on fuel costs of $20/bbl). Research is worldwide, but thus far all commercial processes are based on U.S. inventions and licenses. As strong as is the U.S. lead, complacency is not justified. Strong competition from abroad (Japan, Germany, France, and the Netherlands) is apparent in areas of science and development of new zeolites. More than one half of current publications and patents come from abroad. Most zeolite catalyst patents will expire in the late 1980's and early 1990's, and one can expect that many foreign manufacturers will begin to offer these catalysts, although process patents will continue to be enforced for some time to come. Leadership in this field will require discovery and synthesis of new microporous crystalline materials and development of new applications for them in chemical catalysts, selective absorption and related fields. There is already ample manufacturing capacity and know-how in Japan, Germany, and in the Netherlands in this field to pose serious threats to the U.S. dominance.

National Surveys

A survey of the nations studied revealed a consistent picture of each country's national goals, strategies, and implementation tactics in S&T in general, and MSE in particular. Analysis of the survey questionnaire provided the following conclusions:

There was unanimity of among foreign nations in identifying the same three areas for emphasis in the years 1976-1986, with expectations of continued emphasis in the following ten years. Materials Science and Engineering, biological (and behavioral) science and computers (information) have been and will increasingly be the central foci of R&D funding in all.

When the government role in foreign countries is explored, it is evident that the views of industry, universities and government are sought and received; but in the U.S., by contrast with almost all other nations, this input is informal. S&T directions are set by all governments to assist specific industrial areas. MSE is not so directed in the U.S., while most other nations set MSE directions in a manner intended to target specific industrial market areas. It is particularly noteworthy that in the U.S., there is no official MSE strategy, while in most others surveyed, a specific national plan does exist.

There is a universally accepted role of governments in attempting to ensure the coupling of R&D with commercial exploitation of research results. However, the use of government laboratories in this role is common in most nations, with the general lack of such activity in the U.S. a significant difference.

The availability of adequate trained manpower to carry out the needed MSE is certainly a concern of all nations, but there is a high degree of variability in control of the educational system among the countries surveyed. The extremes in control are the U.S. with its vast decentralized local region dominated higher educational system and Korea in which levels of educational funding are directly tied to the GNP and technical training areas are emphasized as part of the national economic plan. All foreign countries indicate that emphasis in MSE has increased during 1976-1986 relative to other areas of education, with further emphasis expected in the next ten years.

Similar to the U.S., MSE is taught academically in a variety of departmental settings and in all countries but Japan and Korea the trend is toward more multidisciplinary MSE. Research in academic departments is similar the world around, with 30-50% of the research of an applied nature while the remainder is basic. Korea is a striking exception, with 80% of the university research identified as applied. There seems to be a general trend toward more applied research at universities although not in Japan (where industry links are traditionally not close), Korea (where there could hardly be a more applied activity) and W. Germany, where the more applied work is conveniently carried out in the Fraunhofer Laboratories, which are only loosely tied to the universities.

Government policy and funding for MSE education are viewed as marginal to only moderate. Attention to and funding of education of the targeted areas of S&T may be a strategic oversight. Techniques for implementing national goals for MSE are similar among foreign nations with centralized program planning and implementation along with targeted S&T and cooperative mechanisms being favored tools.

Comparative Analysis: U.S. and Foreign MSE

An analysis was made of the competitive status of MSE in the U.S. vis-à-vis other nations. It represents a snapshot in time--as of early 1987 and is intended to illustrate different MSE systems and the efficacy with which the system works to achieve their respective MSE status, good or bad. The analysis has been grouped under three somewhat arbitrary headings that influence the U.S. competitive position in MSE (and S&T): 1) Industry Factors; 2) Technology Factors; and 3) Government Factors:

Industry Factors: Industry factors were analyzed under seven headings: A) Comparative Advantage in Major Markets; B) Comparative Advantage in MSE; C) Productivity; D) Industry Structure; E) Innovation to Commercialization Capacity; F) Resource Factors; and G) Capital and Financial.

In the first five of these, A-E, with a few exceptions, primarily involving Japan, the U.S. was seen to either be at parity with or to have a clear current advantage over the five comparison countries (Japan, France, Germany, the United Kingdom, and Korea). It was, however, determined that in these categories the U.S. position was static or deteriorating.

In categories (F-G), by contrast, the U.S. was seen to have almost no current advantage and a declining or static position in both of them. In sum then, the U.S. can be viewed as being in a disadvantageous position in both resource factors and capital/financial factors influencing our industry capability--and things are worsening. These perceptions are clearly related to some of the subcategories in the Government Factors section (3). They are, of course, important in themselves both as guides to governmental policy makers and to technologists struggling with strategies that seek to reverse the other declining trends through new capital equipment investment. Will needed capital be available, is a major question.

Technology Factors: The picture under the rubric of Technology Factors (2) is more complex. Here the heading was assessed under four subcategories: A) MSE R&D Emphasis (by task); B) R&D Emphasis by Material; C) MSE Resources; and D) Interactions and Interfaces.

In the first of these (A), the U.S. is seen to have a clear advantage (and to be holding it) in the area of basic research. In application, development and manufacturing, the U.S. is less well off. Japan leads in each of these areas that presage the development of new products and processes. Worse, the relative position of the U.S. in each of these areas is deteriorating. This phenomenon clearly relates to the very poor competitive position the U.S. has, vis-à-vis competitors in the area of government-business relations. The U.S. has a long tradition of government support for basic research but essentially no tradition in direct support of nondefense industrial technology. This declining position should carry a strong message to those in the U.S. government concerned about the future of this field. The picture under Materials R&D Emphasis (B) is less clear. The U.S. currently has advantages in some materials areas and not in others; clearly there is an improving position in composites while declining in many others. Indeed, the same comments are relevant to MSE Resources (C) including education, facilities, and funds. Overall, there is a perception of a deteriorating position of leadership that warrants a continuing watch.

Government Factors: Declining or improving positions described above cannot be rated as either bad or good in the absolute. To be meaningful, they have to be compared to what would be appropriate under the national materials strategy of the U.S. Unfortunately, under the Government Factors heading, in strategy itself, the U.S. is at a worsening disadvantage with respect to competitors. The U.S. appears to have neither the structure nor the relationships that can lead to a national industrial and materials policy that is respected by both business and government. As a result of not having a MSE strategy in place, several questions are open to conjecture, as for instance - Is the U.S. declining position in technology (e.g., steel), appropriate to a country at our stage of development, or is it a result of a lack of strategic thinking and advanced planning?

Summary: Despite the caveat that this comparable analysis has no significance as a statistical survey, it has major significance as the combined perception of experts and actors in the field of materials. The portrait it paints is, overall, one of a developed nation which has yet to adopt strategies, structures or mechanisms to defend its declining leadership in the world of materials.

2. INTRODUCTION

> **"Competitiveness is the degree to which a nation can, under free and fair market conditions, produce goods and services that meet the test of international markets while simultaneously maintaining or expanding the real incomes of its citizens."**
> **--President's Commission on Industrial Competitiveness, 1985**

In the early 1970's as the members of the Committee on the Survey of Materials [COSMAT 1974] labored over the monumental comprehensive survey of the state and future of materials science and engineering, their world view was dominated by two principal themes: conservation and energy. Their report deals extensively with the materials issues related to critical materials substitution, reduction of energy costs in production, biodegradability, recovery, and recycle of scrap, all in the context of an awakened public awareness of the finiteness of resources on this planet. These issues are still with us today, and efforts to address them can be found in diverse programs at government, university, and industrial laboratories. However, they pale in importance before the one central theme of the mid and late 1980's, industrial competitiveness.

The years since the development of the COSMAT report have seen the dramatic reductions in size of the domestic U.S. mining and metals beneficiation industries, of commercial shipbuilding, and of commodity steel. The U.S. has seen also the loss of manufacturing in most commodity electronic products and the dramatic loss of market share in on- and off-road vehicles, machine tools, commodity computers, and now even the most sophisticated of the high technology products, semiconductor chips. What is going on? Was this inevitable? Where has the U.S. failed, and what can be done about it?

These are complex issues involving geopolitical and geoeconomic forces far beyond the scope of this study as well as the technological issues to which this study is properly addressed. In formulating the study plan for this present effort it was recognized that the non-technological issues would be addressed by politicians, economists, and others, but that the technological issues--particularly those relating to materials science and engineering, viewed as an enabling technology--should be addressed in the context of these broad trends. Science and technology in the U.S., will suffer as the economic and industrial bases are diminished, and must flourish if the technological base is to do so. There will be limited job opportunities in industry if there is a shrinking industry and U.S. companies assemble products from parts manufactured abroad. If there are few jobs, there will be fewer new students to provide the base for continued industrial advancement. There will continue to be exciting science to be done, but universities will be reluctant to maintain large facilities to do this research if no students are there to be taught. And, of course, there will be less funding available to carry out this exciting research in an environment in which less visible links to the country's economic welfare disappear. The future of science and technology in the U.S. is inextricably linked to our technological competitiveness.

The U.S. emerged from World War II and the Korean conflict with a technological supremacy unchallenged (and some thought unchallengeable). A few decades later the U.S. finds itself counting lost industries and lost jobs and, some say, moving toward a service economy in which little manufacturing is carried out. During the 1950's and 1960's, U.S. manufacturing industries, aided by the artificially low cost of energy and the huge, captive domestic markets could thrive. In such an environment, union demands for higher wages and benefits could be met, profits could be turned over to the stockholders and recapitalization of aging physical plants could be delayed. The traditional trading partners in Europe remained the principal areas of competitive concern, and the U.S.`s traditional insularity kept the nation insensitive to the changes and development in the East which in many ways national policies had helped to stimulate.

First Japan, then Taiwan, Korea, Singapore, and others became the beneficiaries of U.S. assistance of one kind or another much of which led to technology transfer: direct economic aid (motivated by both humanitarian and political considerations); educational assistance (more than 50% of all U.S. Ph.D.'s in Engineering now go to non-U.S. citizens); investment by U.S. firms in manufacturing facilities to take advantage of low local labor costs; and more recently off-shoring (contracting for finished manufactured components which will subsequently be assembled in the U.S.). These same countries, led by Japan which had a history of strong vertically integrated industries prior to World War II, coupled their natural advantages (low-paid, hard working, educationally upward mobile, nationalistic populations) with government policies designed to favor industrial development, attacked the existing markets to obtain increasingly larger market share, and focused limited resources on one, then another industry. These government coordinated efforts manifested themselves in educational programs concentrated on engineering-oriented curricula, encouragement of joint government and industrial development efforts (including shared R&D efforts) and favorable tax and interest environments designed to encourage long-term investments of the type required to bring complex high technology product to the marketplace.

As this technological revolution was emerging in Japan in the late 1960's, the U.S. economic success culminated with the mistaken belief that the Nation was wealthy enough to finance both the costly war in Vietnam and a War on Poverty. The extent of governmental over-commitment during this period did not fully manifest itself until the late 1970's when, fueled by the inflationary effect of rising energy costs and generous cost-of-living adjustments, the entitlement component of the U.S. budget (retirement and medical care dominating) became the most rapidly rising component of Federal spending.

Much of U.S. industry, financially healthy, but unprepared for the assault from abroad, entered the 1970's with too heavy a commitment to labor costs, aging physical plants, and a short-term, bottom line management strategy (which some blame on the business school MBA mentality), at the consequence of stock financed ownership of the major corporations. This complex economic picture was exacerbated by the rising cost of capital in the late 1970's along with much needed, well intentioned, but conflicting demands for environmental clean-up and energy efficiency. Japanese manufacturers, poised and ready, were able to make major inroads into the U.S. consumer market, and with the profits, capitalize the next focused area of attack.

The next stage in this scenario resulted from the overly strong U.S. dollar of the early 1980's, favoring importation of artificially inexpensive goods from abroad. The short-term effect of this exchange-rate disaster was to increase exposure of U.S. consumers to high quality goods from abroad with a consequent brand identification which once made is hard to break. More insidious, and of longer term impact, is the effect of the principal U.S. industry strategy for maintenance of competitiveness--off-shoring of component parts. As these components, with their associated technologies are removed from the U.S. economic sphere, domestic manufacturing plants will increasingly become assembly plants (the low-value added component of manufacturing). Multinational U.S. industries will remain competitive, but the loss of high value-added manufacturing jobs to other nations will make the U.S. economy less competitive.

Focusing on the technological implications of all of the preceding, one notes that nations which only recently were not listed among the major sources of new technology have now become so. Well trained engineering talent applied to every step of the manufacturing process has led to improved quality and reliability and reduced overall manufacturing costs. The ability of managers to make and implement long-term plans creates an environment in which R&D flourishes. Stimulated by government-focused planning and joint laboratories in which cooperative, pre-competitive research can be carried out, limited resources can be made to go further. For much of their recent history, Japan and the newly industrialized countries (Korea, Taiwan, Singapore, etc.) could depend on the West for the development of new technology, but now, as they have matched and in some instances exceeded our capabilities, they must look to their own resources for further development. Thus, there is increasing emphasis on science in the universities and expanded efforts on international cooperation on the science frontiers.

The results of the COMMSE study [COMMSE 1989] have revealed the great intellectual richness of MSE, its criticality to the needs of the national, industrial, and strategic base, and the promise it offers for the future. If trends described in the last several paragraphs continue, an increasingly large fraction of the benefit to mankind expected to emerge from new developments in MSE will emanate from competitors abroad with consequent benefit to their economies and loss to the U.S.'s. Recognizing these opportunities, virtually every developed and most developing countries have targeted MSE as one of the central areas for enhanced R&D.

With this background, COMMSE focused the efforts of one of its panels on the subject of international cooperation and competition with the charge to develop a quantitative assessment of MSE activities abroad; determine the differences and similarities between the ways materials research and development is carried out in the major countries; identify the formative process and implementation strategy for national policy in MSE and compare with U.S. practices; and, assess the role of MSE in international industrial competition. Recognizing the breadth of the task, expertise was sought from the wide range of backgrounds and disciplines listed in the Panel roster. As the study began, it was recognized that many of the elements of this subject had already been studied. Much of the work would involve gathering and assembling data which already existed in studies made by the U.S. and other nations. Furthermore, the scope of the study was limited in several ways to make the task doable. The focus was narrowed to several countries: the U.S.'s traditional overseas trading partners, the U.K., France, West Germany, and Canada; Japan as a major economic competitor and strategic ally; Korea as an example of the newly industrialized countries (or "new Japan's"); China, another emerging country under a different political system; and the U.S.S.R., our principal strategic competitor. The scope was further limited by technical content. Recognizing that other COMMSE panels would deal comprehensively with MSE needs and opportunities, this study deals with only a few materials and industries with focused attention on international competition in these areas.

Data gathering consisted of four components:

1. A questionnaire was constructed and distributed to leading persons in the nations studied knowledgeable about S&T and MSE affairs. The mailing list was compiled from suggestions provided by the NRC-MSE panel representatives as well as the science attaches located in Washington, D.C. The list included

representatives from government, universities, and industry. One hundred twenty (120) questionnaires were sent to the foreign nations identified; 42 responses were received, several of which represented combined replies for two or more persons, indicating about a 40-45% return in total. An identical questionnaire was distributed to Panel membership and associates (20) for a comparable assessment of U.S. S&T/MSE.

The focus of the questionnaire was on national goals, strategies, and implementation tactics in S&T in general, and MSE in particular. Recipients were requested to limit their replies to their nation alone so that answers are believed to be representative only of that particular country.

2. Statistical information about S&T and MSE activities, markets, planned programs, areas of focus and other relevant data was sought from the embassies of the nations included. With the aid of the science attaches information was gathered from various sources, including the open literature.

It was obvious from the outset of this study that there is a woeful lack of comprehensive information about MSE. There are at least four important areas of data necessary for a rational evaluation of what's going on in this field. First, market data cannot be properly evaluated if, for example, sales of advanced ceramics and bathroom whiteware are included in the same industrial categories (e.g., S.I.C. codes). Second, the best estimate of MSE funding by the U.S. Federal Government is based on data developed by the intergovernmental COMAT group which were last updated with 1982 data, and by estimates compiled annually by the Federation of Materials Societies. The estimated annual expenditure in excess of one billion dollars of U.S. Federal funding on MSE requires better information data bases sorted by a variety of categorization schemes. Third, turning to manpower, it is noted that the first attempt to establish the size of the

MSE manpower base was done by the COSMAT study in the early 1970's and not updated until the present study. Fourth, a worldwide database on this field is appropriate. The O.E.C.D. has begun the task, but their data will be only so good as that of the individual member nations, each of which is in no better current position than is the U.S.

3. The competitiveness of the U.S. in S&T/MSE relative to other nations was assessed through the development of a competitive profile scheme in which the U.S. position was rated against that of other nations. The position of foreign nations was determined from information obtained from sources identified in 1-2 above and from specific assessment by Panel membership.

4. Finally, to instill an element of currency of the impact foreign MSE has on U.S. industrial technologies, representative case studies were developed. Though not comprehensive with respect to all industrial areas, the studies were intended to illustrate generic, but diverse cause and effect situations for several materials classes or product types. Seven case studies were undertaken.

3. PERSPECTIVE ON SCIENCE AND TECHNOLOGY (S&T)

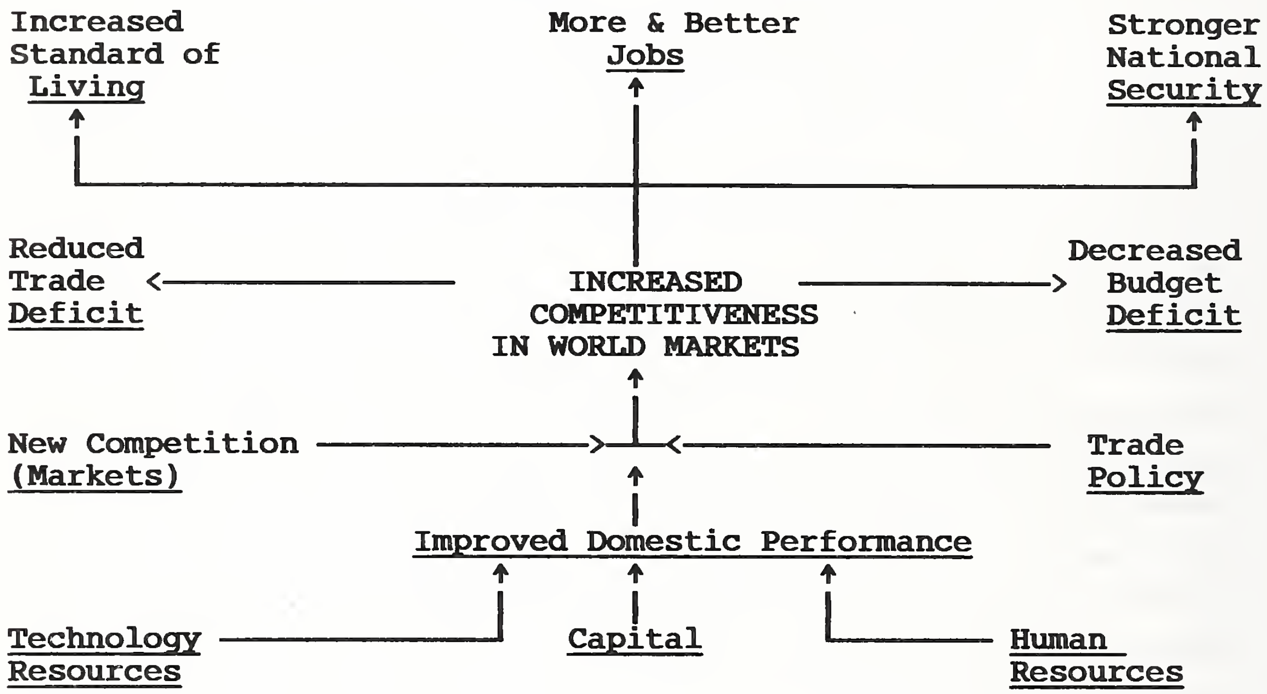
> **"Industrial research is emerging as the driving force behind technical change. Industry's need for technical change is increasing more rapidly than its ability to generate change internally, and this becomes a focus for the strategic plans and growth mechanisms of industry. The internationalization of both R&D and industry are two aspects of this same theme."**
> **--Herbert I. Fusfeld, New York University, 1986**

3.1 The S&T System and National Goals

National goals arise out of changing perceptions, as crystallization of widely-felt needs or as responses to national or international events. Some goals come about through a national desire in which implementation is diffuse and unstructured, almost on an ad hoc basis. Other goals are formulated at some level of government, usually at the Federal level, which embody a formalism and structure for achievement. National goals overall reflect areas of great public concern and for most nations involve consideration of among others, national security, social advancement, health, productivity, and economic well-being. Whatever the descriptor, S&T is inexorably linked to most national goals and its advancement may, in fact, be a goal itself. In 1974, at the time of publication by NAS of the landmark report on MSE [COSMAT 1974], national goals worldwide and their attendant S&T were focused on natural resources, energy, and the environment, as well as on defense. Today, in the late 1980's, these goals, except for defense, have been relegated to lesser roles with major emphasis now placed on 'international competitiveness'. Most nations have adopted this goal for their national agendas and for the U.S. it has become paramount, as illustrated by Chart 1. S&T is the cornerstone of the whole competitive system as it provides the requisite technical change through the generation of new knowledge and the application of this knowledge for commercial advantage.

CHART 1

COMPETITIVENESS: A LINK TO NATIONAL GOALS



SOURCE: [Young Commission 1985]

Virtually, every nation now views S&T as the essential ingredient in fulfilling national aspirations. The emergence of S&T as a recognized force began perhaps 30-40 years ago. Since then, 90% of all science knowledge has been generated [Merrifield 1983] and through S&T the information base is expected to double again within the next 10-20 years. Moreover, all scientists and engineers now living constitute about 90% of all those who have ever lived. This R&D workforce, the majority of which reside or work outside the U.S., is expected to double again within 10-20 years. Two main facts about the S&T enterprise are clear--<u>it is vast</u> in terms of people and money with about 4.3 million persons engaged in R&D and approximately $400 billion spent on an annual basis; and, it is global with over thirty countries having yearly R&D expenditures exceeding $10 million.

Overall, the S&T system is not a single entity, easily described in finite terms. It is complex and dynamic and functions to effect technical change. It encompasses an integration of people and organizations, nationally and internationally, in government and out, and in many walks of life. Implicit in its structural makeup and functional operation are the inter-related elements of cooperation and competition. Cooperation is required to provide the combined technical and financial resources to ensure an international technical base for free trade and national productivity growth. Industrial competitiveness provides the impetus for technical advance and new markets and is the essence of business strategy and success. Cooperation and competition thus are not mutually exclusive as both are necessary to achieve national goals. Reconciliation of the balance between the two determines the ultimate success of a nation's S&T system.

3.2 Characteristics of S&T

Semi-quantitative data are available to illustrate several important summary indicators of the characteristics of the world's S&T system and the national parts making up that system. These are given in Charts 2-7* and are intended to show two basic

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*Many resource documents quote and present analyzed statistical data on S&T and MSE activities, many of which originate from the same OECD, NSF or DOC sources. These appear to be the most authoritative and are used here as available and appropriate. Note further, that money figures, and currency designations given in this report, are those listed in the quoted reference documents. No attempt has been made here to convert local currencies to dollars, or to identify amounts in constant dollars. Caution, therefore, is urged in cross-comparison and correlation of data contained in separate charts as there may be different measures for the same quantity.

things--the input to the system (e.g., major countries and level of effort) and output of the system (e.g., world trade shares and productivity growth). Although there is an inter-relationship between input and output, it should not be inferred that the relationship is linear--the greater the input the greater the output is not a truism. The U.S.S.R., for example, has the largest of all world R&D activity and yet is not the leader in any significant manufacturing area. Conversely, countries such as the Netherlands, Sweden, and Switzerland have captured some high technology S&T areas with relatively small R&D efforts (about $5 billion combined annually). Equal attention must be given to the quality of the system and how it works; later sections will address these issues.

A synopsis overview of the state of the world S&T system (in 1984) is given by Chart 2. The distribution (as based on number of R&D people) of worldwide S&T R&D activities is roughly equal between the industrialized Western nations and the U.S.S.R. with approximately a 35% share each. China accounts for about 12% with the 18% balance made up primarily between the various developing countries, including the newly industrialized nations (N.I.C.) such as South Korea, which has a <1% share. Within the Western nations, the U.S. has a level of effort about equal to the combined levels of the others (17%). Of this, Japan has an 8% share, about one-half of that of the U.S. and one-fourth of the U.S.S.R.

In terms of measures of national economies, the R&D/GNP ratio Chart 3 of the U.S. (in 1985, 2.7%) is now very similar to those of other countries, except the U.S.S.R. (in 1984 3.9%). In comparison, the ratio for Japan in 1985 was 2.8% and following an upward trend. The relative ranks change dramatically if only nondefense designated R&D is considered in the GNP/R&D ratio calculations. These data are given in Chart 4 and indicate that the U.S. level (1.9% in 1985) is well below that of West

Germany's (2.5% in 1985) and Japan's (2.8% in 1985), but above those of France and the United Kingdom. In absolute terms, the U.S. invested more in R&D in 1986 (Chart 5) than Japan, West Germany, U.K., and France combined--$100 billion constant 1982

CHART 2

WORLD TRADE (1984) AND R&D LEVELS

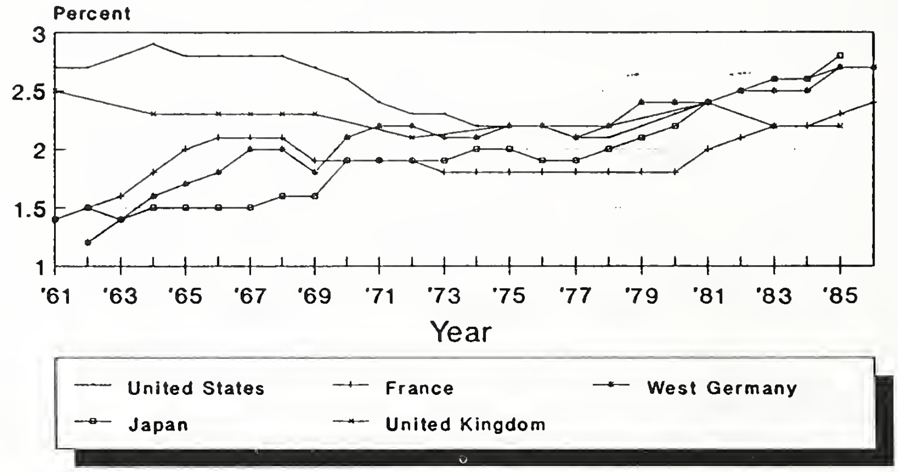
Country	World Trade Shares						Top 10 U.S. Traders %		R&D Share* %
	Exports		Imports		Change: (% 1984-% 1980)				
	$B	%	$B	%	Exp (%)	Imp (%)	Exp	Imp	
DEVELOPED United States	218.0	10.9	327.1	15.9	-0.1	+3.5			18
Japan	168.8	8.4	138.4	6.7	+2.0	-0.1	11	18	8
Canada	89.9	4.5	77.6	3.8	+1.2	+0.8	21	20	9
France	100.1	5.0	105.9	5.1	-0.7	-1.4	3	3	
W. Germany	170.1	8.5	155.6	7.6	-0.9	-5.2	4	5	
U.K.	92.7	4.6	106.2	5.2	-0.8	-0.4	6	4	
Italy	72.7	3.6	81.6	4.0	-0.2	-0.8	--	3	
OTHER DEVELOPED**	376.9	18.8	412.6	20.0	+0.9	-0.8			
(Belgium) (Netherlands) (Others)							2 3	-- --	
DEVELOPING COUNTRIES	470.6	23.5	423.5	21.0	-6.3	-0.3			
(S. Korea) (Taiwan) (Hong Kong) (Mexico) (Others)							3 -- -- 6	3 5 3 5	13
OPEC	85.2	9.2	132.9	6.5	-5.4	+0.1			
(Saudi Arabia)							2	--	
U.S.S.R.	93.5	4.7	80.5	3.9	+0.2	+0.6			35
China	26.6	1.3	21.9	1.1	+0.2	+0.1			12
East Europe	100.0	5.0	95.8	4.7	+0.8	+0.3			
All Others***	24.5	1.2	22.0	1.0	0.	0.			5
Total	2004.	100.	2057.	100.	-3.7	0.	61	69	100

*Based on number of R&D persons; **Primarily OECD countries; ***Calculated by differences

SOURCE: Trade statistics compiled from data given in [DOC 1986]; R&D data based on information given in [Fusfeld 1986]

Chart 3

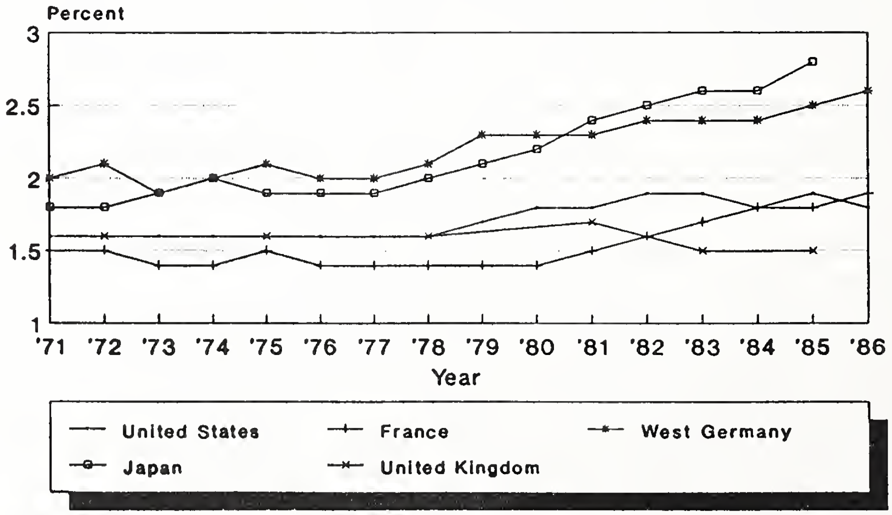
National R&D Expenditures as a Percent of GNP by Country



Source: [NSF 1986; NSF 1987]
Note: The estimated value for the U.S.S.R. in 1985 was about 3.9%

Chart 4

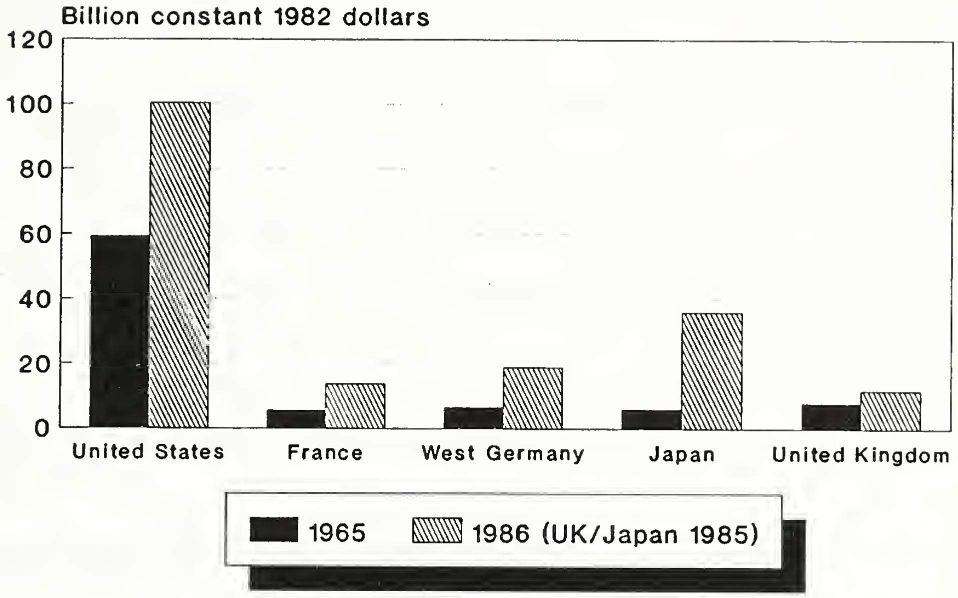
Estimated Ratio of Nondefense R&D Expenditures as a % of GNP by Country



Source: [NSF 1987]

Chart 5

National R&D Expenditures



Source: [NSF 1987]

dollars for the U.S., compared to $79 billion for the other four countries. Between 1965 and 1985 the U.S. share of R&D expenditures among these countries decreased in percent by 24% while Japan increased by 14%, The same relative rankings among countries are reflected by numbers of scientists and engineers engaged in R&D as a proportion of labor force (Chart 6). Again, the U.S. leads with the largest ratio, except for the USSR. In 1984, Japan's ratio (62.4%) was very close to that of the U.S. (65.1%) and climbing at a rate that may overtake the U.S. The level of R&D effort devoted by the various nations qualitatively described above provides information primarily related to the input to the world's S&T enterprise. For the developed Western countries, the U.S. is the obvious leader, following a combined national goal objective of defense and

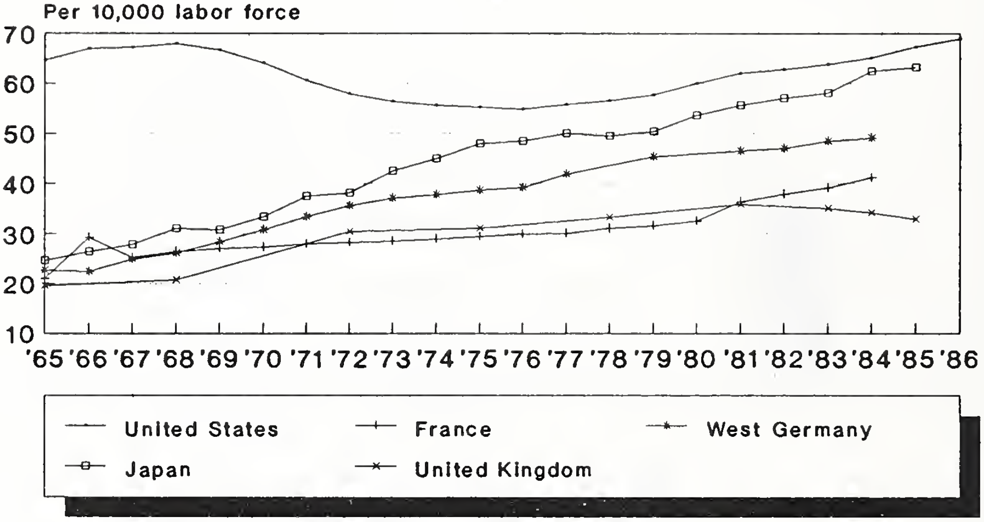


Chart 6
Scientists and Engineers Engaged in R&D Per 10,000 Labor Force Population

Source: [NSF 1986; NSF 1987]
Note: The ratio for the U.S.S.R. was estimated to be 92-105 in 1983

industrial competitiveness, spearheaded by substantial government funding of basic research. Japan is gaining ground as it concentrates its S&T effort toward industry and international trade while increasing its basic science research activity. West Germany, France, and the United Kingdom appear to be following the Japanese trend, while still pursuing an adequate defense posture. The U.S.S.R. S&T appears to be almost wholely devoted to defense, though its substantial basic R&D does provide a broad foundation for industrial advancement. China, on the other hand, is turning attention in a methodical way to build up their industrial technologies. The N.I.C's like Korea have focused their attention on S&T as a means for industrial enhancement, much like a "young Japan" did 10-20 years ago.

Several measures are indicative of the outputs of the S&T systems; these are given in Charts 2, 7, 8 and 9. In terms of world trade of goods (about $2 trillion, imports and exports in 1984, Chart 2) the U.S. was the leader in most of the categories listed, including those of a negative character, like trade imbalances. With an 18% share of the world's R&D it ranked first in total exports and imports with a net balance of trade deficit of about $109 billion. Japan and West Germany, with less than one-half the R&D activity of the U.S., had almost equal exports, much less than one-half the imports, and an overall positive trade balance.

Collectively, the developing countries (13% R&D world share) had about double the world trade activity of the U.S., while the U.S.S.R. had about two-thirds less. Since 1980, the U.S. share of world trade in goods declined slightly in percentage points for exports, but increased more than all nations in imports. The reverse situation was experienced by Japan, a nation second only to Canada in trade with the U.S. Trade data on high-technology* products (Chart 7) and smokestack manufacturers** [DOC 1986] illustrate the same general rankings and trends.

During the last ten years, the U.S. position in high-tech exports while still maintaining a positive trade balance and overall expansion, declined relative to the rest of the world; Japan accounted for a major part of this change. For the smokestack industries, the U.S. position deteriorated badly with enhanced

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* High technology products are defined by OECD and DOC as those for which R&D expenditures exceed 2.36% of the value-added.

** Smokestack industrial sectors are defined by DOC to include motor vehicles and equipment, iron and steel products, primary copper, aluminum, primary lead, primary zinc, industrial and farm machinery, and machine tools.

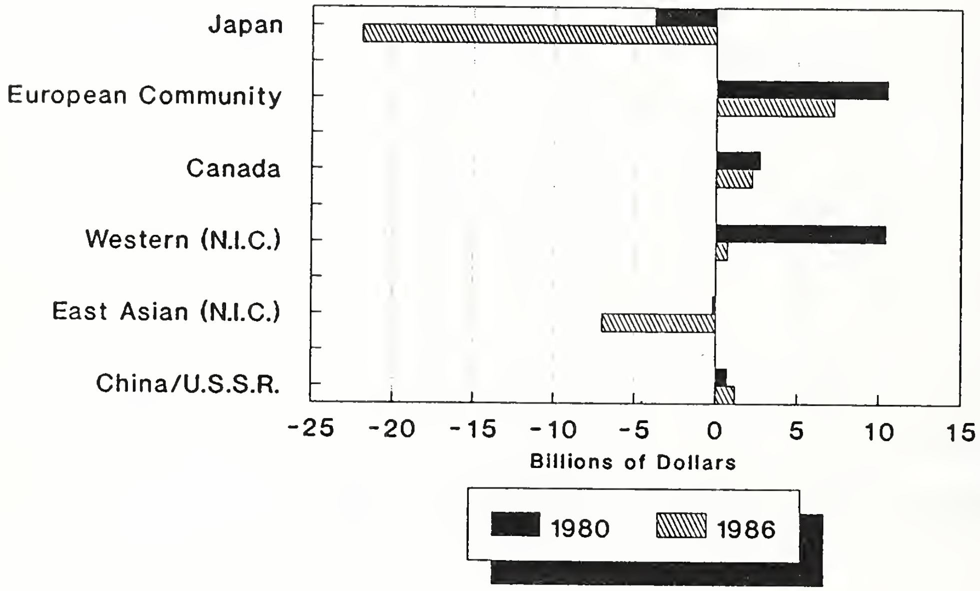


Chart 7
U.S. Trade Balance with Selected Nations; High Technology Products

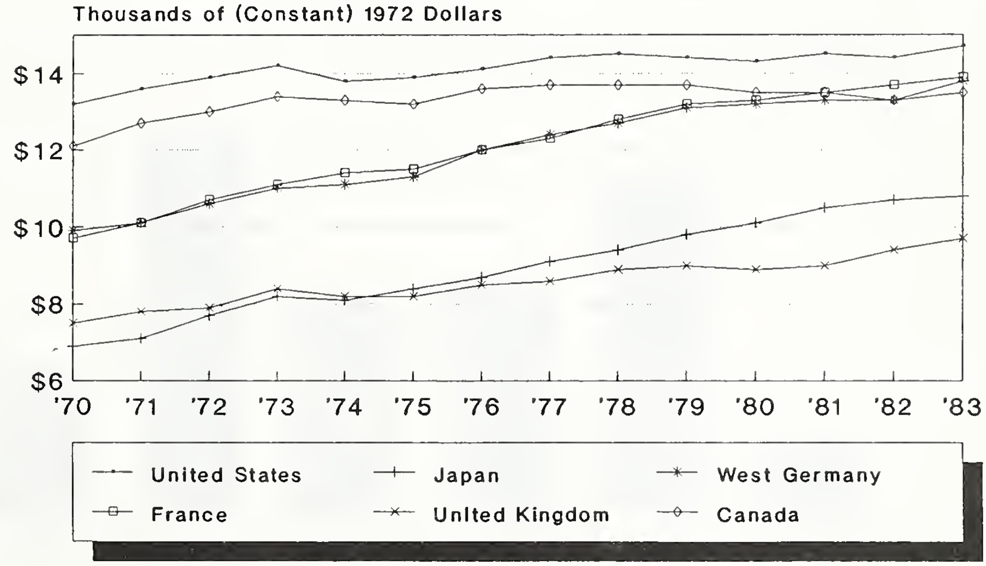
Source: [NSF 1987]

trade activities notable from the N.I.C's and from Europe. Other S&T outputs indicate similar findings. These include measures of technical literature, patents, royalties and license fees, and direct investments; data on these are given elsewhere [NSF 1987].

Inputs and outputs of S&T describe generally the characteristics of the system--its size, makeup, and products, but do not gauge the efficacy with which the system works or its resulting impacts, socioeconomic or other. One prime objective of the S&T system is to (or should be to) enhance competitiveness through technological change; a major factor leading to increased national productivity and increased standard of living. The competitive posture of a nation is set by several interacting features, including an expansive employment environment, availability of investment capital, and particularly productivity levels and growth. One measure of productivity is given by the gross domestic product (value added by firms and individuals) per employed person, such as illustrated by Chart 8, for several major Western nations. The U.S. in 1983 had the highest productivity level overall among these nations with Canada, France, and West Germany not too far behind. Japan and the U.K. had productivity levels about 70% of that of the U.S. A more

Chart 8

Real Gross Domestic Product Per Employed Person in Selected Countries

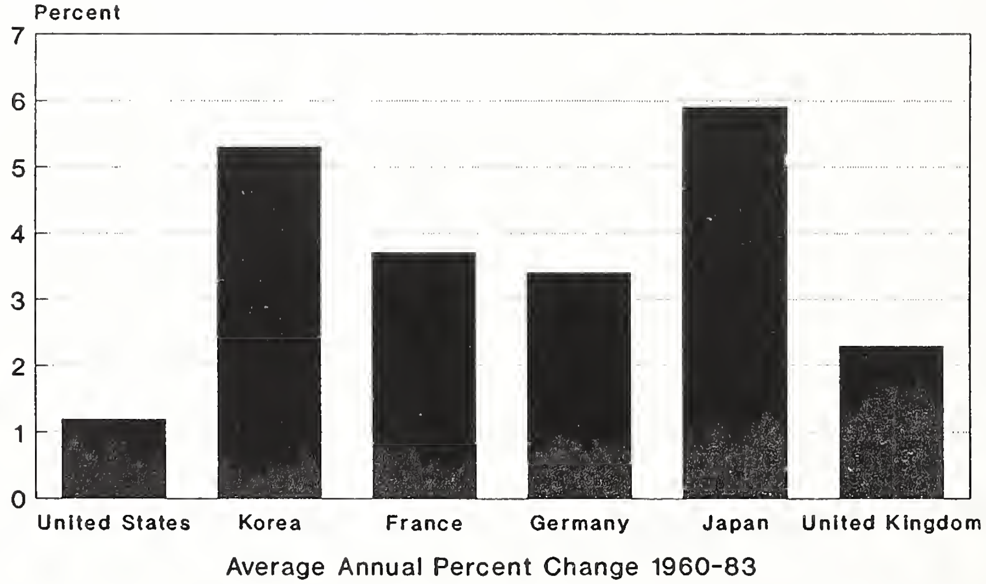


Source: [NSB 1985]

telling statistic, however, is the rate of change of productivity (Chart 9). Since 1960 the productivity growth of most nations has increased but at significantly different rates. Japan's productivity growth during this period was the highest of all major nations and five times larger than that of the U.S. Further, only Japan was able to substantially increase employment while simultaneously producing its leading productivity growth rate. On the other hand European countries experienced a net loss in jobs. Employment in the U.S. grew by more than 40% (mostly in the service industries), but the lack of capital and low investments negated the competitive advantage of a growing workforce and high national productivity.

CHART 9

Productivity (Real Gross Domestic Product Per Employed Person)



Source: [Young Commission 1985]

3.3 **Macro-Trends in S&T**

The S&T system is not a static entity. It drives technical change and in turn, is driven by technical change. New patterns of a changing S&T began to emerge in the post World War II period and were fully evident in the 1970's. These macro-trends in all likelihood represent the directions S&T will take for the remainder of this decade and probably for the years beyond. New and grander scale technical opportunities and needs appear with rapidity. Problem complexity has increased. Organized, multi-participant R&D and centralized research management coupled with intra-and extramural cooperation and collaboration is a dominant operating theme of the S&T system. New relationships between the public and private sectors have evolved and government policies and actions intersect S&T more directly. The traditional R&D roles of industry and academia have changed and now, the industrial sector and its R&D is the principle driving force for technical change. The S&T system is truly international and the national systems, to be competitively successful, rely upon broad extended linkages and cooperative mechanisms involving not only the public and private science and technology factions, but also ancillary groups such as the banking and financial community.

The rising pre-eminence of industrial R&D is a significant structural change in the S&T system. Industry now is the major provider of R&D funds in most of the Western nations (Chart 10), and the dominant performer of government sponsored R&D (Chart 11). Japan, however, contrary to popular opinion, deviates significantly from this norm with their industry the recipient of only about 4% of government R&D funds (in 1981).* In the U.S. it is estimated that industry performed 74.2% of all R&D undertaken (in 1984). Overall it conducted 19.4% of all basic research, 67%

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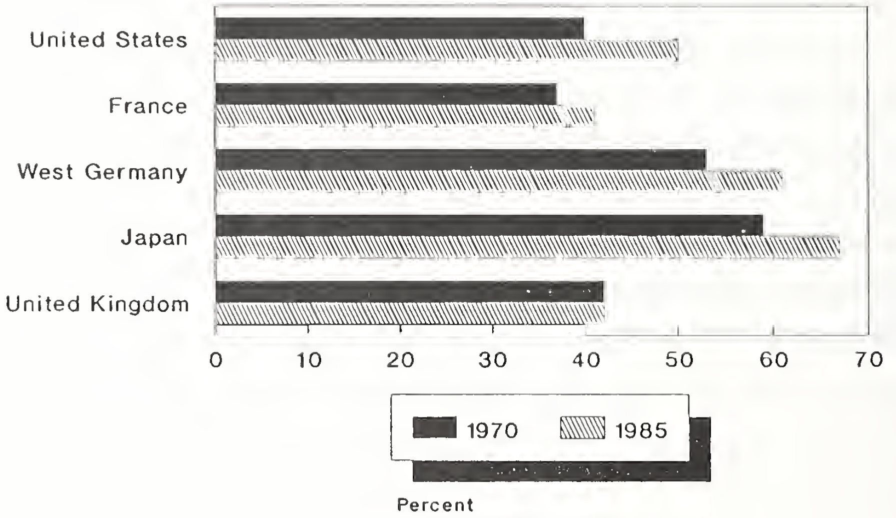
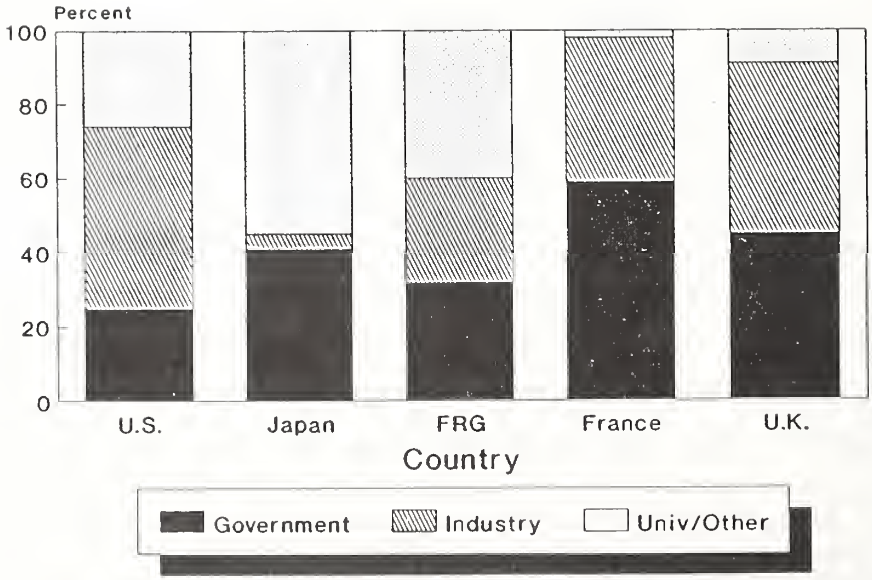
*Note, however, that 41% of government funded R&D in Japan is performed by government agencies, many of which are organized to be directly supportive of industry.

CHART 10
National R&D Expenditures Financed by Industry



Source: [NSF 1987]

Chart 11
Use of Government Funds for R&D



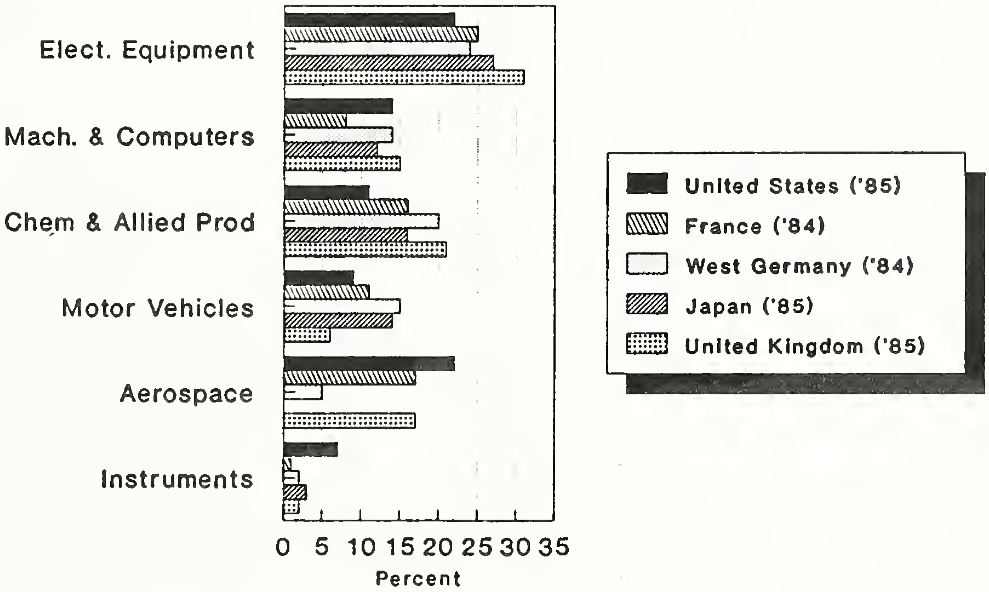
Source: [GAO 1985]

of all applied research and 87% of all developmental work [DOC 1985]. Although comparable data are not available for other nations all other indicators point to an enhanced industrial role in R&D.

Areas of R&D emphasis also have been changing among the major nations. Chart 12 indicates the distribution of industrial R&D among selected market technologies. In the U.S. for instance, the greatest fraction of all industrial R&D funds are now devoted to the high technology manufacturing industries, like aerospace. Increasingly, national industrial R&D worldwide is focusing on areas of R&D specialization to build upon or build

Chart 12

Percent of Total Industrial R&D Expenditures Among Selected Industries



Source: [NSF 1987]

anew a comparative advantage. Chart 13 illustrates the relative emphasis by the business sector for selected industries in several nations. The U.S., for example, has specialized in aerospace, instruments, and office machines/computers while relatively decreasing efforts in all other industrial groupings. West Germany and Japan have concentrated on chemicals, the electrical group, and motor vehicles. The U.K.'s main emphasis area is chemicals with a tendency towards relative de-emphasis of aerospace. France is targeting the electrical and motor vehicle groups while also relatively lessening its R&D for aerospace.

The rise of industry toward the pinnacle of the S&T system has been in concert with equally significant changes in the makeup and structure of industry itself. Here the major trend essentially equates to bigger businesses* and their internationalization, primarily through the proliferation of multinational corporations. To illustrate this fact, in 1978 (latest known compiled data) 45% or more of all industrial R&D was carried out in corporations having more than 10,000 employees while <20% resided in companies having fewer than 1000 workers [OECD 1984]. The U.S. leads in this category with 84% of the R&D performed by the ultra-large companies. Furthermore, the R&D expenditures by the larger firms are indeed very substantial, as for example, General Motors and Ford Motor Company have R&D budgets greater than that of all of Italy [OECD 1984]. This characteristic is not, however, strictly an American phenomena as Toyota and Shell R&D expenditures, for example, approximate those of Denmark or Finland.

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* The tendency toward big business does not lessen the import of small enterprises (<500 employees) for they play valued niche roles in S&T and national economies, but overall their impact on technological change generally surfaces through involvement with large corporations.

CHART 13

RELATIVE EMPHASIS[1] OF R&D EXPENDITURES IN THE BUSINESS SECTOR BY COUNTRY, FOR SELECTED INDUSTRIES: 1975 AND 1981

Industry	Year	United States[2]	West Germany	Japan	United Kingdom	France
Electrical Group....	1975	-0.07	0.28	0.03	-0.06	0.11
	1981	-0.11	0.22	0.26	-0.11	0.17
Chemicals	1975	-0.35	1.51	0.30	0.03	-0.12
	1981	-0.23	1.26	NA	0.39	0.05
Aerospace	1975	0.29	-0.50	-1.00	0.27	0.07
	1981	0.42	-0.75	-0.99	-0.11	-0.21
Motor Vehicles	1975	-0.04	0.11	0.23	-0.30	0.02
	1981	-0.08	0.25	0.18	-0.32	0.17
Instruments	1975	0.33	-0.44	-0.38	-0.52	-0.64
	1981	0.34	-0.67	-0.41	-0.67	-0.81
Office Machines & Computers	1975	0.42	NA	-0.70	-0.38	-0.11
	1981	0.38	NA	-0.58	-0.26	-0.43

[1] The relative emphasis index is calculated by dividing a country's share of R&D expenditures in an industry by its share of all R&D expenditures in the business sector, then subtracting 1. Negative values indicate relative de-emphasis; positive values show emphasis in the industry's technology.

[2] U.S. data for 1975 are total business sector expenditures, and privately-financed expenditures are used for 1981.

SOURCE: [NSB 1985]

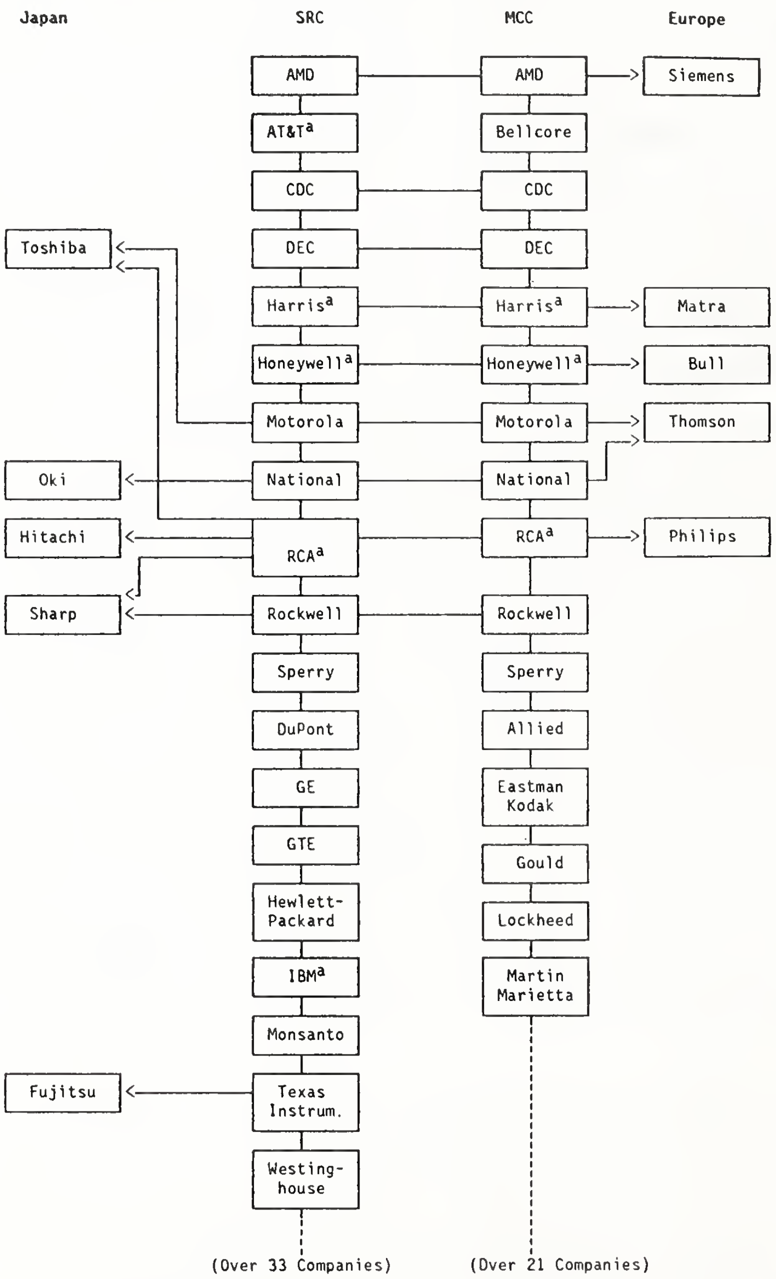
These industrial R&D efforts are far from evenly distributed over the spectrum of businesses. Distinct skewing is evident with R&D concentrated primarily within the manufacturing industries and within manufacturing, in its engineering and chemical subsets. Significantly the U.S. expenditures by the private business sector for manufacturing R&D [OECD 1984] were lower than the other major nations except the U.K while government support was higher than all others. In Japan, manufacturing R&D is almost wholely privately financed.

The changing nature of industrial R&D has been coupled, by necessity, with the creation of a plethora of new technical linkages, nationally and internationally. Technology now diffuses across national borders, with and without government interaction or intervention. Multinational corporations provide a particularly important avenue for the access and transfer of information. They, for instance, in competing for world markets, are confronted by the technical developments of competitors throughout the world and, therefore, have a special incentive to know and assess the status of S&T, wherever it is being created or used. Companies use a variety of means to maintain their awareness of these worldwide technical developments. Some have established research laboratories (e.g., IBM) in other nations. Others maintain fully integrated product development and manufacturing capability in several countries (e.g., Ford in Europe) and thus are able to access the entire technical enterprise in that area. Many have established liaison offices overseas, while still others have established joint operations with foreign companies that lead to cooperative design and production of parts, and thus an exchange of technical information. Further, many multinational companies contract with vendors, located around the world, for components or systems for their products and manufacturing processes, thus obtaining knowledge of foreign technical capabilities. Thus, this somewhat informal multi-connected network provides an excellent mechanism for a rapid flow of non-proprietary information throughout the commercial sector, and S&T (and MSE) must be viewed in an international context, rather than strictly on a national basis. In this environment of rapid technology transfer, cooperation in R&D is prevalent with focus on pre-competitive research. In the U.S., for example, consortia such as the SRC and MCC have been established to assist its microelectronics industry. Through the participation of multinational corporations, however, the technical linkages extend internationally, as illustrated by Chart 14. Similar interactions have been developed also through non-U.S. programs (Chart 15). At the competitive level, joint ventures, partnerships, mergers, acquisitions, licensing arrangements and the like are regular facets of business strategies. More and more the S&T system is moving toward extensive cooperative mechanisms involving interactive arrangements between the technical elements of government, industry, and the universities. Even the multinational corporations find this the most expedient and cost saving mechanism to gather together the financial and technical R&D resources necessary for new product development and market entree. For years cooperative mechanisms have been commonplace for the science part of S&T. The new trend now encompasses the technology segment. The countries that have nurtured an environment in which cooperation has flourished, have seen rewards appearing in the marketplace--Japan is a good example.

The trend of rising industrial importance does not diminish the roles of the other two parts of the S&T triad--the universities and government. Their roles have changed, however. Traditionally the universities have performed the dual function of training people and through research, provided the new ideas and fundamental understanding driving technical change. They still do so but industrial R&D has taken over the role of driver.

CHART 14

PRINCIPAL U.S. LINKAGES



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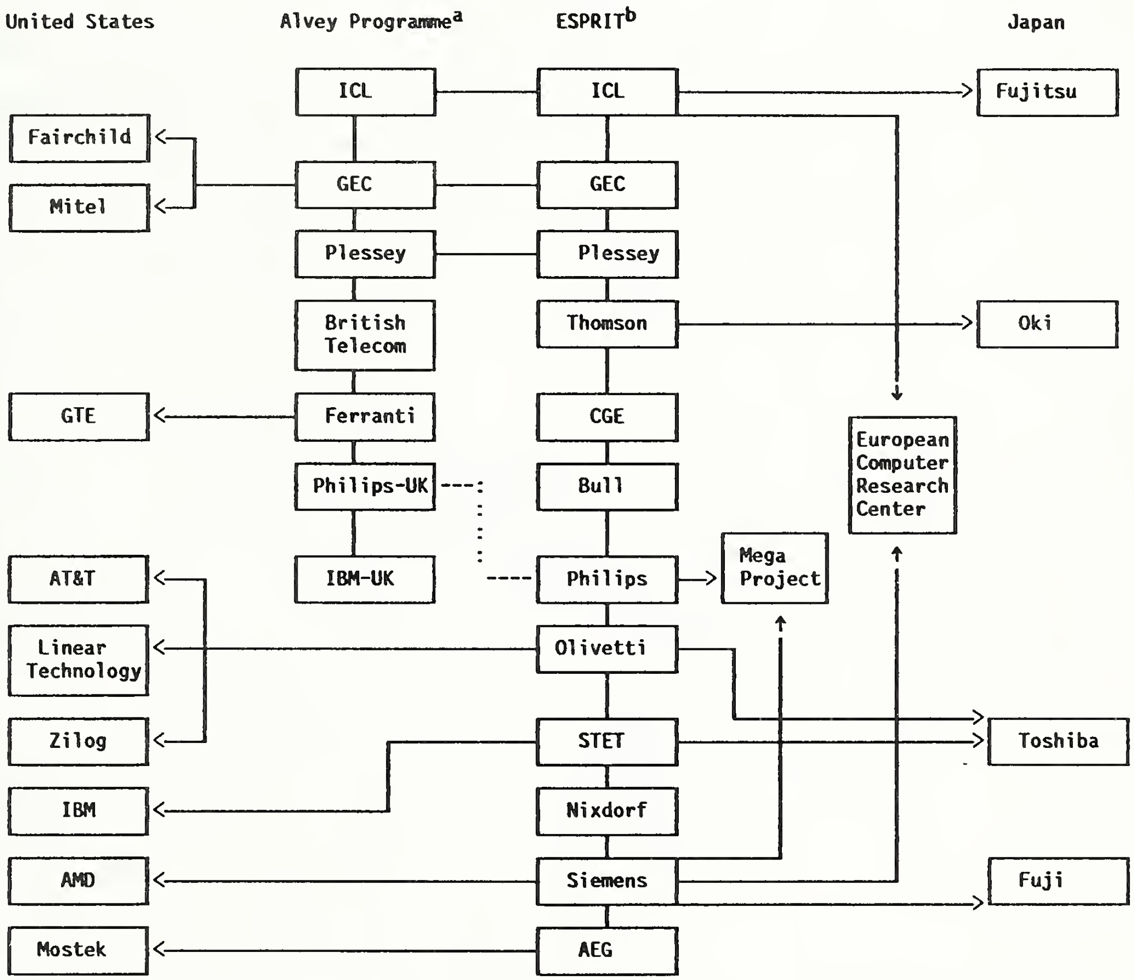
[a] Prime contractor in VHSIC

SOURCE: [Fusfeld 1986]

CHART 15

PRINCIPAL EUROPEAN LINKAGES



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[a] Participants in one or more major programs
[b] Original participants

SOURCE: [Fusfeld 1986]

The university system (at least in the U.S.), today generally constitutes only a small fraction of total national R&D and no more than half of all the basic research. Moreover, the larger research oriented universities (e.g., MIT) have undertaken additional responsibilities as research managers of sizeable multi-disciplinary programs, generally addressing the technological rather than the science side of industrially (or defense) significant problems and needs. Hence, the basic research thrusts have become more directed, even leaning toward the applied. Further, cooperative research within the university, and external to it, has become a mainstay. Indeed team research such as that found at the Materials Research Centers and Engineering Research Centers in the U.S., have become prevalent modes of operation.

Government's role the world over is unique in that it is a performer, a major funder, and a regulator of R&D and, as such, it can, and has, set national S&T directions and priorities. Traditionally, its involvement primarily related to the establishment and maintenance of a S&T infrastructure for broad based capabilities, primarily in the sciences--basic research, education, and the like. Today, while the infrastructure is still a prime mandate, government participation has become more purposeful, direct and decidedly pro-active in S&T to influence or impact specific national affairs or concerns. Government set defense S&T is a typical example of the government focus taken by the U.S., in force ever since the post World War II period. Following a different pathway, other governments, with the U.S.S.R. being a prime exception, have placed civilian oriented R&D and industrial technology center stage (rather than defense) for the past 20 years or so. Whatever the focus, pro-activism in S&T by government nevertheless is a characteristic evident in the major countries, worldwide, though the degree of involvement, styles of approach and ultimate success achieved, may vary significantly.

4. NATIONAL COMPARISONS IN MATERIALS SCIENCE & ENGINEERING

> **"...the heart of the competitiveness issue lies in the differences between our strategy and those of our most successful competitors."**
> **--Bruce R. Scott, Harvard Business School, 1985**

4.1 General Organizational Framework

Even with diverse national objectives the organizational framework in which government S&T and MSE is planned, organized, and carried out, differs only marginally for the major developing and industrialized countries. While policy formulation and program coordination is a recognized government function, most countries have not drawn together all S&T activities under the umbrella of a single agency or ministry. All have followed the "mission" agency approach whereby a government bureau/ministry is organized along the lines more commensurate with, or akin to a national objective, like defense, health, education, industry, or other. Hence, S&T in today's world is but one important facet (and perhaps the major ingredient) of the charter of a mission type ministry. The degree of centralization and structure may differ from nation to nation, but even in Japan and in the U.S.S.R., two extremes in modern day society, there is no one organizational entity within any of the governments of the world responsible for the whole of science and technology or materials science and engineering.

A myriad of major government agencies or ministries of several nations influence their country's S&T and/or have an impact on MSE, as a funder, performer, or regulator of R&D. Although significant fractions of the research funds of many of these parent government organizations go directly for industrial purposes and R&D in fulfillment of their mission objectives, it is noteworthy that all major competing nations do not have, however, a ministry/agency directly concerned with S&T for industry. Japan does, for example, while the U.S. does not.

Importantly, many ministries/agencies also support semi-independent or separately organized research centers, independent research establishments, and/or a national laboratory system.

The mission of these research oriented groups generally follows that of its principal government sponsor (e.g., DOE in the U.S-energy objective or MITI in Japan-industrial objective). Overall they provide for support of a national resource of trained talent and facilities, used by most countries (some more effectively) to extend their S&T capabilities for national purposes, generally in a cooperative mode with industry and/or universities. In Japan MITI's National Laboratories work directly with selected industries or industrial associations on common objective problems. In Germany, the Ministry of Research and Technology supports both industry and the national research organizations, Max Planck Society and Fraunhofer Gesellschaft, in cooperative efforts. Moreover, the Western European nations have extended their individual industrial oriented S&T to collective action through the EC (European Communities). Here new programs have been started (or planned) specifically designed not only to promote national and regional economic growth, but significantly, to develop an infrastructure and funding whereby industry is both the major performer and beneficiary of the R&D. These "industry-government cooperatives" also involve participation by their national universities and the in-house EC laboratories (e.g., Ispra in Italy, Petten in the Netherlands) as needed and appropriate, but the central/key component is industry. Chart 16 provides a capsule summary of these new style programs in Europe.

The U.S. has no direct counterpart cooperative system and organizational framework in place comparable to its major competitors. Some movement in this direction is evident, using,

CHART 16

EXAMPLE EUROPEAN COOPERATIVE PROGRAMS

- BRITE

Basic Research in Industrial Technology for Europe

- $166 Million over 4 Years
- EC Countries
- Pre-Competitive Research Level

- EURAM

European Research on Advanced Materials

- Funding Approved 1986
- EC Countries
- Engineering Development (Metals, Ceramics, Composites)

- ESPRIT

European Strategic Program for Research in Information Technology

- $1.25 Billion over 5 Years
- 5 Countries + EC
- Pre-Competitive Research Level

- EUREKA

European Research Coordinating Agency

- $10 Billion over 5 Years (approximately 50% French Financing)
- 18 European Countries
- Marketing Stage Research

SOURCE: Synthesis of information obtained from [ECC 1987; Fusfeld 1986]

however, primarily existing institutional settings with perhaps modest adjustments in governing regulations and funding arrangements. Current efforts toward better industrial utilization of the U.S. National Laboratories (e.g., Argonne, Oak Ridge, and Sandia National Laboratories) provides one example. The Engineering and Materials Research Centers sponsored by NSF and the University Research Initiatives of the Defense Department are other thrusts but these have university and basic research focus, and are not wholely industrial oriented. Further, cooperative R&D initiated and funded by industry in the U.S. apparently is on the rise following the passage of the Cooperative Research Act of 1984. Chart 17 provides a list of filings under this Act through 1986, although it should be noted that some of these were in existence prior to 1985. These cooperatives take many forms as, for example, MCC (Microelectronics and Computer Technology Corporation), SRC (Semiconductor Research Corporation), and more recently, Sematech (Semiconductor Manufacturing Technology), setup for pre-competitive industrial oriented R&D, or to the other extreme, national/international joint ventures for proprietary research.

CHART 17

R&D VENTURES REPORTED UNDER THE U.S. NATIONAL COOPERATIVE RESEARCH ACT OF 1984[1]

SOURCE: [OPTI 1987]

TITLE AND DATE OF FEDERAL REGISTER NOTICE

1 SOFTWARE PRODUCTIVITY CONSORTIUM; 1/17/85 (11 aerospace/defense firms)

2* MICROELECTRONICS AND COMPUTER TECHNOLOGY CORP.; 1/17/85 (21 companies)

3* EXXON PRODUCTION RESEARCH CO./HALLIBURTON SERVICES (EPR); 1/17/85 (oil and gas well cementing)

4 COMPUTER AIDED MANUFACTURING INTERNATIONAL (CAM-1); 1/24/85 (over 50 members)

5* BELL COMMUNICATIONS RESEARCH, INC. (Bellcore); 1/30/85 (members Regional Bell Operating Companies)

6* SEMICONDUCTOR RESEARCH CORPORATION (SRC); 1/30/85

7* BETHLEHEM/U.S. STEEL; 1/30/85 (DOE contract on continuous casting of steel thin sections)

8 CENTER FOR ADVANCED TELEVISION STUDIES; 2/1/85 (ABC, CBS, NBC, PBS, RCA, HBO, 3M, Ampex, Harris Corp., Tektronic - contracts to universities)

9* NORTHWEST STATES PORTLAND CEMENT CO.; 2/5/85 (30 companies, members of the Portland Cement Association)

10 EMPIRE STATE ELECTRIC ENERGY RESEARCH CORP.- ESEERCO; 2/8/85 (members - 7 utilities)

11 ADIRONDACK LAKES SURVEY CORP.; 2/8/85 (ESEERCO members plus the New York State Department of Environmental Conservation)

12 AGRIGENETICS CORP.; 2/8/85 (a limited partnership - plant biotechnology)

CHART 17 (CONTINUED)

13* MOTOR VEHICLE MANUFACTURERS ASSOCIATION OF THE U.S.; 2/8/85 (Notices filed for 10 different research areas -- AM General Corp., LTV; AMC; Chrysler; Ford; GM; International Harvester; M.A.N. Truck and Bus Corp.; PACCAR; Volkswagen of America; Volvo North America. In two of the projects, the venture includes the American Petroleum Institute and Coordinating Research Council as members; a third is carried out with DOE).

14 MEDIUM RANGE TRUCK TRANSMISSION COOPERATIVE PROJECT; 2/14/85 (Eaton Corp/Fiat)

15 MERRELL DOW PHARMACEUTICALS/HOFFMAN - LA ROCHE; 2/19/85 (Clinical studies of cancer drugs)

16 UNINET RESEARCH AND DEVELOPMENT CO (URDC); 3/1/85 (Uninet, Inc./Control Data Corp. - advanced packet switching)

17* BELLCORE/HONEYWELL; 3/25/85 (advanced gallium arsenide integrated circuits)

18* UNITED TECHNOLOGIES/TOSHIBA; 4/1/85 (fuel cell power plants-development, testing, manufacturing)

19* INTERNATIONAL PARTNERS IN GLASS RESEARCH; 4/10/85 (To fund research at various institutions. ACI Ventures Inc., Weigand & Soehne GmbH; Brockway Inc., Emhart Glass Research, Inc.; Portion Research, Inc.; Rockware Glass Ltd., Yamamura Glass Co., Ltd.)

20 ONCOGEN LIMITED; 4/30/85 (A limited partnership for R&D of commercial products for cancer diagnosis and treatment -- Bristol-Meyers Co.; Genetic Systems Corp.; Syntex U.S.A. Inc.)

21* KAISER ALUMINUM & CHEMICAL CORP. AND REYNOLDS METALS CO; 5/13/85 (R&D of ingot metallurgy and manufacturing processes for aluminum-lithium alloys and recycling technology)

22* PLASTICS RECYCLING FOUNDATION; 5/21/85 (22 members)

23 BELLCORE/U.S. DEPT. OF ARMY; 6/28/85 (gallium arsenide)

24* BELLCORE/RACAL DATA COMMUNICATIONS; 6/28/85 (inter-exchange connectivitiy; image conferencing systems)

25 BELLCORE/AVANTEK; 6/28/85 (telecommunications exchange and access services)

CHART 17 (CONTINUED)

26* BELLCORE/HEINRICH HERTZ INSTITUT FUR NACHRICHTENTECHNIK, BERLIN GmbH; 8/6/85 (optoelectronics, image coding and processing)

27 BELLCORE/ADC TELECOMMUNICATIONS, INC.; 9/5/85 (exchange access services, digital interconnection)

28 APPLIED INFORMATION TECHNOLOGIES CORP. (AIT); 10/9/85 (Battelle Memorial Institute, American Chemical Society, CompuServe, Mead Data Central, Online Computer Library Center -- Artificial Intelligence; telecommunications; micro-electronics; information processing; software and systems engineering)

29* SMART HOUSE PROJECT; 10/10/85 (National Association of Home Builders Research Foundation and 30 corporations -- to develop an integrated home control and energy distribution system)

30* DEET JOINT RESEARCH VENTURE; 10/22/85 (16 Chemical firms -- pesticide research)

31* GEOTHERMAL DRILLING ORGANIZATION; 10/29/85 (16 firms -- multiple projects related to well drilling)

32 PUMP RESEARCH AND DEVELOPMENT; COMMITTEE (PRADCO); 11/15/85 (Borg-Warner, Ingersoll-Rand, Dresser, Transamerica Delaval-- centrifugal pumps)

33* BATTELLE OPTOELECTRONICS GROUP; 11/29/85 (Allied, AMP Inc., Dukane Corp., Hewlett-Packard, ITT, Litton Systems -- optoelectronic manufacturing techniques and packaging)

34* BELLCORE/HITACHI, LTD.; 12/12/85 (optical transmission for tele-communications exchange and access services)

35* INTEL/IXCOR CORP.; 12/12/85 (Development of computer memory circuits -- EEPROM devices)

36* WEST VIRGINIA UNIVERSITY/INDUSTRY COOPERATIVE RESEARCH CENTER; 12/17/85 (W. Virginia University, Monsanto, duPont, Standard Oil, Union Carbide -- fluid particle science)

37* PORTLAND CEMENT ASSOCIATION; 12/24/85

38 SUBSEA PRODUCTION MAINTENANCE JOINT INDUSTRY PROGRAM; BROWN & ROOT, INC.; 1/14/86

39* NORTON/TRW CERAMICS; 1/28/86

CHART 17 (CONTINUED)

40 CHAR-TECH: KEAN MANUFACTURING CORP. AND FABRISTEEL PRODUCTS, INC.; 1/28/86

41* SOUTHWEST RESEARCH INSTITUTE; 2/18/86

42 PETROLEUM ENVIRONMENTAL RESEARCH FORUM; 3/14/86

43 PYRETHRIN JOINT RESEARCH VENTURE; 3/18/86

44 KERAMONT RESEARCH CORP.; 4/3/86

45 SOUTHWEST RESEARCH INSTITUTE; 6/11/86 (Remaining Life Methodology For Disc Rim Cracking)

46 OPEN SYSTEMS INTERNATIONAL (COS); 6/11/86

47 ARMCO INC., BETHLEHEM STEEL CORP., INLAND STEEL CO., AND WEIRTON STEEL CORP.; 6/12/86

48 WICKES MANUFACTURING COMPANY; 7/15/86

49 ENGINE MANUFACTURING ASSOCIATION, et al.; 7/17/86

[1] Some of the cooperatives represent re-registration of older ventures previously filed prior to the passage of the Cooperative Research Act.

The * symbol in the listing denotes a venture, new or old, which is thought to be MSE related.

4.2 MSE Resources

MSE government sponsored R&D, because of its multi-functional and widespread impact, is diffused throughout the multitude of the national governmental bureaucracies and programs. While there are materials programs and coordinating efforts, and there may be materials organizational units, no single upper level ministry or agency in any of the major countries has the sole mandate or mission of "materials" or materials science and engineering. Today its featured role and importance are generally appreciated and recognized and usually in the appropriate context of enabling and critical. Accountability and tracking for MSE R&D, however, is almost always as a subset of a larger technological effort such as a U.S. (DOD) VLSI development program or under a NSF discipline descriptor like the catch-all category, engineering. Accordingly, for most countries, data on the size (e.g., people and funds) and type of government (or industrial) MSE R&D effort seldom are separately tabulated, and when collected are almost never maintained on a routine/statistical basis. Some estimated data obtained through surveys, however, are available on government MSE funding in the U.S., and these are given in Chart 18. Comparable data are not known for other countries, and probably do not exist in a tabulated fashion, though there may be some information on enhancement or special-need programs, such as the EC's EURAM program (European Research on Advanced Materials) or Japan's New Materials for Future Industries, a $300 million, 10 year program.*

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* It is important in evaluating the magnitude of government-funded R&D programs in some other countries, particularly Japan, to note that personnel costs, the usual overhead, and in the case of universities, student tuition, is usually paid through other budgetary sources. Thus, many of the stated program levels should be multiplied many-fold to compare properly to U.S. programs in which these dominant costs are usually included in quotations of R&D budgets.

CHART 18

MATERIALS R&D BY U.S. FEDERAL AGENCY ($M)

	FY76[a]	FY80[b]	FY82[c]	FY86[d]	FY87[d]
DOE	333	514	286	440[a]	440[e](est)
DOD	132	160	147	374	338
Bur. Mines	24	24	30	40	38
NSF	69	89	100	133	138
NASA	52	79	101	84	128
NBS	21	36	14	23	26
Total	631	902	678	1,094	1,108
Reported National Security					
DOD	132	160	147	374	338
DOE (Defense)	59	110	64	104(est)	104(est)
Total Reported Defense	191	270	211	478	442
TOTAL NON-DEFENSE (cur dollars)	440	632	467	616	666
Federal Science Deflator*	.604	.834	1.000	1.145	1.166
TOTAL NON-DEFENSE (cons dollars)	728	758	467	538	571

SOURCE:
[a] COMAT Report 1978;
[b] COMAT Report 1980;
[c] COMAT Report 1982;
d FMS 1988]

*"Implicit Price Deflator for Total Government Non-defense R&D"

4.3 National Profiles

CANADA

Canada, the second largest country in land size in the world, has a population of only about 26 million but ranks seventh in the world in GNP ($367 billion in 1986) and sixth in trade, after the U.S., West Germany, the U.K., France, and Japan. The country shares a 5335 mile border with the U.S. and trade between the two nations ($120 billion in 1986) is more than between any two other countries. About one-third of the U.S.-Canadian trade involves automotive products. Blessed with natural resources and fertile land, Canada ranks first in the world in mineral exports, third in mineral production, first in newsprint, and second in wheat exports. It is a net exporter of energy with crude petroleum constituting the single major mineral export item. Since 1984 Canada has achieved one of the highest economic growth and job creation rates among the OECD nations [Background Notes Canada 1987]. Agriculture and mining, however, are no longer the mainstays of Canada's economy. Particularly since the 1950's Canada has experienced spectacular growth in manufacturing and this growth is transforming the nation from an agrarian to more of an industrial and urban society. About half of Canada's manufacturing involves primary metals and metals fabrication, equipment, machinery and electrical items, chemicals, and wood derived products. Industry is now a leading component of the nation's economy and employs about a third of its work force. Quite logically government research objectives in Canada for a long time had been focused on areas to improve the country's industrial trading position through exploitation of their natural resources and primary processing of raw materials. Government concentrated its efforts on basic research while providing inducements (e.g., R&D tax credits, capital gains exemptions, etc,) to industry for more developmental efforts. In the main, however, industry relied on technology importation for its technical edge, a strategy no doubt influenced by the degree of foreign ownership or heavy investment in Canadian businesses.

Though Canada has always been a world supplier of wood products, grain, metals and minerals, and has developed substantial associated manufacturing markets, inroads to these captive areas by third world countries are on the increase. In Canadian view their traditional industries and markets no longer can be counted upon to fully sustain the nation's economic growth over the long term and new, advanced technologies must be fostered through cooperative R&D efforts. A comprehensive federal science and technology policy [Taylor 1987; OECD 1987] is under development which focuses on strategies for increased R&D expenditures by the private sector to complement federal and provincial state initiatives. New technologies for Canadian market niche development have been identified by The Ministry of State for Science and Technology (MOSST), the government organization most responsible for science policy, advice and coordination [Taylor 1987]. The three specified by the MOSST led study as strategically important to the country's future are: information technology, biotechnology, and advanced industrial materials. These selected areas build upon existing Canadian technical expertise and industrial know how and in effect represent areas where the transitional process from the old to the new is underway. Though small by some measures current federally sponsored government R&D provides a key network of activities, as for instance in the area of advanced industrial materials where government R&D amounted to about CD $29.7 million for the 1985-1986 period. Chart 19 gives a rough division of expenditures by the various government departments along with current research emphasis.

The organizational setting for these R&D programs is indicated by Chart 20. The R&D system of Canada is pluralistic and

CHART 19

CANADA - FEDERAL GOVERNMENT PROGRAMS ADVANCED INDUSTRIAL MATERIALS (1986)

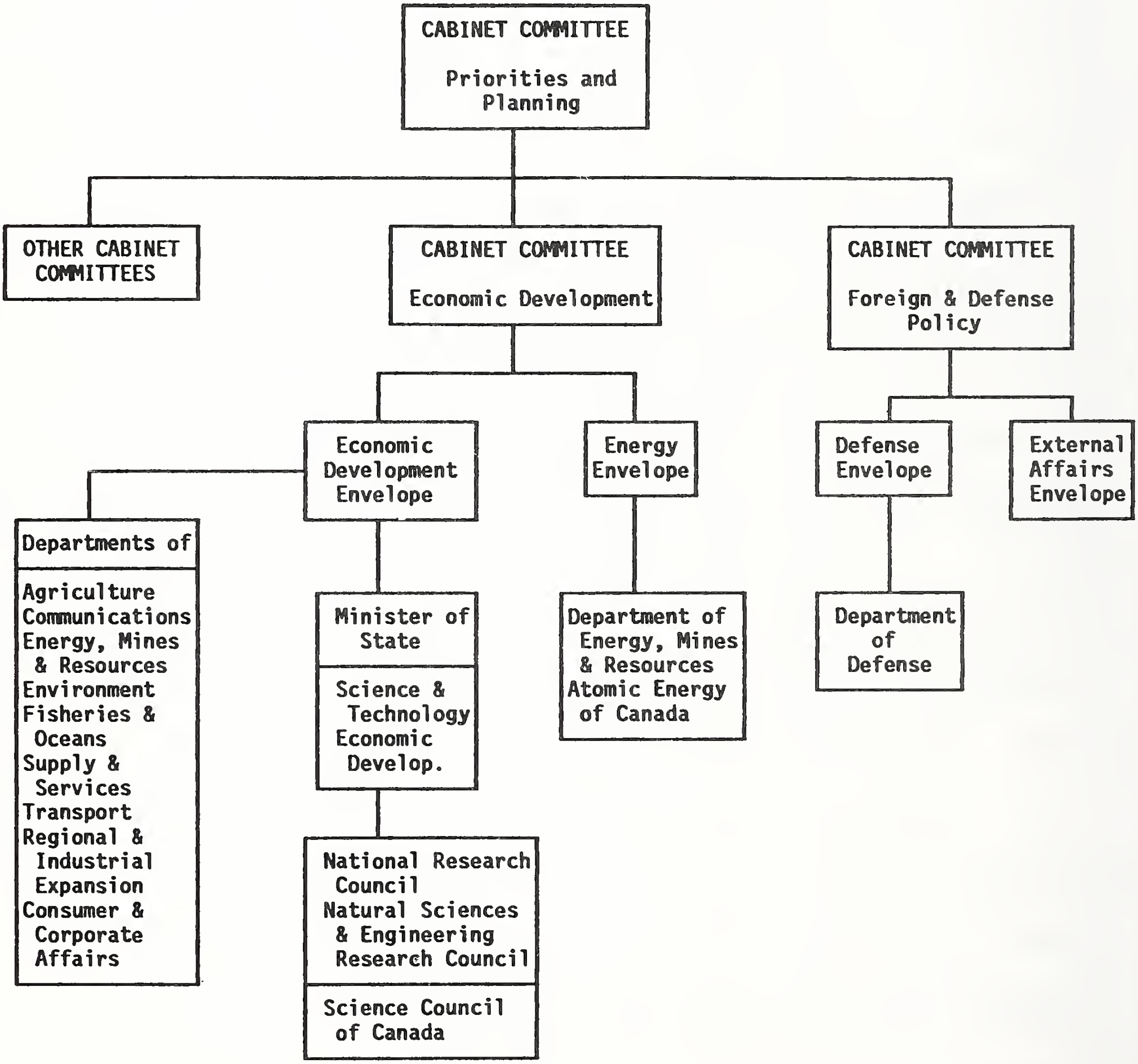
Minist/Agencies & Divisions	$\$X10^6$ 85-86	Clean Steel	Powder Metall	Super Alloys	RST	Com-posites	Polym	Adv Cer	Laser Proc	Treat Coat	NDE	Process Control	CAD/ CAM	Con-ductors
Research Programs														
•Natl Res Coun														
Industrial Matls Research Inst.	9.8		*			**	**	*	*	**	**	*	*	
Natl Aeronautical Establishment	1.4		**	*		**				**	**			
Div. of Space	0.8							**						**
Div. of Physics														
Div. of Chemistry							**							
Div. of Mech. Engineering	1.0												**	
Atlantic Res Lab	0.5							*						
•Energy, Mines and Resources														
Canada Centre for Mineral & Energy Technology	1.7	*			**			**	**	*	**	**		*
•Communications														
Communications Research Centre	0.1					*			*		**			**
•National Defense	5.6													
Defense Research Establishments														
Pacific						**					**			
Ottawa														
Valcartier			*		*	**								
Atlantic					*			*		**		*		
Support Programs														
•Natl Res Coun														
Industrial Res Assistance Prog	4.0					**	**				*	*	*	
Natural Science & Engineering Research Coun	4.8	*	*	**		*	**	*	*	*	*	*	*	*

* Minor Programs
** Major Programs

SOURCE: [Taylor 1987]

CHART 20

MAIN ELEMENTS OF THE CANADIAN R&D SYSTEM



SOURCE: [Ronayne 1984; Doucet 1975]

coordinated and is built around the federal state system of government where policy and programs must have accord between the federal and provincial governments. The federal structure resembles the U.S. system and unites the governments of Canada's 10 provinces with the federal government. The provinces have authority over education and other general local affairs, including regional economic development. The federal government, led by a Prime Minister from the controlling party and his appointed cabinet, has responsibility for defense, trade and commerce, banking, certain taxes, and the like. The ultimate authority for all federal policy on S&T resides in the cabinet.

In 1971 the Ministry of State for Science and Technology was created specifically to advise the cabinet on science policy and to promote and defend science and technology needs. This Ministry coordinates S&T within the federal government and fosters cooperation with the provinces, with public and private organizations, and with other nations. It has no direct budget authority other than for its own organization, but does review fiscal R&D submissions by other government departments. Complementing the MOSST advisory role is the Science Council of Canada, established in 1966 as a Crown Corporation to independently assess the nation's S&T resources, requirements and potential, and to increase public awareness of S&T matters. It draws its membership from industry, universities, and government, but unlike MOSST is not part of the government structure and has no official executive or coordinating role.

Line departments and agencies such as the Department of Regional Industrial Expansion (DRIE), the Energy, Mines and Resources DEMR), the National Research Council (NRC), and the Natural Sciences and Engineering Research Council (NSERC) have the ultimate charter for fulfilling federal S&T policy. Each manages the part of Canada's S&T research or innovation support budget within its own jurisdiction. In 1982-83 the science budget for all departments was about $2.9 billion [Ronayne 1984]. The NRC is generally among the top agencies in funding R&D (about $361 million in 1982-83); its charter includes industrial expansion and regional development through research avenues. NRC operates its own laboratories; gives direct financial support to the universities and industry for specific R&D projects; sponsors coordinating research activities; and develops/maintains the nation's physical standards. The NSERC, established in 1978, underwrites university research supplementing provincial state funding with each covering a particular cost area like equipment, salaries, etc. It distributes its funds ($227 million in 1982-83) through peer-reviewed project grants to the universities in all fields of S&T, using primarily the "undirected" research concept so that a wide range of topical subjects are covered. MSE projects primarily focus on the metals side, but other materials are increasingly being pursued. More industrially oriented R&D is administrated under a separate grants program designed to foster direct collaboration between industry and university researchers; here the participating company gains the right of first access for exploitation of the results.

The main themes of Canada's science policy have been forward looking and for the most part have been directed at achieving a higher level of R&D commitment by industry. Its S&T machinery is somewhat diffuse being scattered among the federal level agencies and the state provinces. Coordination and planning appears to be advanced, but the coordinating organizations lack budget authority. Cooperative R&D internally and externally is an emerging thrust.

CHINA

The People's Republic of China is the world's third largest country in land area, after the Soviet Union and Canada and has a population of just over one billion. It is the oldest continuous major world civilization with records dating about 3500 years, and ancient Chinese scientific and technological achievements, block printing, the navigational compass and gunpowder, for instance, are a source of great national pride [China 1981; Background Notes - China 1983]. Modern day S&T in China, however, started in 1949 with the formation of the Communist style of government and its progress ever since has been tempered by the political scene with some periods of high accomplishments, then low and now high again. The new government assumed control of a people exhausted by decades of war, social conflict and a ravaged economy. The new political and economic system was modeled after that of the Soviet Union. Close alliance was initiated and the centralized, highly structured Soviet type S&T system was installed. Large numbers of Soviet scientific advisors were sent to China and even larger numbers of Chinese to Russia for technical training and upper level education.

The early 1950's saw impressive economic gains, rebuilding of China's war-damaged industrial plants, and a general spread of intellectual freedom, particularly in the sciences. This reached a pinnacle in 1956 when Party Chairman, Mao Zedong issued his famous call: "Let a hundred flowers bloom and a hundred schools of thought contend". The 'hundred flowers' theme lasted but one year when intellectuals started losing favor and the "Great Leap Forward" was initiated. The Great Leap started communes and backyard steel furnaces and did little else other than to disrupt the economy and change the educational system; by 1960 it was largely over, along with relations with the Soviets. The next major upheaval was the "Cultural Revolution", started in 1966, again by Mao, to correct political wrongs and rekindle revolutionary fervor. This was the decade of the red guards, who, prompted by the leaders of government, stirred the pot of civil unrest. The results on science and technology in China were disastrous; colleges were closed, whole laboratories were unoccupied, and scientists and engineers professed other occupations in fear of life and limb.

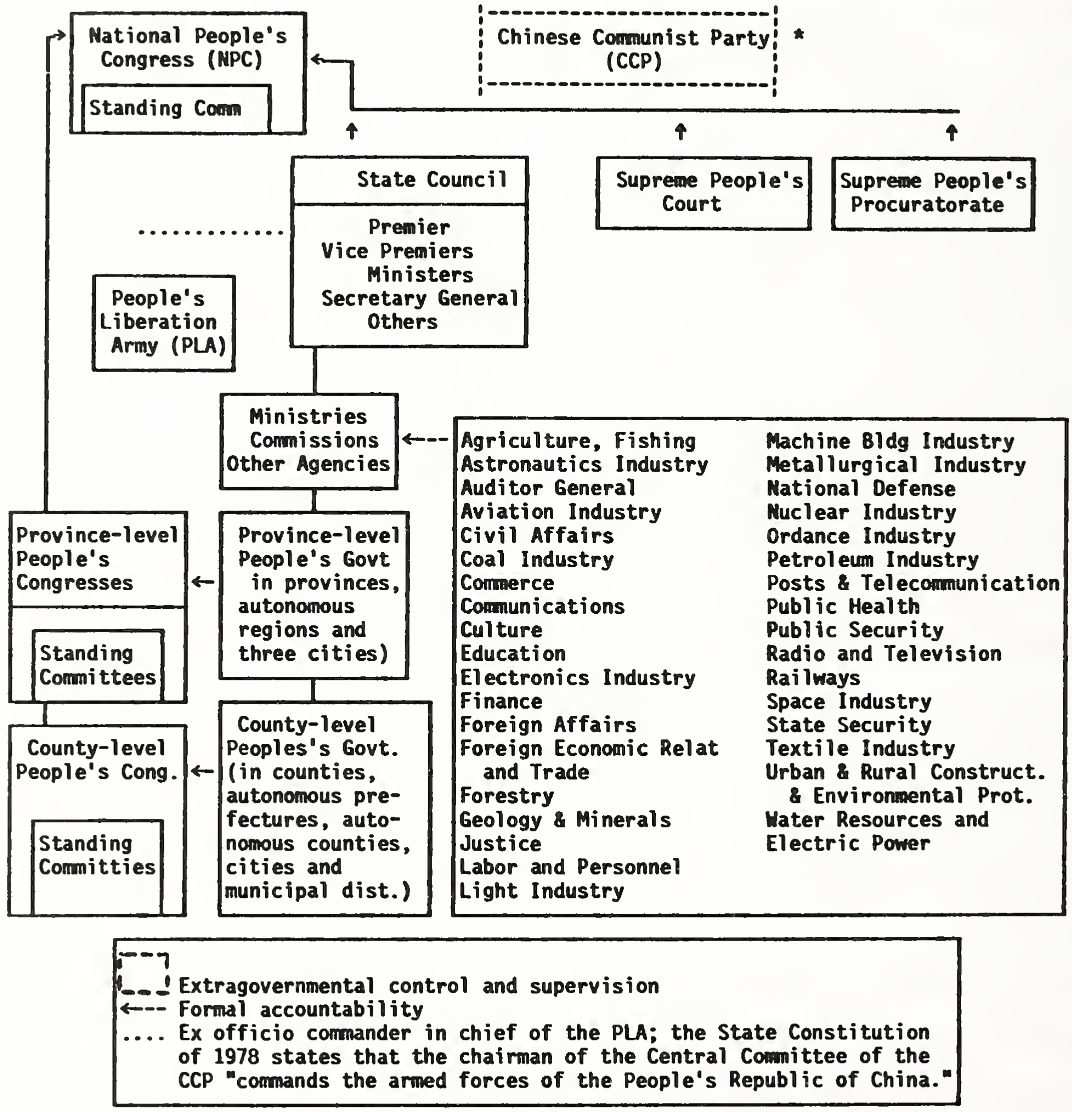
The death of Mao and the overthrow of his top allies, the Gang of Four, in 1976, saw the end of the Cultural Revolution and a major milestone for the revitalization of S&T. All intellectuals, but especially scientists and other professionals were essentially brought back into the life of society and into government. The roles of researchers and teachers were expanded to include a degree of policy making in government and in the Party, in recognition of the fact that a program of modernization and industrialization to be successful, must include in the planning those performing the program. This process of coordination and joint participation in planning and implementation, coupled with less Party control and decentralization of decisionmaking, is now a major distinctive feature between the Chinese and the Soviet Union's S&T systems. [The trend was started with the initial break with the Soviets, but was somewhat delayed in implementation due to the various political disruptions.]

In 1975 just prior to Mao's death, Premier Zhou Enlai put forth a new set of economic goals, which were reaffirmed in 1978 and defined more in detail. These were described as the "four modernizations", targeted to raise the economic power of China by the year 2000 to a rank much above its self-proclaimed status as a third world, less than developed country. The four modernization elements were agriculture, industry, defense, and science and technology, the latter being central to the other three [Suttmeir 1980; Tang 1984]. Within this context a key strategy was the massive importation of Western technology, including whole manufacturing plants and the simultaneous buildup of S&T. Budgets were increased, new institutes formed, science education expanded, and interaction with Western S&T activities encouraged on all fronts, including a significant outreach exchange program for additional education of their already well trained, up-to-date students from the better Chinese institutions. In 1981 China's large budget deficits and increasing inflation rate forced an austerity program and a stretch out of goals; the S&T program plan set forth in 1978 for the period 1978-1985 by the All-China Science Conference was impacted in its time scheduling, not in intent. The plan identified 27 "spheres" for comprehensive research, eight of which were designated as of special prominence: Agriculture; Energy; Materials; Computer Science and Technology; Lasers; Space; High Energy Physics; and Genetic Engineering. As with most nations there is in China a continuing debate on the balance between basic and applied research. Government call at the higher level for close ties between research and production, however, tends to ensure that a sound proportion of applied research is carried out by almost every R&D establishment, with self preservation being one prime motivation factor. Thus a S&T promoted international market capability is intimately tied to China's move toward industrial modernization and overall economic interdependence with the Western world and Russia. Currently, China has significant trade with about 150 (mostly Western) nations, designed primarily in the interim for technology importation, and for self reliance in the future.

The organizational structure of scientific research and technology development follows government divisional lines with additional special entities for focus and planning and Party oversight. Chart 21 indicates the main elements of the Chinese government; its role is to implement Party policies. The primary instruments of state power are the State Council, an executive body corresponding to a cabinet; the NPC, a legislative body; and the judicial branch, the court system. Under the State Council are an assortment of ministries, agencies, and commissions which approximately equate to the numerous agencies within the executive branch of the U.S. governmental system.

CHART 21

THE STRUCTURE OF THE CHINESE GOVERNMENT



*Article 2 of the State Constitution of 1978 states: "The Chinese Communist Party is the core of the leadership of the whole Chinese people. The working class exercises leadership over the state through the Chinese Communist Party."

SOURCE: [Bunge 1984; Suttmeir 1980; Tang 1984]

Research and development activities fall under the purview of several parts of the bureaucratic government structure. Civilian R&D policy and programs are planned and coordinated by the State Scientific and Technology Commission (SSTC), an organizational unit of the State Council. Its activities are roughly divided among four sectors: the Chinese Academy of Sciences (CAS); the universities; the industrial sector; and other ministerial sectors (e.g., agriculture). Military research is handled separately by the defense organizations; the National Defense and Technology Commission apparently controls operations, but little is known about it except that there is tension between it and the civilian counterparts, in the areas of funding, exchange of data, and duplication of efforts. Needless to say that the civilian sector feels that it is less favored than the defense side.

Chart 22 summarizes the major research establishments in China as published in 1984 [Bunge 1984], but modified here to include only organizations thought to have relevance to MSE. To this is added a new organization, The National Natural Science Foundation of China (NSFC). It was formed in 1986 to promote basic research in the universities and elsewhere much along the same lines as the NSF in the U.S. Chart 23 gives the organization of NSFC. Whatever the institutional framework, CAS, the ministries, or others, the major organizational mode of R&D in China is the research institute--one or a set of small laboratories having a narrowly defined research, focus such silicate chemistry, or transformer research or chemical metallurgy, etc. Their size varies with need, from 100 to 1000 persons, the average being less than 500. Technical staff constitute about half of the total with senior people amounting to no more than 20 or so for the average size institute.

The other major organization exerting influence on S&T is the China Association for Science and Technology (CAST). This national group is funded by government and acts as the umbrella representative for more than a 100 of the nation's learned (professional) societies. Although formed in 1958, the current liberal government approach to intellectuals, has allowed CAST to provide a more or less unencumbered forum for free scientific exchange and open policy advice to government, without fear of redress.

CHART 22

MSE RELATED MAJOR RESEARCH ESTABLISHMENTS IN CHINA

SOURCE: [Bunge 1984]

The main research centers are listed below in alphabetical order under subject headings

AGRICULTURE AND ENVIRONMENTAL PROTECTION

Environmental Science

Chinese Academy of Sciences

- Dalian Institute of Chemical Physics
- Institute of Environmental Chemistry, Beijing
- Institute of Geography, Beijing
- Institute of Hydrobiology, Wuhan
- Institute of Microbiology, Beijing
- Nanjing Institute of Soil Science
- Shanghai Institute of Organic Chemistry

EARTH SCIENCES

Geology and Geophysics

Chinese Academy of Sciences

- Changsha Institute of Geotectonics
- Institute of Acoustics, Seismoacoustics group
- Institute of Geology, Beijing
- Institute of Geophysics, Beijing

Ministry of Geology and Minerals

- Colleges of Geology at Changchun, Zhangjiakou, Xian, Chengdu, Wuhan and Heifei
- Institutes of Geology, Geomechanics, and Plateau
- Geology forming parts of the Academy of Geological Sciences
- Linked to provincial bureaux of geology

Nankai University, Tianjin, Geology Department

State Seismological Bureau

- Factory No. 581, Beijing
- Institute of Engineering Mechanics, Harbin: earthquake engineering
- Institutes of Geology and Geophysics, both in Beijing
- Seismological Research Institute, Wuhan

University of Beijing, Geology Department; Geophysics Department - Solid Earth Section (mainly geomagnetism and seismology)

University of Nanjing, Geology Department

Zhongshan University, Guangzhou, Geology Department
In addition to geology departments in ten other small universities.

EARTH SCIENCE AND TECHNOLOGY

Chinese Academy of Sciences

Chanchun Institute of Applied Chemistry: petroleum synthesis, solar cells
Chengdu Institute of Biology, Bio-Energy Resources Division
Chengdu Institute of Organic Chemistry: natural gas utilization
Dalian Institute of Chemical Physics: liquid fuel synthesis, fuel cells
Guangzhou Institute of Energy Conversion
Hefei Institute of Plasma Physics
Institute of Electrical Engineering, Beijing: magnetohydrodynamic generation, solar energy
Institute of Engineering Thermophysics, Beijing: gas turbines
Institute of Geology, Beijing: geothermal energy survey and exploitation
Institute of Physics, Beijing: fusion (Plasma Physics Division) and solid-electrolytes for advanced batteries (Crystallography Division; see also Institute of Ceramic Chemistry and Technology below)
Lanzhou Institute of Chemical Physics: petroleum fractioning
Shanghai Institute of Ceramic Chemistry and Technology: solid-state batteries for intermittent energy storage or electricity generation load levelling and for cars
Shanghai Institute of Nuclear Research
Shanghai Institute of Optics and Fine Mechanics: laser initiation of fusion
Shanxi Institute of Coal Chemistry, Taiyuan
Southwest Institute of Physics, Dongshan: fission and fusion
University of Science and Technology of China, Hefei, Department of Thermophysics

CHART 22 (CONTINUED)

Ministry of Coal Industry

- Central Coal Research Institute, Beijing
- Changsha College of Coal Research
- Fushun College of Coal Research
- Institute of Coal Dressing Design, Beijing
- Institutes of Coal Chemistry at Beijing, Taiyuan and Yantai
- Tangshan College of Coal Research
- Other research laboratories run by provincial mining bureaux and major collieries

Ministry of Machine Building Industry

- Institute of Transformer Research, Beijing
- Research departments attached to Xian, Paiding and Shengyang Transformer Plants

Ministry of Nuclear Energy

- First, Second, ... and Fifth Research Institutes
- Institute of Atomic Energy, Beijing
- Uranium Geology Research Institute, Beijing

Ministry of Petroleum Industry, Academy of Petroleum Research

- Colleges of Petroleum Engineering at Urumqu, Xian, Shenyang, Beijing and Nanchung (in Sichuan)
- Fushin Institute for Oil Shale Refining and Hydrogeneration Research
- Harbin Institute of Petrochemistry
- Institute for Petrochemical Research, Beijing
- Institute of Crude Oil Refining, Beijing
- Institute of Petroleum, Beijing
- Institutes of Petroleum Research at Lanzhou, Dalian and Fushun
- Sichuan Institute of Natural Gas Research, Pingquan

CHART 22 (CONTINUED)

MINERAL INDUSTRIES

Iron and Steel

Chinese Academy of Sciences

- Fujian Institute of Research on the Structure of Matter - Sanming branch
- Institute of Chemical Metallurgy, Beijing
- Shanghai Institute of Metallurgy
- Shenyang Institute of Metals Research

Ministry of Metallurgical Industry

- Changsha Institute of Mining and Metallurgy
- General Iron and Steel Research Institute, Beijing
- Northeast College of Technology, Shengyang
- Southwestern Iron and Steel Research Institute, Chengdu
- Taiyuan Iron and Steel Research Institute

Mineral Geology and Geophysical Prospecting

Chinese Academy of Sciences

- Anhui Institute of Optics and Fine Mechanics, Hefei - Remote Sensing Division
- Changsha Institute of Geotectonics
- Commission for Integrated Survey of Natural Resources, Beijing - Energy Resources Department
- Guangzhou Institute of New Geological Techniques
- Guiyang Institute of Geochemistry
- Institute of Remote Sensing Application, Beijing
- Lanzhou Institute of Geology
- Wuhan Institute of Geodesy and Geophysics

Ministry of Coal Industry

- Central Coal Research Institute, Beijing
- Institute of Geology and Exploration, Beijing
- Xian Coal Field Geological Research Institute
- Xian Institute of Coal Geology for Coal Ash Analysis

CHART 22 (CONTINUED)

Ministry of Geology and Minerals

- Academy of Geological sciences - 18 research institutes
- Aerogeophysical Prospecting and Xinkiang Aerial Survey Teams
- First and Second Marine Geological Survey Teams
- Geological Instrument Factories: Beijing, Shanghai, Xian, Chengdu and Chongqing
- Institute of Exploration Techniques, Beijing
- Institute of Geophysical Prospecting, Xian
- Institute of Geophysics and Geochemistry, Langfong, Hebei Province
- Research Groups on Ore Deposits Associated with Quaternary and pre-Cambrian Sedimentary Rocks, Tianjin; Ore Deposits Associated with Volcanic Rocks, Nanjing; and Sedimentary Ore Deposits, Chengdu

Linked to provincial and municipal bureaux of geology, each with a number of field prospecting brigades, and to research institutes under the jurisdiction of provincial governments, e.g., Shaanxi College of Metallurgical Prospecting and Design, Xian and Guilin Institute of Metallurgy and Geology

Ministry of Metallurgical Industry

- Institute of Geology, Beijing

Ministry of Petroleum Industry

- Institute of Scientific Research for Petroleum Exploration, Beijing
- Sichuan Institute of Natural Gas Research, Pingquan

Ministry of Urban and Rural Construction and Environmental Protection

- Institute of Geology, Beijing

<u>Mining science and technology</u>

Chinese Academy of Sciences

- Wuhan Institute of Rock and Soil Mechanics - Statics of Rocks Masses and of Soils divisions

CHART 22 (CONTINUED)

Ministry of Coal Industry

- Central Coal Mining Research Institute, Beijing
- College of Coal Mine Design, Beijing
- Fuxin College of Coal Mining
- Mine Safety Instrument Development Institute, Fushun
- Shanghai Coal Mining Machinery Research Institute
- Shangtun College of Mining, Jinan
- Sichuan College of Mining, Fuling (town where River Wu joins the Yangtze)

Ministry of Machine Building Industry

- Shenyang Institute of Heavy and Mining Machinery

Ministry of Metallurgical Industry

- Central-South Mining & Metallurgical College, Changsha
- General Mining & Metallurgical Research Institute, Beijing
- Shenyang Institute of Ore Dressing Machinery
- Tangsha Institute of Mining Research
- Xian Institute of Metallurgical Construction

<u>Nonferrous metals</u>

Chinese Academy of Sciences

- Changchun Institute of Applied Chemistry
- Institute of Chemical Metallurgy, Beijing
- Institute of Physics, Beijing - Laboratory of Physical and Chemical Analyses
- Shenyang Institute of Metal Research

Ministry of Metallurgical Industry

- Baoji Institute for Nonferrous Metals
- General Research Institute for Nonferrous Metals, Beijing
- Shanghai Institute of Materials Research
- Shanghai Institute for Nonferrous Metals

Exhaustive but confusing lists have been avoided in these sections relating to Mineral Industries. The research centres under various ministries and provincial authorities seem to present a picture of considerable fragmentation, duplication and mutual isolation in activities. R&D institutes run by individual mines and plants are too numerous to be included.

CHART 22 (CONTINUED)

TRANSPORTATION AND INFORMATION TRANSFORMATION

Aerospace

Chinese Academy of Sciences

- Guangzhou Institute of Electronic Technology
- Institute of Engineering Thermophysics, Beijing
- Institute of Mechanics, Beijing
- Lanzhou Institute of Chemical Physics
- Nanjing Astronomical Instrument Factory
- Space Science and Technology Centre, Beijing
- University of Science and Technology of China, Hefei, Modern Mechanics Department: high-temperature thermophysics

Ministry of Aviation Industry

- Aeronautical Institutes at Shenyang, Xian and Chengdu
- Colleges of Aeronautics at Harbin, Shenyang, Beijing, Zhengzhou, Nanjing, and Nanchang
- Turbojet Engine Research Centre at Kiangyou in Sichuan
- \`303' and \`625' REsearch Institutes in Beijing, etc.

Ministry of Space Industry

- Institute of Space Technology, Beijing

Quingh University, Beijing, Engineering Mechanics Department: ionized gas dynamics

Xian Polytechnic University, Aircraft Engineering Department

Computers

Chinese Academy of Sciences

- Chendgu Institute of Computer Application
- Chengdu Scientific Instrument Factory
- Computer Centre, Beijing
- Harbin Institute of Precision Instruments
- Institute of Automation, Beijing
- Institute of Computer Technology, Beijing
- Shenyang Institute of Computer Technology
- Xinjiang Institute of Physics, Urumqi, Computer Application Division
- University of Science and Technology of China, Hefei, Radio and Electronics Department - Computer Section

CHART 22 (CONTINUED)

Fudan University, Shanghai, Computer Science Department

Ministry of Electronics Industry

- \`1448' Research Institute, Changsha
- Research Institute of Shanghai Instruments and Meters Plant

Qinghua University, Beijing, Computer Technology and Science Department

Shanghai Polytechnic University, Electronic Engineering and Computer Science Department

University of Beijing, Computer Science Department

University of Nanjing, Computer Science Department

<u>Electronics</u>

Chinese Academy of Sciences

- Chengdu Institute of Optics and Electronics
- Factory 109, Beijing
- Institute of Physics, Beijing
- Institute of Semiconductors, Beijing
- Shanghai Institute of Metallurgy
- Shanghai Institute of Organic Chemistry
- Xinxiang Semiconductor Device Factory (in Hebei)

Fudan University, Shanghai, Integrated Circuits Laboratory and Physics Department

Ministry of Electronics Industry

- Over 50 research establishments, including First, Second, Third, ..., Tenth Design Institutes, and \`1411' Research Institute, Beijing

Normal University of Beijing, Physics Department

Qinghua University, Beijing, Radio Electronics Department

Shanghai and Xian Polytechnic Universities, Electronic Engineering Departments

University of Beijing, Electronics Factory under Physics Department

CHART 22 (CONTINUED)

University of Nanjing, Radio Physics Department

Railways

Ministry of Railways

- Academy of Railway Sciences, Beijing: Railway Design, Railway Construction, Desert, Tract, Locomotive and Rolling Stock, Chemical Metallurgy, Steel
- Construction, Signalling and Communications,
- Scientific and Technical Information, plus seven other research departments; Laboratories of Brake, Bridge, Concrete, Diesel, and Soil Mechanics
- Changsha College of Railways
- Close affiliations with Shanghai and Xian Polytechnic Universities

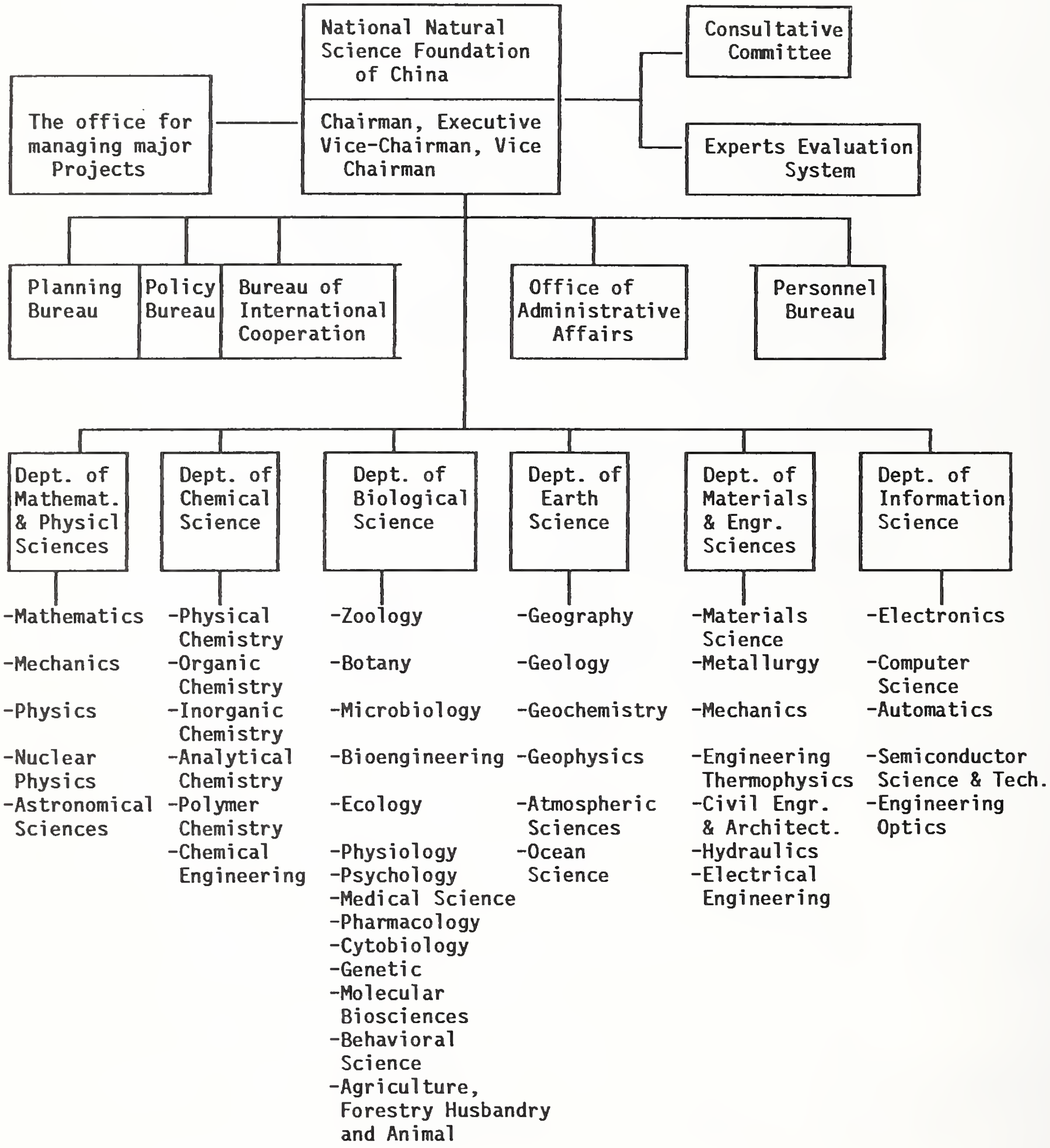
Telecommunications

Chinese Academy of Sciences

- Institute of Electronics, Beijing
- Institute of Physics, Beijing, Laser Division
- Institute of Semiconductors, Beijing, Laser Beam Originating Devices and Microwave Devices Division
- Wuhan Institute of Physics, Ionosphere Physics Division
- Xian Institute of Optics and Precision Mechanics

CHART 23

NATIONAL NATURAL SCIENCE FOUNDATION OF CHINA



SOURCE: [NSFC 1986]

FEDERAL REPUBLIC OF GERMANY

The distinctive feature of industrial and economic policy, planning, and programs in West Germany (FRG) is its broad based consensus-building process. This process combines elements of decentralized decision making and regional implementation, with sectoral automony a keyword and representation by major interest groups a guiding premise. These characteristics also typify the S&T system in FRG and set it apart from the approaches used by the rest of Europe in their organization and implementation of R&D. Modern day S&T grew from a strong tradition of basic research and industrial R&D coupled through a network of premier, largely privately-based, research organizations and national (large scale) research centers. Science and technology policy and directions are coherently articulated and are generally stable with each new administration, changing only to accommodate new national needs, as defined by the consensus process. Overall S&T objectives include [West Europe Report 1986]:

- Expand scientific knowledge and technological innovation as a fundamental prerequisite for a modern, export-oriented economy.
- Increase economic performance and competitiveness.
- Preserve national resources and the environment.

Support for research using public funds originates through the ministries of the federal government and through the Länder governments, the German equivalent to the state governments in the U.S. At the federal level the Ministry of Research and Technology (BMFT) is the lead government organization in S&T, having the overall charge to provide R&D support and to coordinate (not control) overall government R&D policy and programs through a loose federation-like advisory committee system (about 50 groups and 400 members in total). Approximately every four years BMFT publishes a cabinet approved Federal

Research Report detailing the policy, plans, and programs for R&D in FRG; the last report was issued in 1984 [FRR 1984]. Chart 24 gives an organizational breakdown (1984) of BMFT, indicating the breadth and scope of its S&T activities, including MSE.

CHART 24

ORGANIZATION OF THE FEDERAL MINISTRY OF RESEARCH AND TECHNOLOGY

1. **ADMINISTRATION; BASIC PRINCIPLES OF RESEARCH & TECHNOLOGY POLICY**

    10 Initial Assessment Office
    11 Administration; Finance; Principles of Research and Technology Policy
    12 Interdisciplinary Questions of Research Sponsorship and Research Installations
    13 Infrastructure

2. **BASIC RESEARCH; RESEARCH COORDINATION; INTERNATIONAL COOPERATION**

    21 Basic Research, Research Coordination
    22 International and Intra-German Cooperation

3. **ENERGY; BIOLOGY; ECOLOGY**

    31 Nuclear Energy; Energy Research Program
    32 Biology; Ecology; Fossil and Renewable Energy Sources

4. **INFORMATION AND PRODUCTION TECHNOLOGIES; LIVING AND WORKING CONDITIONS; SPECIALIZED INFORMATION**

    41 Information and Production Technologies, Support for Innovation
    42 Living and Working Conditions; Specialized Information

5. **AEROSPACE; RAW MATERIALS; EARTH SCIENCES; TRANSPORTATION**

    51 Aerospace
    52 Materials Research; Earth Sciences; Transportation

SOURCE: [Ronayne 1984]

BMFT receives about 60% (in 1984 about DM 7.0 billion) of all federal government R&D funds, about half of which go directly to industry on a cost shared basis, usually 50:50. The remainder is used to support major national research centers, educational institutions and private research organizations, many of which have an industrial research focus. The Ministries of Defense, Economics, and Education and Science also support R&D in various sectors and handle about 14%, 10% and 8% respectively, of the government research monies with the balance managed and distributed by other government ministries. Industry is further assisted by specific business subsidies and special tax deductions for R&D. Support for the universities and general education is derived primarily from the Länder and local governments, but also from the federal government.

The institutional setting and operational scheme [Ronayne 1984] for the performance of government sponsored research, however, is perhaps the unique element of the FRG S&T. It bears some resemblance to that of Japan and has some of the characteristics of the national lab system, and private R&D laboratories (e.g., Battelle, SRI) in the U.S., but conceptually it is different in scope and governing philosophy. In the FRG a significant fraction of federal research funds are channeled to a series of quasi-independent research institutes or laboratories through major non-government research associations (societies). The research institutes are generally small in size (though not always) as compared to U.S. standards, highly focused and autocratically ruled. The societies are roughly categorized as related to education, fundamental research, applied research, and developmental research, with considerable overlap (but not authority) in most areas.

The combined research capabilities of the societies, the large national centers, the universities, and industries provides the FRG with a complete R&D system (Chart 25), covering all aspects

CHART 25

CHARACTERISTICS OF R&D FACILITIES IN THE FEDERAL REPUBLIC OF GERMANY*

	Education	Fundamental Research	Applied Research	Development	Introduction Into Market
Universities	●	●	○		
Max-Planck-Gesellschaft Society for Advancement of Sciences		●	○		
Grossforschungseinrichtungen Large Scale Research Centres		●	●		
Fraunhofer-Gesellschaft for the Advancement of Applied Research		○	●	●	○
Industries			●	●	●

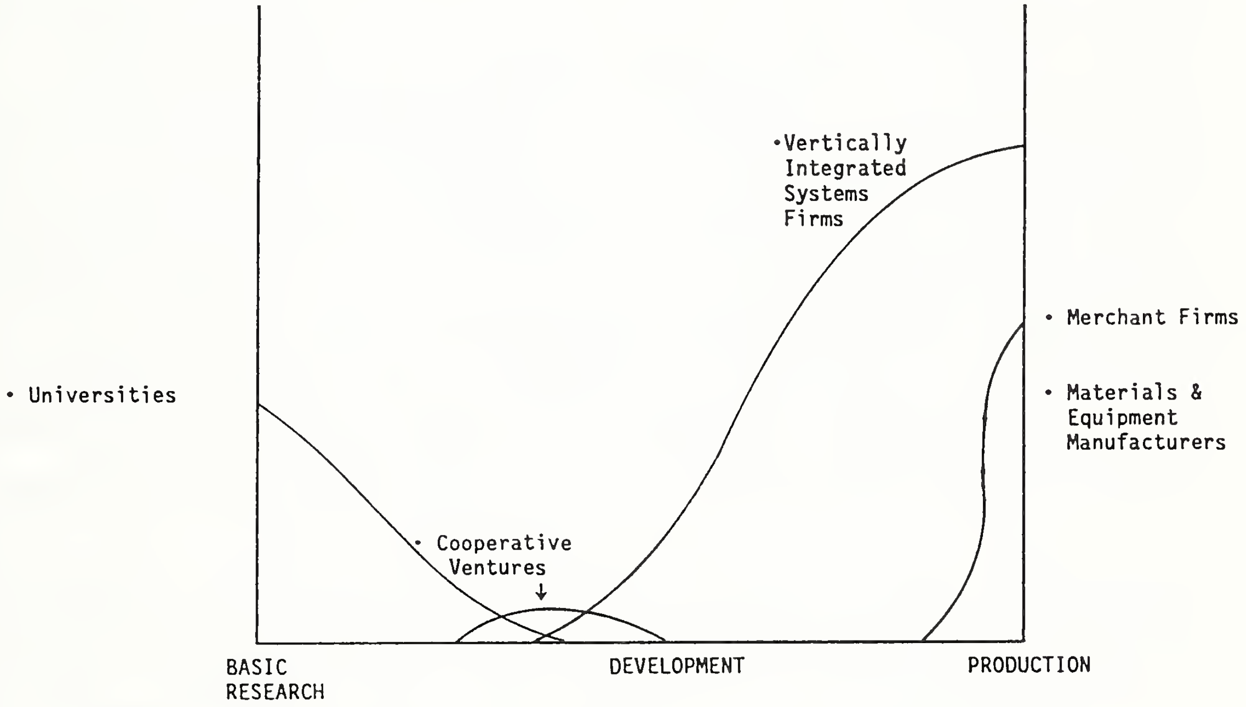
* Solid Circles - Primary Research Focus
** Open Circles - Secondary Research Focus

SOURCE: [Fraunhofer 1986]

of the innovation process, from invention to product. The FRG has filled the R&D gap between basic research and production whereas the U.S. has not. Chart 26 schematically indicates one view of the extent of effort over the spectrum of R&D in the U.S. and shows a relatively small effort in cooperative development. A similar schematic illustration for FRG (and Japan) would indicate a much larger area under the cooperative venture region.

CHART 26

SPECTRUM OF U.S. R&D



SOURCE: [Prabahah 1987]

Indeed, there is no R&D laboratory system in the world comparable to that of the FRG and many lessons are to be learned from its institutional characteristics:

MAX PLANCK SOCIETY (MPG-The Max Planck Gesellschaft): This society, founded 76 years ago, is an autonomous basic research organization, comprised of about 60 separate institutes covering diverse topics from nuclear physics to molecular biology to coal gasification to patent law. MPG was created on the premise that fundamental research, especially those areas requiring an interdisciplinary approach, could nurture best in an unencumbered environment, free of explicit justification other than science-based and free of the teaching and administrative responsibilities so typical in a university setting. This is the guiding principle today though mitigated by national concerns coupled to constrained budgets. Basically, MPG is a premier organization where accountability is measured in terms of scientific value and recognized achievements. If one of its institutes loses its scientific standing, it is closed down and replaced by another, formed from a core group and leader having a more renowned stature. Decisions to establish or abolish an institute are based upon recommendations from the MPG Research Policy and Planning Committee in consultation with the Länder and federal governments and with other national research societies.

Collectively the institutes of MPG employ about 10,000 people, about 40% of which are scientists. Individual institutes vary in size, depending upon need, interest and staff reputations, from as large as 1000 people to as few as 10 or 12. The federal (e.g., BMFT) and the Länder governments provide 85% or more of the MPG operating and capital budget on a 50:50 basis. In 1986 the total budget of MPG was about $500 million, a level equal to that ten years earlier.

THE GERMAN RESEARCH SOCIETY (DFG-Deutsche Forschsgemeinschaft): Universities in the FRG are financed generally through a two-part system. The Länder governments provide for staff and operating costs with the federal government covering research through its ministries and through The German Research Society. The DFG was established in 1951 specifically to foster university research, in a manner (e.g., proposals, peer review) much like the National Science Foundation does now in the U.S. The DFG, however, is an autonomous, nongovernment body composed of representatives from the universities, major scientific establishments, academies of science, and the state and federal governments. Administratively it is located within the Federal Ministry of Education and Science. The DFG has a budget approximately equal to that of the Max Planck Society.

THE FRAUNHOFER SOCIETY FOR APPLIED RESEARCH (FhG-Fraunhofer Gesellschaft): The FhG was set up in 1949 by the BMFT to perform engineering oriented research for industry on a contract basis [Paul 1984; Fraunhofer Information Package 1986] . By 1973 its role had been strengthened and expanded to make it the government's central applied R&D organization with the primary responsibility to develop technologies and to foster their diffusion to industry, especially small businesses. FhG is comprised of some 34 separate institutes (in 1987) and employs about 4000 workers, of whom one-third are scientists and engineers. Its 1987 expenditure budget was about DM 500 million with support derived through an industry-government financing arrangement on a project-to-project basis. Approximately two-thirds of costs are currently covered by direct industrial contracts. The balance is handled by government, but these are linked to the degree of success of the research that is carried out. Industrial sponsors are given exclusive access to the R&D results and can even obtain government assistance in financing their share of the costs.

Each FhG institute has a commercial orientation and serves as a technology conduit. Their function is not only to conduct applied R&D, but also to apply the R&D. Technical disciplines provide the organizational focus for each of the institutes. One may concentrate on silicate research like the Institut für Silikaforschung in Wurzburg, or one may focus on semiconductor devices and processing technology like the Institute for Solid State Technology in Munich. Typically a FhG institute is housed in a separate facility, usually in the general locale of an university (not on campus), has a staff of about 100 (about 30-50 scientists/engineers, 20 or so students, the balance consisting of support staff) and has a nationally recognized director. Ties with the university are loose. The director may hold a university chair and he and his staff may do some teaching, but contractual arrangements are kept to a minimum.

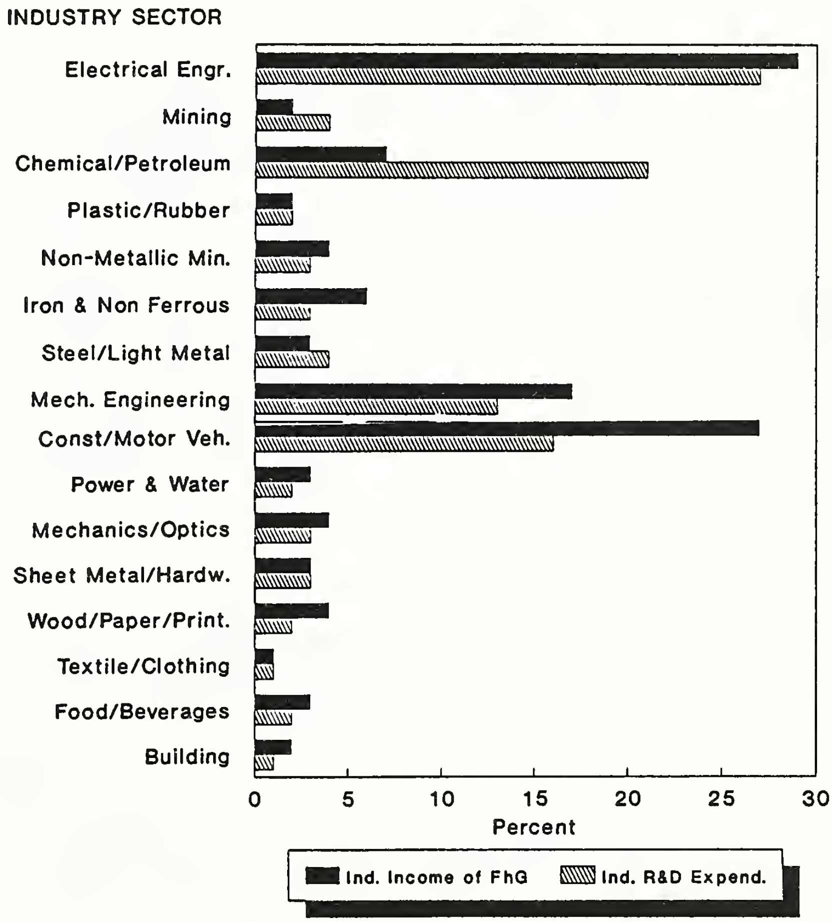
Collectively, the institutes cover nine generic technology areas as follows:

1. Microelectronics
2. Information technology
3. Production automation
4. Production technologies
5. Material and component behavior
6. Process engineering
7. Power and construction engineering
8. Environment research
9. Technological economic studies, technical information

The materials and component behavior segment ranks first in terms of staff allocation (~500), and second in budget, along with microelectronics (about DM 53 million each in 1985); production automation had a budget in 1985 of about DM 68 million involving a staff of some 400 persons. Using a different categorization scheme, the activities of the FhG roughly match or exceed industrial R&D levels (on a percentage basis). Chart 27 compares expenditures for the FhG's R&D with industries' own expenditures on R&D for several major areas. For both R&D groups, focus on information and communication (electrical) and transportation (motor vehicles) is high.

Chart 27

Origin of the Industrial Income of the FhG & Industrial R&D Expenditures

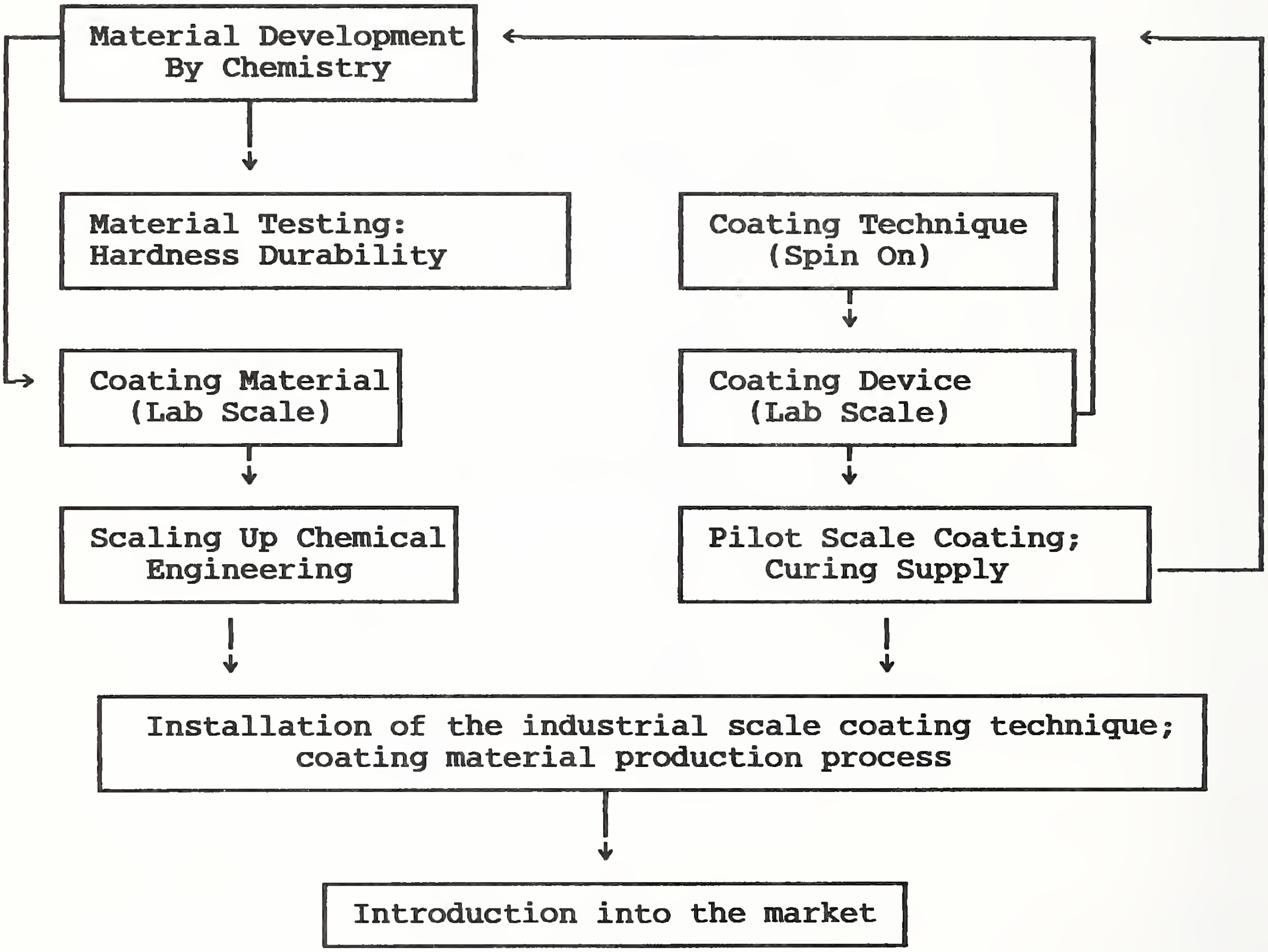


Source: [Fraunhofer Information Package 1986]

FhG institutes often cooperate in interdisciplinary projects, a strategy which enables the FhG to develop products from the early stages. An example is given in Chart 28. A scratch resistant coating on plastic eyeglass lenses was developed, beginning

CHART 28

DEVELOPMENT AND TECHNOLOGY OF A HARD COATING ON PLASTIC EYE GLASS LENSES



SOURCE: [Fraunhofer Information Package 1986] with the coating material development and ending up with the installation of the production unit. Three FhG institutes under the management of Fraunhofer-Institut für Silicatforschung (ISC) were incorporated in the effort. Technology development is clearly the business of FhG and they have been successful in doing it. The doubling of their industrial contract work during the last ten years proves at least that industry values their service.

Though partially funded by public funds, FhG institutes do not function as government laboratories in the conventional sense. They function on an independent basis, rather than to implement directions and priorities set by government. Relationships with government ministries hence vary but probably are the closest for those institutes engaged in some facet of defense R&D (about 20-25% of FhG R&D was defense related in 1984). In 1955 a conscious decision was made by government to permit FhG to accept defense projects, with the belief that a combined civilian and defense R&D effort would benefit each more than separate activities in isolation. For strictly commercial ventures FhG is highly rated within Germany; measures of success for the combined civilian/defense R&D tactic are not known.

GOVERNMENT INSTITUTIONS FOR LARGE SCALE RESEARCH: The FRG has established a series of independent research institutions for the conduction of long-term, complex research which require considerable expenditures in terms of financing, planning, and management. These large-scale facilities are essentially complementary to the other private and state supported R&D organizations. In 1984 there were 13 such institutions which collectively employed 20,000 persons, including 5000 scientists engaged in a variety of focused research efforts. Six of the facilities deal with technologically oriented areas--energy, biotechnology, maritime, and aeronautics; others are concerned with medical research, toxicity, and the operation of large

experimental facilities such as the HERA particle accelerator in Hamburg or the planned synchrotron installation also to be located in Hamburg. For nationally coordinated programs one of these institutions is often selected as the overall research manager. On the whole these large scale establishments have increasingly turned their attention to national industrial concerns, concentrating on joint research, technology transfer, new technology business start-ups, and contract research. Starting in 1985 the new research agendas (particularly for those formerly engaged in nuclear R&D) include R&D on:
(1) Microelectronics, information and communications technology,
(2) Materials technology and, (3) Environment.

Materials science and engineering has been a long-standing cross-cut theme of the majority of the German R&D programs. In 1985 the BMFT formally inaugurated a new ten year Materials Research Program [BMFT 1985] having an annual budget of about DM 100 million. The central objective of this program is the development of a limited number of key areas in materials having high scientific and economical potential, where major technological progress can be expected by cooperative, interdisciplinary research between the national German institutes and industrial laboratories. [Seitz 1986]. The BMFT has assigned the Kernforschungsanlage Julich GmbH, KFA (The Nuclear Research Center at Julich) to manage the new materials research effort, which encompasses the following areas:

1. High Performance Structural Ceramics
2. Powder Metallurgy
3. High Temperature Metals and Special Materials
4. High Performance Polymers
5. Advanced Composites

As identified in Chart 29, about 30 institutes representing the large research establishments, the FhG and the MPG participate in this program. To this are added a significant complement of industrial laboratories (43 in ceramics alone; see Chart 30) for an overall national German effort in MSE.

CHART 29

ACTIVITIES IN RESEARCH INSTITUTES WORKING IN MATERIALS SCIENCE, FINANCED BY GOVERNMENTAL FUNDS

SOURCE: [BMFT 1985]

INSTITUTIONS		ACTIVITIES IN MATERIALS SCIENCE
Frauenhofer-Society for Applied Science	Institute for Research in Silicates, Würtzberg	New nonmetallic, anorganic materials (including Sol-gel process)
	Institute for Applied Materials Research, Bremen	Composites: metal-metal, metal-plastic, surface layers, interfacial bonding techniques
	Laboratory for Durability Measurements of Industrial Materials, Darmstadt	Measurements of life-long durability and mechanical resistence of composites metallic and nonmetallic materials
	Institute for Mechanical Testing of Materials, Freiburg	Mechanical and technological characterization of materials, behavior of structural material under static and cyclic loading, determination of fracture behavior
	Institute for Nondestructive Testing, Saarbrücken	Development and preparation of new/improved techniques for nondestructive evaluation of new materials (ceramics, composites, etc.)
	Institute for Production Technology, Aachen	Technique for high speed production of materials (for ex. with lasers)
Max-Planck Society for Promotion of Science	Institute for Research on Iron, Düsseldorf	Metallurgical processing techniques, materials science and technology
	Research Institute of Solid State Materials, Stuttgart	Optical, electrical, magnetic and mechanical properties of nonmetallic, crystalline and glassy materials

CHART 29 (CONTINUED)

INSTITUTIONS		ACTIVITIES IN MATERIALS SCIENCE
Nuclear Science Research Center Jülich, Inc.	Fritz-Haser Institute, Berlin	Microstructure evaluation of polymers with x-ray lithography
	Institute for Materials Science, Stuttgart	Research on metallic, powder metallurgical and ceramic materials
	Institute for Plasma Physics, Garching	Surface science of metallic materials
	Institute for Polymer Science, Mainz	Interdisciplinary research (physics, chemistry, materials science) for characterization and synthesis of neon (including electrical conducting) polymers
	Institute for Research in Dynamics, Göttingen	Surface Science
	Institute for Reactor Materials	Development and testing of high temperature metallic and ceramic materials; coating, composites
	Institute for Solid State Research	Research on properties of solid materials, crystal growth, material development of metallic materials (lattia defects and radiation damage, phase transformations and critical phenomena) mechanical (and electrical) properties of (doped) polymers
	Institute for Plasma Physics	Analysis of materials for fusion reaction technology
	Institute for Surface Science and Vacuum Physics	Applied research in surface-and vacuum physics

CHART 29 (CONTINUED)

INSTITUTIONS		ACTIVITIES IN MATERIALS SCIENCE
Institute for Reactor Science & Technology, Karlsruhe, Inc.	Institute for Applied Nuclear Physics/Institute for Neutron and Solid State Physics	Interface and microstructural research
	Institute for Radiochemistry	Basic science in surface chemistry
	Research Institute for Materials and Solid State Reactions	Research and development of specific materials (multi-phase ceramic and metallic materials (with respect to high wear resistance. High temperature deformation of metallic materials
	Institute for Nuclear Materials	Material reliability (life time durability(low temperature mechanical properties of polymers
Research Center, Geesthact, Inc.	Institute for Physics	Development and characterization of materials for the ocean technique as well as high temperature materials, analysis of brittle behavior of nuclear steel containers under pressure
German Airspace Research Center	Materials Research, Institute for Materials Science	Development of high temperature and light weight materials; production of metallic, ceramic and composite materials
Hahn-Meitner Institute for Nuclear Research, Berlin, Inc.	Nuclear Chemistry and Reactor Technology	Radiation damage in solid state materials (life long durability prediction)
	Radiation Chemistry	Interface processes and energy conversion, photo chemical analysis on polymers

CHART 29 (CONTINUED)

INSTITUTIONS		ACTIVITIES IN MATERIALS SCIENCE
German Synchrotron Institute	Synchrotron Laboratory, Hamburg	Synchrotron radiation ranging from atomic and solid state physics to polymer density and molecular technology
Governmental Agency	Ministry for Science and Technology	Research, development, and testing of materials of technical importance, especially with respect to the mechanical, tribological, corrosive, biological and environmental stress behavior

CHART 30

GERMAN COMPANIES ACTIVELY INVOLVED IN HIGH PERFORMANCE CERAMICS

Audi AG

Basalt Feuerfest GmbH

BASF AG

Battelle-Institut e.V.

Brayer AG

Bosch GmbH

Brown, Boverie & Cie. AG

C. Conradty GmbH & Co. KG

Cremer Forschungsinstitut GmbH & Co. KG

Daimler-Benz AG

Degussa AG

Didier-Werke AG

Dornier-Systems GmbH

Dynamit Nobel AG

Elektroschmelzwerk Kempten GmbH

Feldmühle AG

Ficht GmbH

Friedrichsfeld GmbH

Grenier + Partner Motoren GmbH

W.C. Heraeus GmbH

Hoechst CeramTec AG

Hutschenreuther AG

Interatom GmbH

ISD - Ingenieurkeramik GmbH

Klöckner Humboldt Deutz AG

Kolbenschmidt AG

Krupp Widia GmbH

Kühnle, Kopp & Kausch AG

Ernst Leitz GmbH

Lonza-Werke GmbH

Lurgi GmbH

Maschinenfabrik Augsburg-Nürnberg

Neue Technologie GmbH

Motoren-u. Turbinen-Union

München GmbH

Nuken GmbH

Porsche AG

Schott Glaswerke

Seilstorfer Metallurgische

Verfahrenstechnik GmbH & Co. KG

Sigri Elektrographit GmbH

H.C. Starck GmbH

Vereinigte Aluminiumwerke AG

Volkswagen AG

SOURCE: [Seitz 1986]

FRANCE

France is a highly nationalistic country, aggressive in political and economic European affairs. Its culture revolves about individualism where strong class distinctions prevail, with status gauged by occupation, educational level and family, and national backgrounds. France is the second largest trading nation in Western Europe (after West Germany) and ranks about fourth overall in the world. Since World War II it has shifted its economic base from agricultural (though still important) to industrial. France has developed a modern and highly diversified industrial enterprise which generates about one-third of its GNP and employs about one-third of its (highly skilled) workforce [Background Notes - France 1986]. It is now a major producer and exporter of steel, chemicals, motor vehicles, nuclear power, aircraft, electronics, telecommunication products, and weapons. The latter five product areas have been featured items on the government's agenda for industrial advancement.

National planning and policymaking in France for all areas, economic, industrial, defense, science and technology, or other, is unified. It is highly centralized within a governmental system structured for maximum coordination and control, but tempered by a modicum of regional autonomy primarily for tactical implementation of state guided plans. In the spectrum of things the French structured system is on one end and the U.S. on the other with the FRG, U.K., and Japan somewhere in between [Lederman 1986]. Government pro-activism and interventionalist approach to industrial policy started in the aftermath of World War II. It came into full bloom with the entrance in 1958 of the de Gaulle era, the beginning of the Fifth Republic and sweeping changes in government structure greatly strengthening the authority of the Executive in relation to Parliament. All succeeding governments, whether on the left or the right, have adopted the policy of strong direction and involvement, declaring it legitimate and necessary for economic growth. Whatever the regime, economic and industrial planning on a national basis has been maintained. Though tactics and tools have changed, major directions and operational schemes have not, and include the elemental themes of sectoral economic approach (technology targeting), public ownership of both manufacturing and financial organizations (along with designated "National Champion" firms), and an elite cadre of public officials, preferably trained at one of France's prestigious Grandes Ecoles, at the helm. These directions are reflected through the development of comprehensive "five-year" plans that detail the grand scheme for that period, and tie together target objectives, tasks and operational guidelines of the various ministries and departments for the whole of government. The continuity of the French system over the years (like Japan) is the foremost characteristic that sets apart from the systems operative within its Western nation counterparts [Paul 1984].

Science and technology in France are integrated within the controlled, corporate-like government organizational framework. French policies toward S&T were initiated 300 years ago by Jean Bapiste Colbert, a minister under Louis XIV, who developed the basic premise that national independence could be best served through strong state direction of technical projects [Science March 1986]. In more modern times this tenet has held fast. In the 1960's civilian (and military) nuclear technology development was pursued to achieve independence from the U.S. with notable commercial success. In the early 1980's the same rationale was applied to justify the government laid detailed plan geared to promote France's competitive position in world markets. Accordingly government research budgets have been increased in an effort to achieve the pledge set by a 1982 law to reach a national R&D expenditure of 2.5% of the GNP by 1985 (as compared to the 1980 level of 1.8%). In 1986 the figure was less than 2.4%, but growing at the rate of about 5% per year (8% in 1988), which is somewhat faster than that of the U.S. Chart 31 indicates the French public R&D budget for 1987 and 1988, and

CHART 31

FRENCH PUBLIC R&D BUDGET, 1987 AND 1988

	Millions of Francs		
	1987	1988	%Change
Ministry of Research & Higher Education			
Research Section	21,039	21,425	1.8
Higher Education (Research)	1,658	1,653	0.0
University Research	7,097	7,440	4.8
Other Ministries	8,813	9,190	4.3
Annex to the Telecommunications Budget			
Electronics Research	2,543	2,268	-10.8
Space (Appropriations only)	4,376	4,762	8.8
Research in Telecommunications	4,364	5,004	14.7
Other Research	1,050	2,250	--
Research Tax Credit	1,100	1,600	45.5
Contribution to EEC Research	1,060	1,353	27.6
Total Civil R&D Budget	53,100	56,945	7.2
Defense R&D Budget	30,186	33,219	10.0
Total Government Expenses for R&D	83,286	90,164	8.3

BUDGET FOR MAJOR RESEARCH AGENCIES, 1988

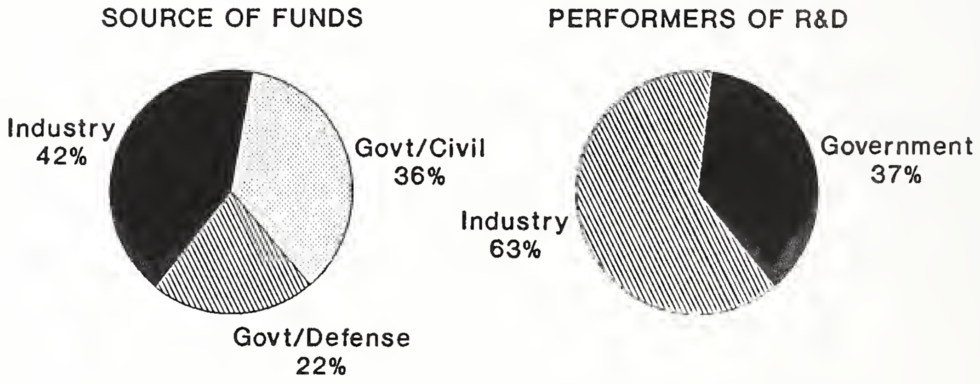
	Millions of Francs		
	1987	1988	%Change
Natl. Ctr. for Scientific Research (CNRS)	8,812	8,955	1.6
Atomic Energy Agency (CEA)	6,730	6,654	-1.1
National Space Agency (CNES)	5,022	5,425	8.0
National Agronomy Research Inst. (INRA)	2,196	2,187	-0.4
Aeronautics Research Program	2,192	2,486	13.4
Electronics Research Program	2,105	2,098	0.0
National Health and Medical Research Institute (INSERM)	1,576	1,608	2.0
National Research for Cooperation and Development (ORSTOM and CIRAD)	1,197	1,236	3.2
Inst. for Oceanographic Research (IFREMER)	777	797	2.5
Fund for Research & Technology (FRT)	750	930	24.0
Natl. Research & Development Agency (ANVAR)	726	784	8.0
Foreign Affairs Department R&D	696	801	15.0

SOURCE: [FAST 1987]

shows the budget breakdown for the major government research agencies. To this industry adds it share for a total R&D level of about $24 billion in 1987 (Chart 32).

Chart 32

*Total R&D in France - 1987



*Approx. $24B at $1 = 6FF

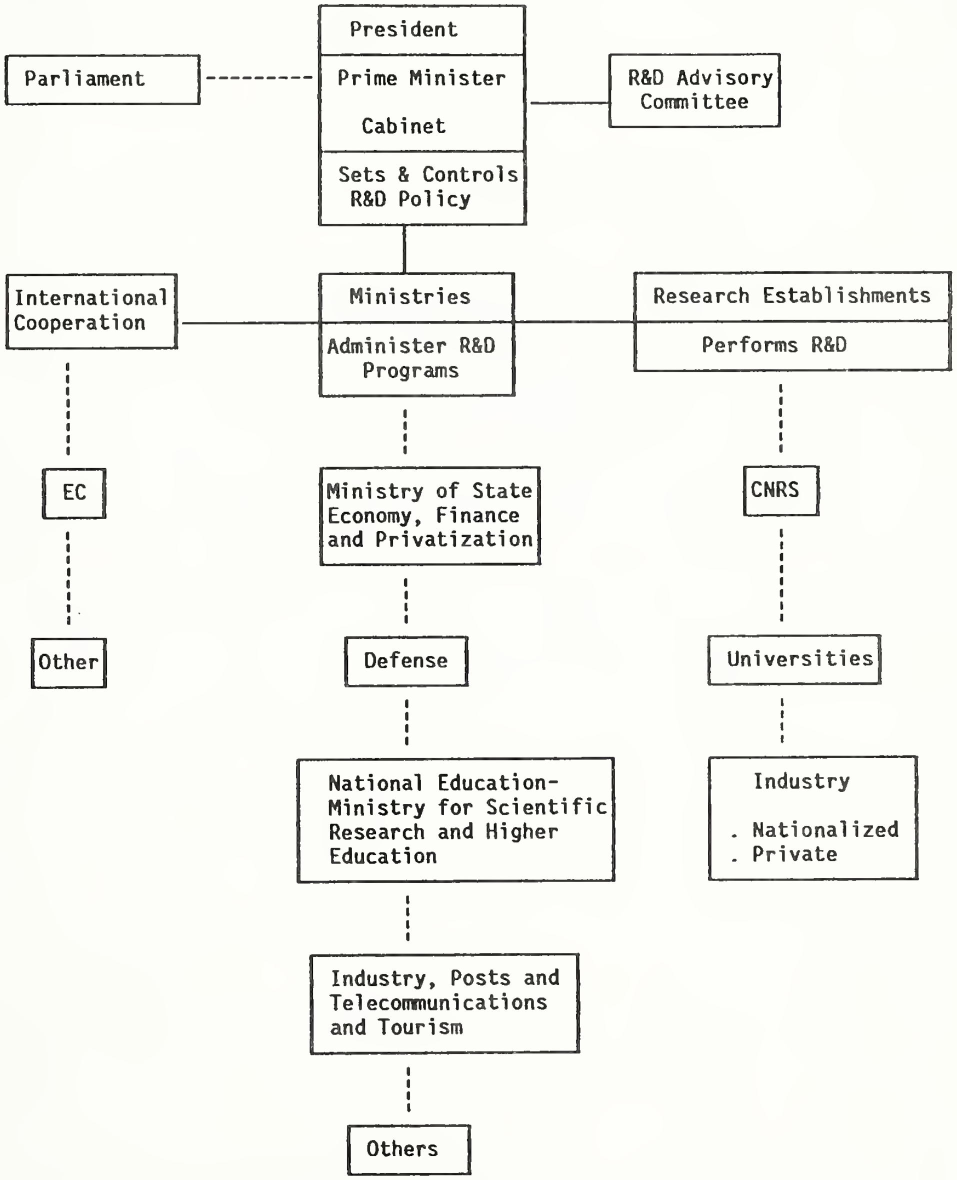
Source: [Cotto 1988]

Today (1988) the same structured control by government prevails although there has been a serious attempt to lessen top-side administrative rigidity by delegating greater responsibility to the local levels. This is in recognition of the fact that times have changed and policies and operational modes appropriate to national scale projects like breeder reactors or spacecraft are far different than those needed in industrial development in areas such as biotechnology, microelectronics, or advanced materials. The overall strategy, however, appears to be one of degree and pointed towards not less, or more, but better government control.

Organizationally and operationally the R&D system in France is enmeshed in an inter-ministerial structure, each covering different mission spheres like defense, industry, education, etc. Chart 33 indicates its basic elements. Execution (management) of

CHART 33

THE ORGANIZATION OF RESEARCH IN FRANCE



SOURCE: [Allen 1975; Background Notes - France 1986] programs occurs at the ministry level, though at times with new governments, responsibilities have combined or realigned and the names of ministries changed. The Ministry of Research and Technology, for instance, was formed in 1981 to focus government R&D into national industrial technology programs as well as provide oversight and management of the nationalized industries. Following the general elections in 1986, some revamping of the ministry alignment is occuring. Most ministries, however, have been in existence for decades and their functions no doubt will continue in one form or another.

Overall, the framework is similar to that in the U.S., but there the comparison ends. In France the link between politics and research is overt and a long-standing tradition. All policy and actions start at the top at the presidential/prime minister level. The President is elected for a seven year term. He names the Prime Minister, presides over the cabinet, and overall is the dominant element in France's constitutional system. The Prime Minister determines policy and controls administration through its ministries. The executive strongly influences the agenda of Parliament through the submission of legislative bills. The fall of government (Prime Minister, cabinet, etc., but not the President) can occur upon vote of censure by Parliament. Policy advice on research is provided primarily through one lead committee, the Conseil Supérieure de la Recherche et de la Technique. Defense receives about 37% of the government's R&D budget with the remainder divided between the other ministries (See Chart 31).

Within the ministerial system the government operates a host of research establishments and laboratories. By far the most extensive and important agency for R&D is the Centre National de la Recherche Scientifique (CNRS). Founded in 1939 and operational in 1945, CNRS is attached to the Ministry of Education and is organized much along the lines of the traditional academic disciplines, supporting primarily basic research in chemistry, physics, earth, atmospheric and ocean sciences, life sciences, engineering, social sciences, mathematics, and humanities. Inter-disciplinary research had not been a favored practice, but in the last few years cross-cut programs have been established in communication science and new materials, though CNRS does not have a research directorate for MSE. In 1988 CNRS had a budget of FF 9.0 billion, about 16% of the total civilian R&D expenditures, and employed almost 10,000 scientists and 15,000 support staff in 1350 laboratories or universities, other government agencies, and industry [Information Technology R&D 1985; FAST 1988].

Links between industry and CNRS are not particularly strong but are on the increase. Part of the difficulty stems from the fierce independence of its workers. In the late 1970's the first attempt by CNRS to develop ties with industry brought a strike by the research staff, the majority of which are unionized. Since 1981, however, cooperative agreements with 27 separate public and private industrial companies have been established [Science March 1986]. Complementing these are more extensive, strictly scientific accords with 30 countries, including the U.S. CNRS typifies the separatist approach taken by many of the French R&D organizations and they have been criticized for it, in government and out. Recent calls have been for dismantling CNRS and reforming it into a NSF type granting organization by transferring its laboratories to the universities. This sweeping adjustment to one of France's premier research agencies did not occur, but some reorganization and other changes are in the making [Science October 1986]; the final scenario is yet to be seen.

Higher education in France began with the founding of the University of Paris in 1150. Enrollment is about one million in 69 universities and an additional 60,000 in special schools such as the Grandes Ecoles. Both categories produce scientists, engineers, and administrators with more of a basic/fundamental background and little training in the practical side of the applied sciences and/or the business aspects of R&D such as management, marketing, or finance. In general the universities, working independently or in association with CNRS, conduct France's basic research. The Grandes Ecoles and numerous government agencies are the sites for applied research; industry performs about 63% of all R&D and almost all development activities. Cooperation between these research sectors is minimal [Information Technology R&D 1985].

As a complement to their internal research efforts, the French have sought to extend their S&T base through international cooperative programs. Being a charter member of the EC, France is a strong advocate of European independence and has promoted and been instrumental in the formation of several collaborative research alliances. These for the most part are geared toward industrial development and involve multi-nation participation, usually under the auspices of the EC. The two most notable examples are ESPRIT (European Strategic Program for Research in Information Technology) and EUREKA (European Research Coordinating Agency), the latter being the French response to the U.S. SDI program, but oriented for technology, not defense. Both programs require participation by industry on a funding and research conduction basis. Charts 34 and 35 give the main characteristics of these programs.

CHART 34

ESPRIT

EUROPEAN STRATEGIC PROGRAM FOR RESEARCH IN INFORMATION TECHNOLOGY

- Cooperative R&D
  - Focus on Semiconductors/Computer Technology
  - Objectives
    - Narrow Technology Gap
    - Reduce Technology Importation
- Joint Funding
  - $1.25 Billion (1984-89)
  - 50% European Communities (EC)
  - 50% Industry Participation:

United Kingdom:	General Electric Company International Computers Ltd. (ICL) Plessey Company
France:	Compagnie Generale de l'Electricite (CGE) Cie, des Machines Bull Thomson - CSF
Federal Republic of Germany:	AEG - Telefunken Nixdorf Computer Siemens
Netherlands:	N.V. Philips Gloeilampenfabriken
Italy:	Olivetti Societe Torinese Esercizo Telefonici (STET)

- Project Approach
  - Focus on Technical Niches
  - Cluster Participation (Universities, Big + Small High Tech Firms)
  - European-Wide Markets Through Standards Development

SOURCE: Synthesis of information obtained from [ECC 1987; Fusfeld 1986]

CHART 35

EUREKA

EUROPEAN RESEARCH COORDINATING AGENCY

- Cooperative R&D
  - Marketing Stage Research
  - Focus on Product and Process Development
  - Alternate to Joining SDI
- Joint Funding
  - $10 Billion (1986-1991)
    - About 50% French Financing
    - Industry + Government Incentives
  - Eventual 18 European Countries Participation
    - 13 Initial Projects
      - France
      - Germany
      - Great Britain
      - Italy
      - Belgium
      - Spain
      - Switzerland
      - Netherlands
      - Luxembourg
      - Austria
- Initial Materials Projects

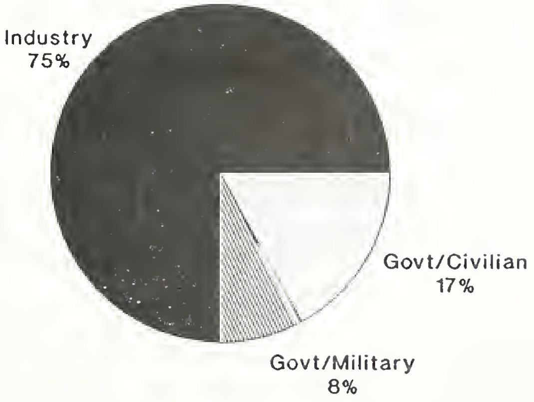
Participants	Years	Approx Cost	Objectives
France, Germany Spain	6	$25M	Automatic Neutron Diffraction for Metallic Parts Control
France, Italy	6	$24M	Development of Metallic and Ceramic Component for Car Engines

SOURCE: Synthesis of information obtained from [ECC 1987; Fusfeld 1986]

Materials science and engineering research in France, like for most nations is difficult to quantify, but is estimated to involve about $1 billion overall, divided between industry and government (Chart 36). Research on materials in France is prevalent and extensive activities are underway or planned in the various R&D establishments, public and private. Chart 37 indicates some general features of MSE in France and at least in a qualitative way indicates a high level of commitment. France has been extraordinarily ambitious in the support of new and advanced technologies and their record has been mixed. Success has been achieved in commercial aircraft with their entry of the Airbus while the Concorde has been a financial disaster. Notable progress is evident in nuclear power and telecommunications markets, but they have made only marginal gains in microelectronics, a targeted technology. France has demonstrated strong government direction and intervention in technology areas cannot by itself produce a competitive industry. It remains to be seen how well France can turn good basic research to commercial success in advanced materials.

Chart 36
R&D Funding of Materials Science and Engineering in France - 1987

R&D Budget: Approx. $1 billion



Source: [Cotto 1988]

CHART 37

MATERIALS SCIENCE AND ENGINEERING IN FRANCE

SOURCE: [Cotto 1988]

General Information

- 700,000 jobs in industry (1987)
- Industrial Activity $70 billion
- Materials R&D Budget (1987) $1.4 Billion

- Public Research Budget
  $286 Million

  - Civilian $200 Million
  - Military $86 Million

- Corporate R&D Budget
  $857 Million

  - Research $286 Million
  - Development $571 Million

National Program to Activate the Development of Materials (I.D. Mat Program)

1982 - Material Report (MRES)

- State of the art and potentialities
- Materials development

1986-1992 - I.D. Mat Program

Objectives

- Give a status to the field of materials science and engineering
- Stimulate the cooperation between:
  - different disciplines (chemistry, physics, mechanics ...)
  - university-industry (education, access to large physics equipment ...)
  - different industrial sectors (synthesis, processing, assembly ...)

- Try to coordinate the action of the different government agencies and ministries

CHART 37 (CONTINUED)

Area of Interest

- Generic area

  - structure and constitution laws
  - aging and transient regimes
  - interfaces
  - synthesis

- Mutation of traditional materials
- Advanced composites (MMC, CMC, OMC)
- Engineering polymers
- Advanced ceramics
- High performances metallic alloys
- Electronic materials
- New building materials

1987-1988 - Ministry for Research and Higher Education (MRES)
11 National Programs

- New materials (mutation of traditional materials, composites, ceramics, superconductors)
- Biotechnology
- Manufacturing
- Transportation - Civil engineering
- Molecular engineering

The Instruments of These Programs

- Education

  7 "Pôles FIRTECH matériaux" ERC

  Research Training of Engineers in Field of interest for industry

  - advanced materials
  - metallurgy
  - synthesis and processing
  - mechanics and materials
  - surface - interface and composites
  - mechanical engineering of materials

- Increase the number of engineers with research experience

CHART 37 (CONTINUED)

- <u>Industry-Government laboratories cooperation</u>

  - GRECOS (coordinated research groups)
    CNRS/MRES

  - teams of government laboratories
  - basic research upstream of the development of new technologies by industries

  - high strains
  - adhesion
  - chemistry of composite materials
  - mechanics of composites
  - rheology of polymers
  - membranes

- <u>GIS (Group of Scientific Common Interest)</u>

  - teams of government laboratories and industrial firms
  - pre-competitive research

  - organic matrix composite
  - structural adhesives for automobiles
  - fibers metal reinforcement
  - ceramic capacitors
  - polymer alloys
  - modelisation of injection of polymers
  - fracture at high temperature
  - processing of metals

- <u>Actions concertées</u>

  Peer review of proposals made by industry-universities teams:

  1988 - multimaterials interfaces
  - MDE
  - ceramic composites

- <u>Actions directes</u>

  1 industrial firm - universities

- <u>Laboratoires mixtes</u> - CNRS-industry

  - Saint Gobein (glass, cast iron)
  - Rhône Poutenc (ceramics)
  - SEP (thermostructural composites)

JAPAN

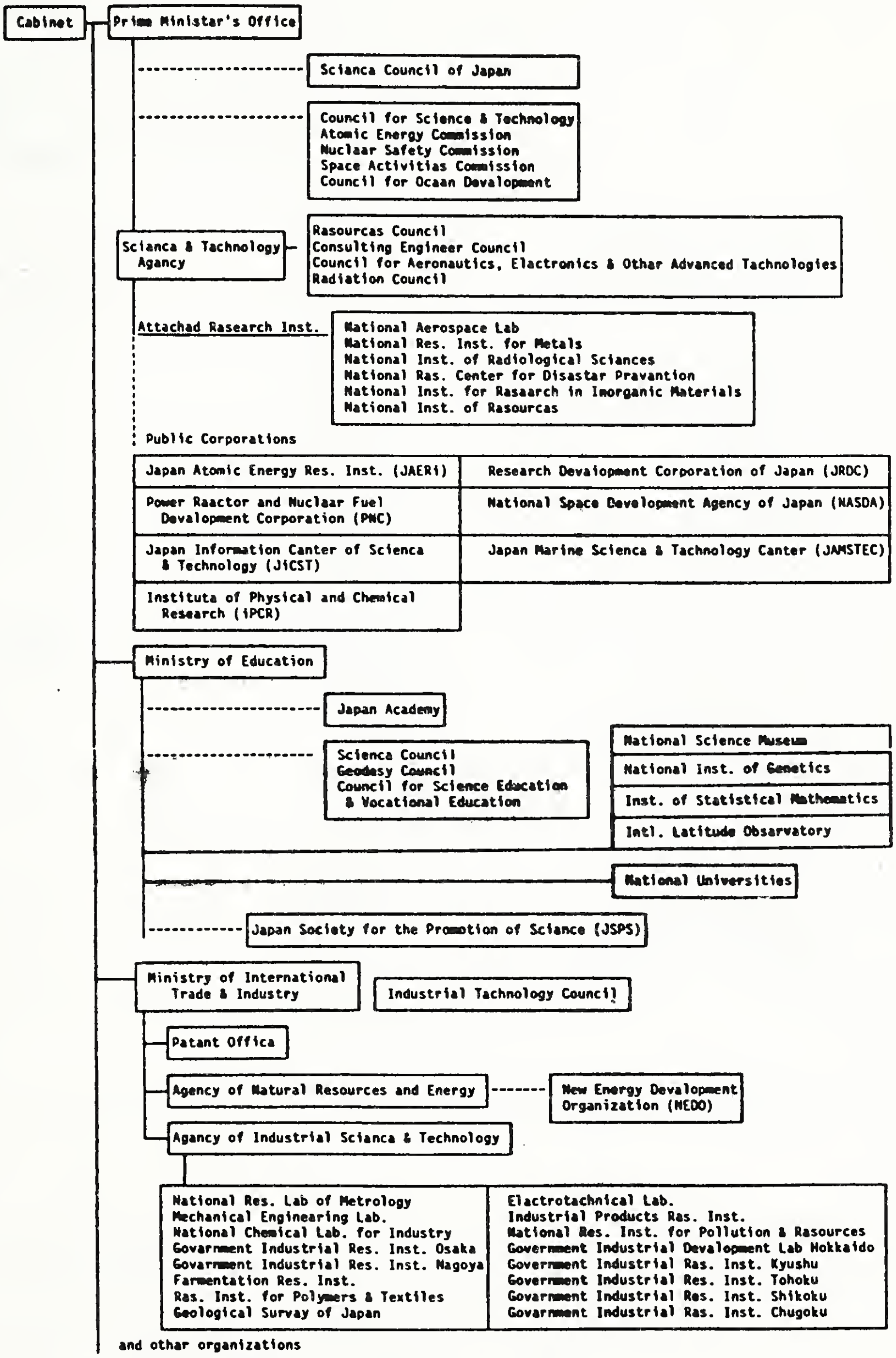
In recent times Japan's technological system has been studied (e.g., [JTECH 1986]), modeled, and sometimes copied perhaps more than any other. The reasons for this are many and stem from their industrial achievements which have led to international marketplace dominance in areas such as consumer electronics or impending capture of markets like semiconductor chips and devices. Their road to success is for the most part a Japanese "road" especially built to match their culture, traditions, and particularly, their technical status and needs. In the main their industrial policy, fueled originally by profits from captured markets (e.g., steel, shipbuilding), has been directed not at failing or stagnant industries, but at the new opportunities and the strengthening of already vital, expanding private industrial segments. Currently Japan has reached a juncture in its industrial development, as past goals have been achieved and technological leadership or equality obtained. Long-term planning has been a key feature of their industrial strategy with the future the primary concern, not saving or recapturing the industrial past. Questions relative to Japan's current technological status are now being addressed at the cabinet level with new general S&T guidelines in the making [S&T Policy - Japan 1986]. Its S&T (and by implication, MSE) system is conceptually steered towards rapid technological leapfrog advancement or catch-up through technology purchase and enhancement (e.g., manufacturing R&D), not strictly maintenance of a leadership position, like that of the U.S.. Hence basic research had not been emphasized previously, but now a more broad based research front is viewed as necessary for additional/new advancement. Changes in this direction are already underway for certain key industrial areas like advanced materials and information technology.

Nonetheless, the Japanese S&T and MSE establishment is a highly structured enterprise, instrumental in numerous past technological successes and highly capable of more in the future. It is comprised, however, of conventional organizational elements and implementation/strategy instruments not too dissimilar from those available and used throughout the world. What is atypical to Japan is its systems approach--its long-term and consistent policy, stimulated and coordinated by government but coupled to an effective communication link between the public and private sectors, including a multi-level advisory/committee arrangement. The term 'cooperative' has been frequently used to describe Japanese R&D. A better descriptor might be 'orchestrated division of activities and responsibilities' with government acting as the catalyst and industry taking a lead role as a funder and performer of R&D. As the research turns more developmental, cooperation in proprietary areas is almost minimal and company-to-company competition is intense. Communication, consensus, and common action by leaders for national good is always maintained through the committee/public forum system, but never through paid lobbies however, as this is not an allowed practice in Japan.

Within government the highest policy making body for S&T is the Office of the Prime Minister [Ronayne 1984; JTECH 1986; Ceramics-Japan 1984]. Chart 38 identifies the major government organizations in Japan responsible for S&T. Two advisory councils, the Science and Technology Council (Kagaku Gijutsu Kaigi) and the Science Council, provide guidance on S&T and on pure science matters. The membership on these councils are made up from leading spokepersons of S&T in government and out; chairmanship resides with the Prime Minister of Japan. These councils establish national goals and provide broad directions for S&T (and MSE) and, in general, decide S&T issues of national import. Overall the councils have great impact on Japan's federal S&T yearly budget of about ¥1700 billion in FY87, (Chart 39).

CHART 38

MAIN RESEARCH ORGANIZATION ON SCIENCE AND TECHNOLOGY IN JAPAN



SOURCE: Combined information from [JTECH 1986; Ceramics - Japan 1984;
JFCC Information Package 1987]

CHART 39

JAPAN'S FISCAL 1987 SCIENCE & TECHNOLOGY-RELATED BUDGET
(In millions of yen)

Agency	Total Science & Technology-related Appropriations	Increase Over Prev. Year
Diet	525	1.5
Science Council of Japan	856	- 0.8
National Police Agency	925	2.9
Hokkaido Development Agency	143	0.6
Defense Agency	74,135	12.1
Economic Planning Agency	710	0.8
Science & Technology Agency	425,232	1.2
Environment Agency	7,914	- 4.9
National Land Agency	160	-23.7
Ministry of Justice	806	- 0.3
Ministry of Foreign Affairs	6,298	- 4.5
Ministry of Finance	1,009	7.5
Ministry of Education, Science and Culture	780,174	4.6
Ministry of Health & Welfare	39,761	10.1
Ministry of Agriculture, Forestry & Fisheries	66,748	0.4
Ministry of International Trade & Industry	221,409	1.8
Ministry of Transport	14,516	9.4
Ministry of Posts & Telecommunications	29,042	17.7
Ministry of Labor	3,635	22.4
Ministry of Construction	5,506	- 5.3
Ministry of Home Affairs	536	1.6
Total	1,655,040	3.5

SOURCE: [NSF-Tokyo Office 1987]

Two ministries (MITI and ME) and one agency (STA) essentially share government operational responsibilities for S&T, including planning, funding, and oversight. In addition to these, two others provide a check and balance mechanism. The Federal Trade Commission governs on the legality of business practices and often judges/rules on MITI plans and activities. The Ministry of

Finance approves all budgets and justifications for enhancements and baseline support:

Science and Technology Agency (STA). This agency is located within the Prime Minister's Office. It receives about 26% of government R&D funds [GAO 1985; NSF-Tokyo Office 1987] for major national projects like the space and the reactor programs. The agency also has the charge to stimulate basic research within industry and through its Japan Research Development Corporation (JRDC) support new technology developments (Exploratory Research for Advanced Technology-ERATO) using start-up companies as one implementation mechanism. Attached to STA are six research institutes, two of which, NIRIM (National Institute for Research in Inorganic Materials) [Ceramics - Japan 1984; NIRIM Information Package 1986] and NRIM (National Research Institute for Metals) are the principal laboratories most related to MSE. Although under STA, they often perform R&D in cooperation with MITI, the industrial oriented ministry.

NIRIM (and very soon NRIM) is located at Tsukuba Science City about 60 kilometers northeast of Tokyo. Using the U.S.S.R.'s Novosibirsk as a model, the Japanese Government, in 1966, moved to create a "Science City" to house a collection of its research institutes [Tsukuba Science City 1984]. Science City organization can be roughly classified into five groups: university and educational training; construction; science and engineering; biology and agriculture; and common-use facilities. In theory these special laboratory capabilities, all located in one place could serve as a one-stop shopping means to further industrial advancement. Planning for NIRIM was initiated in 1966 and completed in 1971, and it became the very first laboratory to move into its Tsukuba Science City. There are now approximately 46 national institutions and universities located at Tsukuba.

The national institutes of the STA, and indeed much of Japanese science, operates on the "Research Group" system. It is instructive to quote NIRIM's printed brochure on the rationale and structure.

> " Research Group System
> Specialists of various fields form a research group in order to attain a project target. They investigate inorganic compounds which meet practical requirements, with particular attention to properties, composition, structures, and synthesis.
>
> The group research period is usually settled at five years. At the end of the period, it is determined whether the research project is to be terminated or to be extended for an additional specific period of time. When a research project is completed, the research group is dissolved and a new research group is organized to undertake a new project. Thus, this is an effective system for creative research. In addition to this, the system of Visiting Research Officers also serves the same purpose effectively."

The concept of a finite number of targeted research objectives is central. There are about 120 research scientists divided into 17 groups. Typically, each group has some eight researchers formed around on topics such as "diamond," "tantalum carbide," "zinc oxide." The facilities are on a par with any equivalent laboratory in the U.S. The new high pressure facility is the second biggest in the world, and it is moving slowly but surely into a commanding position in high pressure synthesis and forming technology.

The connection to industry is extremely effective. It is achieved in two ways. In a relatively new area--such as metastable growth of diamonds, the NIRIM personnel develop a material or process, obtains a patent, and markets the patent to corporations.

The second method is by having visiting scientists from industry associated with each group, paid for by the companies. Some 45-50 are in the Institute at any one time; usually no more than one per company. The rationale again is given explicitly in their brochure.

> " Visiting Research Officers
> Visiting Research Officers are invited to further the efficiency of the research group system. They may be invited to participate in a specific part of the research which cannot be fully carried out by the members' own efforts. This arrangement fosters good relations with various universities, private industries, and national and public research organizations, for promoting the exchange of scientific and technological knowledge and for training younger research personnel in the Institute."

Ministry of Education, Science and Culture (ME). This ministry accounts for about 47% (in FY 87) of government research funds [GAO 1985; NSF-Tokyo Office 1987], the total of which is provided to the universities and national centers for scientific research. University research is supported directly by funds based on formulas (e.g., number of professors and other similar factors), peer reviewed research proposals, and by allocations according to salary costs, building facilities, and large-scale instrumentation. University-industry interactions are minimal (a problem recognized by ME) since paid consulting by professors is not allowed nor is joint university-industry research an accepted practice.

Ministry of International Trade and Industry (MITI). This ministry is the central government organization having industrial development as its primary charter. It receives only about 13% of government R&D funds, relying on cooperative mechanisms with industry to leverage considerably more R&D. MITI formulates industrial technology plans, determines and provides for subsidies and/or funding and selects/persuades/organizes participating industrial R&D groups/associations to work with one or more of MITI's 16 national labs. The national labs fall under the jurisdiction of one of MITI's operational arms, AIST (Agency of Industrial Technology and Science), which in FY 1985 had a budget of ¥122 billion. A sister agency, JITA (Japan Industrial Technology Association) functions as the licensing agency of AIST and provides regular information on foreign technology developments.

Typical of MITI's procedural mode is their program on advanced materials (R&D Project on Basic Technology for Future Industries). This program, under the auspices of AIST, targets three general research areas, biotechnology, electronics devices, and new materials; Chart 40 lists the seven advanced materials projects. In the general case AIST forms a non-government advisory committee for each project and an industrial association is created to work cooperatively with all other members of the organization and MITI's national labs. Chart 41 illustrates some of the interactions developed through this arrangement. Selection of participating companies is made by AIST based on financial standing, reputation, and R&D ability. Its budget is controlled by MITI, but supplemented heavily by industry by equal or more amounts. The national labs conduct the more basic/applied research while the industrial labs focus on development. All gained information is shared among member companies with a time lag assured before general distribution. MITI's goal is to produce a knowledge base and infrastructure for follow-on proprietary research by the now-experienced industrial groups.

CHART 40
AIST (MITI) SUPPORT OF NEW MATERIALS RESEARCH FOR FUTURE INDUSTRIES

Project Name	R&D Period (FY)	Total R&D Expenditure (1)	Budget (1) for FY 1985
1) High Performance Ceramics	1981-90	13,000	961
2) Synthetic Membranes for New Separation Technology	1981-90	10,000	556
3) Synthetic Metals	1981-90	5,000	375
4) High Performance Plastics	1981-90	6,000	299
5) Advanced Alloys with Controlled Crystalline Struct.	1981-88	8,000	610
6) Advanced Composite Materials	1981-88	11,000	721
7) Photoactive Materials (2)	1985	--	70

1) Unit = 1 x 10^6 yen
2) Basic Plan in Formation

SOURCE: [JTECH 1986]

CHART 41

AIST (MITI) SPONSORED INTERACTIONS BETWEEN INDUSTRY AND NATIONAL LABS

	INDUSTRY	NATIONAL LABS
Synthetic Membranes	Asahi Chem., Asahi Glass Kuraray, Sumitomo Elec., Daicel Chem., Teijin Toyobo, Toray, Mitsubishi Chem.	Res. Inst. for Polymer & Textiles Nat'l Chemical Lab for Industry Industrial Products Res. Inst.
Synthetic Metals	Asahi Chem., Teijin Sumitomo Chem., Toray Sumitomo Electric	Res. Inst. for Polymers & Textiles Electrotechnical Lab
High Performance Plastics	Asahi Chem., Teijin Toray, Mitsubishi Chem., Mitsubishi Petrochem.	Res. Inst. for Polymers & Textiles
High Performance Ceramics	Toshiba Corp., Kyocera Ltd. Ashai Glass, NGK Spark Plug, NGK Insulators, Showa Denko K.K., Denki Kagaku Kogyo K.K., Toyota Machine Works, Kobe Steel, Toyota Motors, Inoue Japax, Sumitomo Electro-Chemical, Kurozaki Refractories, Shinagawa Refractories, Ishikawajima Harima Heavy Industries	National labs participating in the association are the Government Industrial Research Institute, Nagoya, Mechanical Engr. Laboratory; Govt. Industrial Research Institute, Osaka, and National Inst. for Research of Inorganic Materials. The initial term is 10 years (3 years for basic research, 3 years for model development, and 4 years for production and evaluation). The funding is 13 billion yen or approximately $57 million.

SOURCE: [JTECH 1986]

Among the 16 research institutes under AIST, the oldest is the Electrotechnical Laboratory [ETL 1985]. ETL is also the largest national research organization in Japan and has contributed to the advancement of science and technology as well as the development of Japanese industry in the field of electrical engineering and electronics for almost a century.

ETL was established in 1891. In 1948 the part concerned with communication was transferred to the Nippon Telegraph and Telephone Corp. to establish the Electrical Communication Laboratory. After further evolutions under MITI in the direction of strengthening the electronics activity, ETL was moved in 1979 from Tokyo to its present location and modern facilities in the Tsukuba Science city.

ETL's role includes technology development in close collaboration with industry, but it is also responsible for Japan's standardization program in its areas of technical coverage (serving the roles of the U.S. NBS in this area). In FY 1985 ETL's budget of ¥9,000 million and a staff of 698 persons were dedicated to activities in 13 research divisions and one special division on Josephson Computer Technology. Programs include fundamental science, materials, electronic devices, information science, computer systems and computer science, automatic control, radio-and opto-electronics, quantum technology, advanced technology (space, cryogenics, high temperatures, etc.), energy, energy systems, and standards and measurements.

The programs of ETL as with all MITI labs are composed of a mix of internally generated activity augmented by ETL's share of those national programs which Japan uses to coordinate major new technology developments. It is useful to note this lab's participation in such a program to highlight that phenomenon. In 1985 a very significant event occurred in the semiconductor industry. The country of Japan sold approximately $10 billion worth of semiconductor devices and integrated circuits, equalling or surpassing the United States' share of the world's market for the first time. One of the major reasons often given for this dramatic increase in semiconductor technology in Japan has been the establishment of cooperative research projects between industry and the Japanese government through MITI. In particular, the establishment of joint laboratories with personnel shared from member companies has been an innovative approach to research and development in Japan. Of these, one of the most important current laboratories is the OJL, Optoelectronics Joint Laboratory (actually formally terminated in the Spring of 1987 as this report was being written) [JTECH 1985].

OJL was started in 1981; it had a lifetime of six years, to March 1987, with a significantly reduced budget (company funds only) during the last year. OJL had the charge of working on generic materials technology that would be of use to all of the companies in developing III-V devices. Thus, OJL did not work on devices themselves, but worked on a broader range of basic materials research which the member companies needed for device development. This approach had a number of advantages; for example, the companies did not have to give away any of their processing and fabrication secrets that are so important in device development and manufacturing, and at relatively low cost they could participate in materials research that might be considered too expensive for any one company. Along with ETL, nine companies joined OJL, and MITI's contribution to OJL's budget was approximately one-third of the total. On average during its life, OJL had 50 technical staff and a budget of $37.5 million. Its efforts led to 130 patents and 510 papers and publications. As its work is now completed, the laboratory is being dismantled. Advanced equipment which is still of value will be sold off to member companies. Technical researchers will return to their companies of origin carrying the newly developed technologies with them, the best and most efficient form of technology transfer.

OJL was a unique, extremely well-equipped facility working on generic technology research that is of interest to all the member companies, but which allows participation of the companies without compromise of privileged information regarding processing and fabrication techniques and device design concepts. The choice of material for this research has been almost exclusively GaAs (and related, lattice-matched compounds such as AlGaAs).

Project areas covered included: bulk crystal growth (leading to the world's best GaAs); maskless ion implantation (dominated by Fujitsu and giving Japan a lead in focused ion beam implantation); epitaxial growth (MBE and MOCVD); applied surface physics (a variety of surface science and physics programs including super lattice disordering techniques); fabrication technology (dry etching, e.g., reactive ion beam etching); and materials analysis and characterization (focused on understanding defects in undoped GaAs).

Another example of Japan's cooperative R&D approach is the Japan Fine Ceramics Center [JFCC Information Package 1987]. JFCC is a newer attempt at institutionalizing ceramic R&D in Japan. It is an attempt to extend their capability for both pre-competitive "basic" research by consortia as well as offering smaller companies a base for sophisticated proprietary research up to a pilot plant level.

The operation opened in April 1987 in an extremely large, expensive, 100,000 sq. ft., well equipped facility in Nagoya. The capital cost exceeds ¥11 billion (¥5.9 billion industry, ¥4.6 billion local government, ¥.5 billion MITI). JFCC expects to have a staff of 100-150 scientists at steady state (1997). The

Center resembles a Battelle in many ways, but it will serve some unique functions for all of Japan's ceramics industry:

1. Standards and reference work, and making available sophisticated facilities.
2. Data bases for everyone's use.
3. Some basic research in ceramics and hence the training of personnel.
4. International contacts for Japan's ceramics industry.
5. "Promotion" of industry-university-government cooperation.

JFCC is much too new to evaluate as yet. Its main significance at this point is the fact that it has been brought into being in response to a need that was not being met either by Japan's very strong ceramics industry or by universities or government labs. Moreover, two of the three very first projects are joint or networked with other national centers. It is worth noting that the first two are nine-year and six-year-long contracts.

Thus, within the overall government scheme to strengthen Japan's technical base a concept of industrial research associations has evolved [Fusfeld 1986]. This mechanism, authorized under their Industrial Technology Association Law, encourages and permits cooperative industrial and government efforts to advance the research needs of particular industrial sectors. These industrial associations are individually designed to satisfy particular needs ranging between promotional trade association type organizations to research conducting entities. The Japan Fine Ceramics Association is an example of the former and ICOT (Fifth Generation Computer Systems Project) or the JFCC of the latter. Whatever the type, authorization by MITI is required. Government funds can be provided to support the association activities in whole or part; or alternately a government loan can be provided, to be repaid when commercial success has been achieved. The key to the association concept is that an individual company can choose to join (or not join) an association and contribute support funds. This decision rests with the company and generally depends upon their individual competitive position and financial situation. The government simply provides the cooperative mechanism and support if needed, but does not issue directives.

To complement Japan's already complex cooperative venue, a new dimension has recently been added. In October of 1985, the Diet established the Japan Key Technology Center [Key-TEC 1987] to be run under the joint oversight of MITI and the Minister of Posts and Telecommunications (MPT). The Key-TEC program is viewed by Japanese officials as a part of a needed effort to boost science and creativity through long-range advanced applied and fundamental research on key, very advanced technologies. The focus of the programs is to be about ten years out in front of current knowledge and is not supposed to result so much in prototype products as in generic information upon which products can be based later. Because of the advanced technology mission of Key-TEC, one could describe the program as a Japanese civilian analog of the DOD's DARPA (Defense Advanced Research Projects Agency). Official descriptions of Key-TEC present it as a free-standing private sector activity, but in fact, the government seems to be playing a stronger role. The law enacted by the Diet says what broad areas of technology are to be addressed, sets forth the concept, and leaves it to the private sector to propose the details subject to government approval.

The operating income for the Key-TEC program comes largely from the dividend cash flow from NTT stock and the Japan Tobacco Monopoly. This is currently estimated at about ¥26 billion per year from NTT and ¥5 billion per year from the Japan Tobacco Company. Key-TEC is functioning as an investment banker in advanced research. The Key-TEC corporation calls for proposals from the private sector and has them evaluated by a panel of experts which in some cases seems to equate to senior university faculty. The proposals must come from a consortium of at least two private companies. The companies must put up at least 30 percent of the funds and some number of staff to perform the work as well as to serve as management of the enterprise. Emphasis is placed on the overall adequacy of the proposed resources, the credibility of managers to lead a team effort, and the track record of the participating organizations. Successful bidders form a new corporation chartered to receive the funds and to perform the R&D for the specified length of time. The corporation may not engage in other commercial activities, i.e., it may not enter a business based on its technology. Alternatively, Key-TEC may make loans up to 70 percent of a research project's costs. These loans are interest bearing only if the project is successful. There is a separate capital account set up by the government to pay the operating expenses of the corporation itself so there is no central overhead charge to the annual income from the NTT stock.

In practice, there are very close ties to the government. First, of course, is the fact that MITI and MPT had veto power over the entire proceeding at the outset. Second is the fact that so much of the project funding comes from MPT's former entity NTT. This means that the government strongly influences the Key-TEC operating mode and indeed carefully monitors the financial operations. Further, the subject matter is to be fundamental (or key) technologies which come under the jurisdiction of either MITI or MPT, technologies which can "contribute substantially to strengthening the bases of the national economy and national life". There seems to be an unwritten understanding that about half of the funding shall go to projects of interest to MITI and the other half to MPT.

With the addition of the Key-TEC mechanism, it appears that Japan is attempting to correct a previous deficiency--the lack of internal basic research, something they had to borrow from other nations, the U.S., and Europe. They are doing it within the cooperative research context in which industry plays a prime role through government fostered and structured actions. With research cooperatives underway covering all aspects from invention to product, Japan seems to have finely tuned its bandwagon for the market events of the nineties and beyond.

KOREA

Although still categorized by many as a developing nation, South Korea has achieved such remarkable economic success over the past 25 years that in many respects it can be considered to be one of the world's main middle-income (per capita income is 1/7th of the U.S.), industrialized countries [Bunge 1982]. In-roads to the commercial world markets have been substantial and the term, 'newly industrialized country' (N.I.C.) may no longer be a proper descriptor of Korea, as it is now a leading manufacturer and exporter of industrial goods and services-from steel, to electronic components, to automobiles, to design and overseas construction of major industrial plants. The Samsung (electronics) and Hyundai (transportation) conglomerates, for example, in 1986 were respectively, the 42nd and 44th largest industrial corporations in the world with sales for each of approximately $14 billion, about 1/7 of that of (U.S.) General Motors, the front-runner of all companies [Fortune 1986].

The rapid industrial development of Korea matches, or even exceeds that previously demonstrated by Japan, and for many of the same reasons. The industrial success story of Korea is more or less typical of its Pacific-rim N.I.C. counterparts, Hong Kong, Singapore, and Taiwan, who individually and collectively have attained the status of (more than) competitive equals in many world markets [Westphal 1987]. They have in a relatively short time broadened their economic foundation from agriculture and/or light, labor-intensive manufacturing like textiles to the more capital-intensive, sophisticated, higher technology product areas. As a result of this turn-around the U.S. and other developed countries now experience significant trade deficits of billions of dollars each year with these four nations/states, in markets the leaders once held sacrosanct.

Although the nuances may be debatable, the basic pathway used by Korea for its industrial development involved methodical importation of foreign technology and assimilation and enhancement of that technology through development and mastery of improved and low cost production capabilities. This process proceeded rapidly because of diverse reasons, such as a homogeneous culture, low paid but highly productive and reasonably educated workforce, foreign aid and defense assurance and a strong government that placed industry and its associated S&T in a favored position, with rewards to those corporations and organizations most successful in promoting international trade. Though guided/structured by government, the specific methodology used by industry for importation of foreign technology perhaps is the single most dominate reason for Korea's and its Pacific-rim sister countries' successful strategy. Here, Korea's industry relied almost exclusively on importation effected through licensing and limited joint ventures, rather than on direct foreign investments wherein the technology was not Korean controlled. Proprietary transfers, transfers through the open literature base and copy-cat product manufacturing duplication gave its industry the technical foundation. This, coupled with overseas education of its R&D scientists and engineers, build-up of its in-nation S&T capabilities, including intense technical training involving its national labs, and a government led industrial cooperative system gave Korea its industrial prowess.

Korea continues to be technologically progressive through an industry oriented towards export markets. It now allocates a larger share (about 1%) of its GNP to R&D expenditures and has a higher proportion of its workforce trained as engineers and scientists than any other N.I.C. outside the Pacific-rim. Other subtle differences, however, separate Korea and its Eastern nation cohorts from other less developed countries and explain their disparagingly levels of technological/industrial advancement. All N.I.C's have employed a foreign technology importation strategy but nations like Brazil, Mexico, and even Israel, have relied more on direct investment by overseas corporations and completely foreign-owned subsidiaries to build their technical base, thereby lessening the opportunity for technology assimilation [Westphal 1987]. Moreover, Brazil and similar status nations have not emphasized efficient production, the key to a competitive position, nor have they encouraged but have even restricted, in-country technology transfer through internal cooperation. This added to fact that in parallel with importation, they, unlike Korea, have attempted to emphasis independent technology development rather than product enhancement and learning from the purchased/borrowed foreign base. Herein lie some of the basic reasons for Korea's success on one hand and the lack of greater technical/industrial advancement by other N.I.C.s on the other.

Government leadership, more than any other causal factor, has been the instrumental force behind Korea's economic and technological growth. Its level of commitment to stimulate industrial development though a consummate export strategy is matched only by a governmental administrative structure equally geared for economic policy-making and implementation. It is a top-down, centralized administration with 19 separate ministries making up the State Council, the operational government arm equivalent to the president's cabinet in the U.S. The Council is headed by a prime minister, who reports directly to the President of Korea, an elected post. As an adjunct to the State Council, each ministry maintains a separate, government paid advisory body consisting of about 100 leaders and experts chosen from the universities and industries. Technical affairs are the designated charge of the Ministry of Science and Technology, with important facets also enmeshed in the Ministry of Commerce and Industry and in the Ministry of Education. Through these ministries the government exercises exacting control of S&T. Levels of industrial R&D are set as a percentage of profits;

restrictions and incentives through control of investments, financing, taxes and tariffs, are applied to benefit export oriented industries; educational patterns are set to establish the level of students by field; government educational/research institutes are maintained to broaden the technical base and promote technology transfer; the list is almost endless.

Among the government supported S&T organizations KAIST (Korean Advanced Institute of Science and Technology) is one of the largest overall and the largest with respect to MSE R&D (followed by the Korean Institute of Machinery and Metals and the Korean Standards Research Institute). KAIST [KAIST 1986] was formally established in 1981 by the Ministry of Science and Technology by merging the Korea Advanced Institute of Science (est. 1971) and the Korea Institute of Science and Technology (est. 1966). This was done to foster new technology development through education and the conduction of R&D, 80% of which is funded by government. It is currently located in Seoul but by 1989 expects to move to Korea's Science Town in Daedeog. Similar in concept to Japan's new science city, the complex is scheduled to house about 65 research institutes in the next three years; about 15 are now operational.

In Korea there are about 3000 Ph.D's overall in S&T (primarily located at the universities) and 300 in MSE. It is noteworthy, that current B.S. metallurgical students in Korea and the U.S. are about equal. Though university research in Korea is not considered to be well funded by most standards, KAIST produces about one-half of all the new Ph.D's each year with approximately 20/year graduates in MSE (expected to increase to 30-40/year). For all practical purposes about one-half of all published papers in MSE come from KAIST R&D [Schwartz 1986].

KAIST couples its R&D to industrial needs in several ways. First, it conducts contract research directly for corporations.

Second, it engages in government-industry cooperative R&D. Third, a KAIST subsidiary, Korea Technology Advancement Corporation (K-TAC), was established to facilitate the commercialization of research results developed at R&D organizations under the Ministry of Science and Technology. K-TAC provides a linkage role and a multitude of services, including technical (and managerial) assistance, licensing or purchase of technology, and the establishment of new businesses through joint investments.

Overall, MSE in Korea is roughly divided into two major R&D categories, that related to conventional materials improvement and import reduction (substitution), and that needed for future technology development (advanced materials) [Kang 1986]. The former is essentially financed by industry; the latter is almost wholely supported by government in a public-private cooperative mode. In 1985 there were about 29 advanced materials projects, covering advanced metals, polymers, composites, and fine ceramics. Chart 42 provides a sampling of these along with participating organization and areas of focus.

CHART 42

MAJOR R&D SUBJECTS ON ADVANCED MATERIALS IN KOREA (1985)

SOURCE: [Kang 1986]

Subjects	Institutions	Status & Results
<u>Metals</u>		
Amorphous Materials	KAIST, KIM, Seoul U. Korea U. Choongnam U. Choongbuk U., Kumsing Samsung, POSCO, Sammi Hyosung	Developed 1" Ribbon - KAIST Amorphous Wires - KAIST Basic Research - Choongnam U. & Korea U. Co-alloys for Magnet - Kumsung & Samsung Initiated Project - POSCO & Sammi
Shape Memory Alloys	KAIST, Kyungbuk U., Seoul U., Kumsung, Poongsan	Nitinol Engine - KAIST Research on Cu-Zn- Kyungbuk U., Kumsung & Poongsan Initiated in 1984
Superconductors	Hanyang U., Kumsung	Nb-Ti System for NMR Application - Kumsung
Hydrogen Storage Alloys	KAIST	Metal Hydride Heat Pump - KAIST
Superalloys	KAIST, KIMM, Sammi	Chemical Tanks & Turbine Blade - KAIST Alloys for Turbo-engine - Kimm Started in 1985 - Sammi
<u>Ceramics</u>		
Structural Ceramics	KAIST, KIMM, Sunkyung, SSangyoung, Daehan, Tungsten, Yonsei U., Hanyang U., Seoul U., Inha U.	Si & Si_3N_4 Sintering - KAIST Basic Research on B_4C Plate - KAIST Ceramic Cutting Tool - KAIST & SSangyoung Silicon Nitride Tool - KAIST & SSangyoung Ceramic Diesel Eng. - KAIST, KIMM & Ssangyoung Oxydation Mechanism - Yonsei U., Hanyang U., and Inha U. Zirconia Cutting Tool - Daehan Tungsten

CHART 42 (CONTINUED)

Subjects	Institutions	Status & Results
Ferrites	KAIST, KIMM, Inha U., Pusan U., Kyungbuk U., Samwha, Samsung, Daewoo, Saehan, Sunkyung	Mn-Zn Ferrite & Ferrite Single Crystal - KAIST Iron Oxide - Ihna U Ba-Ferrite & Ferroxplana - Pusan U. BBT, DY & SPS Cores - Samwha Electronics Res. on Single Crystal for VTR Head - Samsung Soft Ferrite Core - Daewoo Gamma Ferrite Powders - Sunkyung Recording Media Powders - Saehan
Piezoelectric Matl.	KAIST, KIMM, Inha U., Ferrite, Daewon Ferrite & etc.	Sensor & Humidifier - KAIST Igniter - KAIST
<u>Polymers</u>		
Polymers for Information Industry	KAIST, KRICT, Seoul U. Kolon, Cheil Synthetic Co., Daehan Wire, Lucky, Dongjin Chemical Engr.	Research on Photoresists, Photosensitive Films and Plastic Optical Fibers - KAIST Development on Photoresists - KRICT Plastic Package - Lucky 7 Dongjin Chemical
Engineering Plastics	KAIST, KRICT, Lucky, Samyangsa, Sunkyng, Dongyang Nylon, Cheil Hannam Chem. Daehan Yuwha, Honam Petro, Hanyang Chem., Lalong	Development of Compounding Technique - KAIST Polyester-, Polyolefin-, Styrene-, Polyamide-System Engineering Plastic - Lucky Nylong-system - Kolon, Dongyang Nylon
Reinforced Plastics	KAIST, KRICT, KIMM, Sunkyung, Kolon, Lucky, Hankuk Fiber	Development of Hybrid Composites - KAIST Development of Plastics for Composites - KRICT Composite System Development - KIMM Product Manufacturing and Development - Others

CHART 42 (CONTINUED)

Subjects	Institutions	Status & Results
High Strength Fibers	KAIST, KIMM, Seoul U., Choongnam U., Sunkyung S., Kolon, Dongyang Nylon	Pilot Plant for Carbon Fiber - Sunkyung and Choongnam U. Pilot Plant for Aramid Fiber - KAIST & Kolon Aramid Pulp - KAIST Other Polymer Fibers - KAIST
<u>Composites</u>		
Glass Fiber	Hankuk Fiber, Lucky	Glass Fiber Yarn, Roving & Mat. Production
Carbon Fiber	KIMM, Choongnam U., Sunkung, Hankuk Fiber, Lucky & Cheil Synthetic	Developed - KIMM & Sunkyung Carbon Fiber Prepreg Production - Hankuk Fiber will Produce CF Prepreg - Lucky, Cheil
Aramid Fiber	KAIST, Kolon	Developed Kevlar Fiber
GFRP	KAIST, KIMM, Hankuk Fiber, Lucky, Oriental, & etc.	Pressure Container - KAIST & KIMM FRP Pipe & Tank - Hankuk Fiber, Lucky, Oriental
FRM	KAIST, KIMM	Research on SiC/Al, Al_2O_3/Al-KAIST & KIMM Research on B/Al - KAIST
Carbon/Carbon	ADD, Choongnam U.	R/D on Carbon-Carbon Composites

UNITED KINGDOM

Since the early 1960's the United Kingdom (U.K.) has, by most measures, experienced less than optimal economic performance and certainly less than the majority of its counterpart industrialized nations. Fueled by periods of inflation, wage/labor disputes and low national productivity and saddled with the problems inherent in having nationalized major industries and overriding defense spending commitments, the competitive edge of the U.K. had waned and continues to ride on an uneven keel today. Even though both the Labor and Conservative governments when in power have sought remedial and long-term solutions, the U.K.'s national industrial policy has been largely ad hoc, much akin to that found in the U.S. Where the U.S. has developed an arms-length approach to an unified industrial policy, the U.K. has not and accordingly promoted government intervention. Much of this was founded on macroeconomic approaches, but also geared toward the then novel measures intended to directly affect the actions of industry including government fostered business mergers, new-type government-industry advisory committees as well as cooperative research, targeted markets, government department reorganization, and the like [Paul 1984] .

These new policy measures attracted considerable attention worldwide, but especially in the European sector where some were adapted in modified form for individual national purposes. In the early 1960's the National Economic Development Board was established in the UK. to provide a forum where business, labor, and government could air views on the future of the economy. In 1966 the Industrial Reorganization Corp. (now defunct) was formed to aid industrial restructuring, as, for example, the Ministry of Technology engineered mergers creating the computer firm, International Computer Ltd. In 1975 another government agency, the National Enterprise Board was set up to provide direct financing, primarily for new startups in targeted industrial areas, like the formation of Inmos, the semiconductor manufacturing firm. In a different area the Science Research Council for Applied Research and Development was established to provide policy guidance on a variety of topics such as applications of new technologies and the education and training of engineers. "Buy British" campaigns were initiated with the government assuring some pre-production orders along with concerted efforts to educate industrial decision-makers (50,000 persons over three years) on the virtues of a British developed new technology.

Starting in the mid 1960's and continuing today is a general redirection of the U.K.'s national research establishments to R&D more akin to market oriented needs. These high quality research organizations, like the National Engineering Laboratory, the National Physical Laboratory, and Harwell, started working with industry on a contract basis or the cost shared mode. Harwell, for example, in the early 1970's, building on their nuclear fuel processing expertise, developed with industry a sol-gel process for preparing oxide powders having closely controlled crystallinity, shape, and size. Similar successes were achieved in developing the basics for better steel plant refractories and carbon fibers for composites [COSMAT Vol IV 1974]. Today Harwell essentially operates as an independent laboratory, serving industry primarily in a self-sufficient fiscal mode.

In complementary adjustments to the U.K.'s R&D system a major new five-year, $500 million program was established by the government in 1983 to bolster the U.K.'s competitive position in microelectronics. The program, named after John Alvey, who chaired a government commission to consider national efforts in this area, follows a consortia model involving cooperative R&D between industrial companies, government laboratories, and the universities [Fusfeld 1986]. Costs were shared between industry and government on about a 50:50 basis. In 1987, a follow-on Alvey program was under consideration by the government [Research and Development 1987], but not formally approved. Proposed is a pre-competitive research effort in information technology directed toward the applied practical problems, rather than the basic. As planned, government would fund about 40% of the $1.58 billion budget, with the remainder coming from industry. About half would go into an application scheme to support specific projects on generating commercial products; the rest in risk capital for the more speculative work. Along the same lines the U.K. just approved the initiation of another collaborative type program aimed at developing high technology products [Research and Development April 1988]. This multi-million dollar "Link program" will make funding available for selected university projects, provided that the costs are equally shared with industrial sponsors; government labs and research institutions of all types could also be involved in this overall effort to improve partnership arrangements between the diverse sectors. It is anticipated that up to $735 million will be spent by government and industry during the next five years. Projects will cover molecular electronics, semiconductor materials, industrial measurement systems, genetic engineering, and nanotechnology. It is presumed that the basis for the projected R&D on materials technology under the Link program had its origin with the submission in 1985 to the Department of Trade and Industry of the "Collyear" Report. The Collyear committee proposed a five- year, £120 million program "For the Wider Application of New and Improved Materials and Processes" [Collyear 1985]. Recommendations included 50:50 funding between government and industry; collaborative (consortia-type) R&D including demonstration projects which are crucial to the advancement of manufacturing industries; and, materials coverage of composites, engineering ceramics, rapid solidification of metals and alloys, electronic materials, surface and joining technology, near net shape shaping methods, and assurance of product performance during service. Although the Collyear program had been originally disapproved, elements may have resurfaced under the Link banner.

Government policy and efforts in the U.K. in confronting economic and competitive issues on the whole, have had to accommodate a diverse number of government departments, many of which participate in policy decision making. Moreover, an added problem has been government-business relations, which like in the U.S., typically are on the adversarial side so that most government actions are viewed by companies with somewhat of a bit of skepticism and caution. British businesses have always appeared wary of government even though the government plus the nationalized industries account for about 25% of the country's labor force and the public enterprises for more than 10% of the total industrial output [United Kingdom 1987]. Still the U.K.'s approach to industry reflects a firm view that government can strengthen existing industrial segments and create new ones [Paul 1984]. Embodied in this strategy is their S&T establishment and a government R&D system of about $6.1 billion/year.

The U.K. has long been recognized as a bastion of scientific research, but also has been perceived as ineffectual in capitalizing on that research. Opinions in Great Britain and elsewhere typify the outputs of the U.K. R&D system as "invented by the British, developed by the Americans, and mass produced and sold by the Japanese" [Barks 1987]. The whole process of innovation and commercialization is, of course, complex and the U.K. situation is not far different from that thought prevalent on the U.S. scene and appearing on Japan's horizon*.

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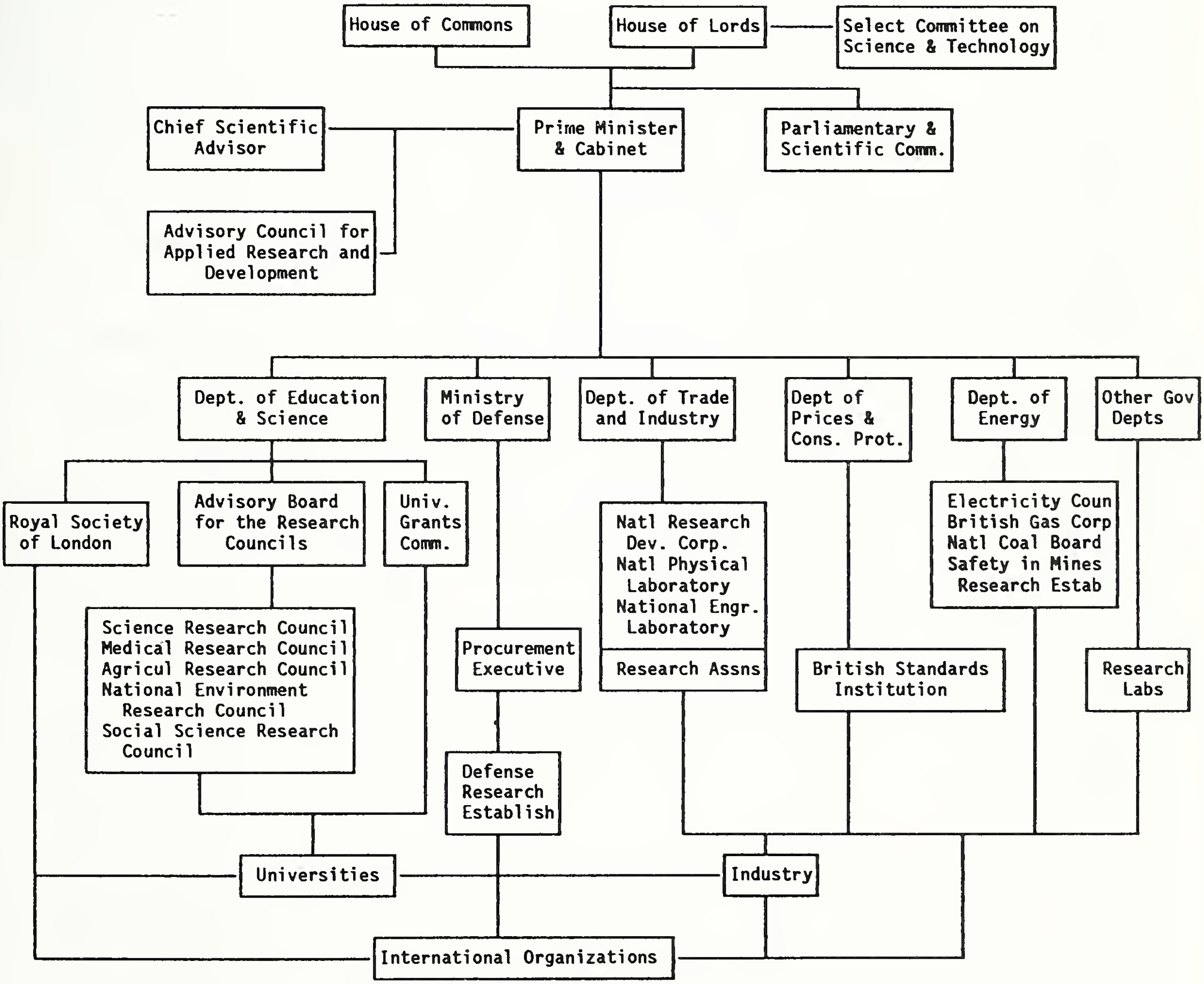
* A catalog along with descriptive cause and effect situations of successes and failures in the commercial introduction of new materials for the U.K., Germany, Japan, Denmark, and U.S. is given in a report prepared for the Department of Industry, U.K. [Modern Materials in Manufacturing Industry 1983].

Chart 43 gives the organization of the R&D system in the U.K. The system is extremely pluralistic and decentralized and in many

CHART 43

ORGANIZATION OF R&D IN THE UNITED KINGDOM

SOURCE: [Ronayne 1984; Williams 1974]



respects resembles the U.S. system in that S&T policy and planning is carried out by several government departments, advisory boards, and commissions. While new programs have been established in the U.K. and new approaches (collaborative research) are being tried, the elemental organization of R&D has remained fairly static over the years though departments have been reorganized, combined and/or renamed, as, for example, the merging of the Department of Trade and the Department of Industry. On the whole there is no primary coordinating group within government for R&D and individual departments maintain an autonomous operation [Lederman 1986]. Fragmented efforts appear to prevail and in recognition of this a new call by the House of Lords Select Committee recommended that a cabinet minister have the responsibility for the nation's R&D and be backed by a council of science and technology [Research and Development March 1987]. Currently the Advisory Committee on Applied Research and Development (ACARD) is the main body influencing coordination of applied R&D between government and external groups [Ronayne 1984]. It, however, has no management function nor does it allocate resources; it does provide the primary pipeline conduit for industry access to top government department heads. The ACARD complements the activities of the Advisory Board for the Research Councils (ABRC), a government committee set up in the Department of Education and Science. The ABRC is more than advisory in that it allocates funds to educational research councils for subsequent distribution in the five main areas listed in Chart 43, none of which specifically pertain to MSE.

The principal government agencies for civilian R&D are the Department of Trade and Industry and the Department of Education and Science, with some added activity by the Department of Energy. Support for industry is provided by Trade and Industry in two ways; by direct investment (e.g., loans, pre-production guarantees) in firms through its National Research Development

Corporation, and by direct R&D contracts, usually on a cost shared basis. In 1983 61% of its funds were spent this way in an effort to increase technological innovation by industry. The balance of the Department's resources go to support programs in other government departments and in its own laboratories, like the National Physical Laboratory. These in-house research laboratories provide specialized help/advice/service to industry to develop standards, explore new fields and enhance mature technologies.

The majority of all university research funds come from the government's budget and are administered by the Department of Education and Science. The five Research Councils provide for the ordinary costs while the Grants Committee handles the overheads, facilities, equipment, etc. In 1983 the Department spent about $1 billion on university research, a sum which included major funds for the four major research laboratories operated by the Councils [GAO 1985].

Defense R&D consumes more than 50% of the U.K.'s research dollar (pound). The Ministry of Defense provides this support primarily to industry via contracts and for operation of its own set of laboratories. The Ministry funds little (< 2% of its budget) for basic type research at the universities.

The other part of U.K.'s R&D system is, of course, industry. On the whole industry contributes less of its own money on R&D than the government spends, a practice just the opposite to the happenings in most other Western nations. British industry is a mixture of publicly and privately owned firms. Several important industries that are (or were) publicly owned include steel, railroads, coal mining, shipbuilding, certain utilities, and most civil aviation. These receive significant attention in the government's overall scheme of things, so that industry may view R&D funding in the context of "if I won't then government will".

Currently, industry does not have to officially disclose their R&D expenditures, as required in the U.S. New rules have been proposed making disclosure mandatory, primarily as a mechanism to persuade industry to increase their investment in R&D [Research and Development March 1987]. British tradition and conservative industrial viewpoint may, however, inhibit significant change in outlook or direction, and future inroads to new markets may have to come from government actions in the main. This after all was the basic policy initiated by government some 20 years ago.

UNITED STATES

The patterns of the modern day S&T system in the U.S. began to clearly emerge during the post World War II period, but had roots and traditions stemming from years before. In 1863 the National Academy of Sciences was founded by an Act of Congress to provide advice to government agencies upon request and has acted in this capacity ever since. The first World War brought about the formation of another advisory group, the National Advisory Committee for Aeronautics (NACA), but little came of its efforts to influence the development of the basis for a science policy. During the 1930's a Science Advisory Board was established by Executive Order to advise the President on science matters, but it too had little impact on governmental science directions. This was followed by the creation in 1940 of the National Defense Research Committee, which almost immediately led to the formation of the Office for Scientific Research and Development (OSRD). The establishment of this office in effect was an landmark as it provided the origins for the current U.S. science policy. Under their auspices, for the first time the U.S. government articulated a program, provided substantial funding, and set up a contract mechanism for R&D at the universities and at their newly established, affiliated "national labs". The basic tenet for this contract research was free scientific investigation, but on a government designated technical problem area. Through this process untold military advancements were made; radar, for example, was fully developed and, of course, the atomic bomb came into being.

In the post war period government attempted to articulate a science policy and it has been evolving ever since. A Presidential-commissioned study produced in 1945 the now famous report "Science, the Endless Frontier" [Bush, 1945] which advocated among other things, the promotion of industrial research by increasing the flow of new scientific knowledge through the support of basic research, and the creation of a government agency to develop and promote a national policy for scientific research and education. Nothing formally came of these recommendations but they nonetheless set the directions in the years following taken by numerous, but independent, governmental agencies. In 1946 the Office of Naval Research was established as was the Atomic Energy Commission along with the formalization of the National Laboratory system (e.g., Oak Ridge, Argonne, Brookhaven, etc.). In 1950 the National Science Foundation was finally established having as one of its mission roles to develop national science policy and to coordinate the basic and applied nondefense Federal research activities. This role was never completely fulfilled. Prompted by the U.S.S.R. successes in space, an Office of Science and Technology (OST) headed by a Presidential Science Advisor was established in 1962 in the Executive Office to set national R&D policy and serve as the prime S&T coordinating arm. This science-direction organization was abolished in 1973 and the head of NSF became the President's Science Advisor. Subsequent actions caused by pressures from the technical community saw the re-establishment in 1976 of a science presence in the Executive Office through the formation of the Office of Science and Technology Policy (OSTP), an organization having a more constrained charter than its predecessor, OST, and less impact in that its post of Director was less than that of cabinet level. In 1982 a Science Council, reporting to the Director, OSTP, was established to improve coordination of the national research effort. OSTP also chairs a coordinating Committee on Materials (COMAT), made up of representatives of the government agencies engaged in materials R&D. Among the many functional responsibilities of OSTP one is to provide advice to the Office of Management and Budget (OMB) on scientific and technological considerations in the Federal budget. Increasingly, however, it is OMB rather than OSTP that sets science directions and makes key technical judgments through its rigidly controlled budget review and approval process, a process which is attuned to financial and political considerations, as well as science and technology.

Because of the division of powers concept embodied in the U.S form of government the Legislative Branch of government has been equally involved in setting science policy and directions in the U.S. In a process of bargaining, negotiation and compromise with the Executive branch, laws and corresponding appropriations enacted by Congress guide the course of governmental action, sometimes for years ahead. These legislative actions generally stem from recommendations presented to it by the President, but often result from its own initiative, as, for example, some of the legislation identifying the criticality of materials to the nation. Over the years Congress has developed an elaborate committee system for review and enactment of legislation. Committee staff provide expert advice and serve as a prime communication channel between the Executive Branch and non-government experts and advisory/lobby groups. Formal legislative hearings with testimony by informed persons in government and out provide a second advisory mechanism. A third route influential on S&T involves institutions attached directly to Congress; the Library of Congress, the Office of Technology Assessment (OTA), and the General Accounting Office (GAO). These serve as analytical arms of Congress in assessing technological needs and the resources and programs in place or required to meet these needs. The Academies of Sciences and of Engineering constitute the major independent private advisory sources on matters pertaining to S&T and have provided important guidance to the whole of government on MSE. This report and its forerunner, the COSMAT Study, are but two examples.

In a parallel way government began to consider MSE early on as a separate entity [Huddle 1976], though to this day, while there are sizeable materials programs, a comprehensive government policy on materials has not been formulated. In 1952 the

Materials Policy Commission (the Paley Commission) reported to the President on this topic. In 1973 another follow-on group, the National Commission on Materials Policy, again addressed the question. Shortly thereafter in 1974, the NAS Committee on the Survey of Materials Science and Engineering (COSMAT) presented its report. Each of the two commission studies, though flavored by the events of that particular time, underscored the necessity of a major government role, a coherent MSE policy and institutional rearrangements within government. Other than to bring materials more to center stage, little on a national scale immediately resulted.

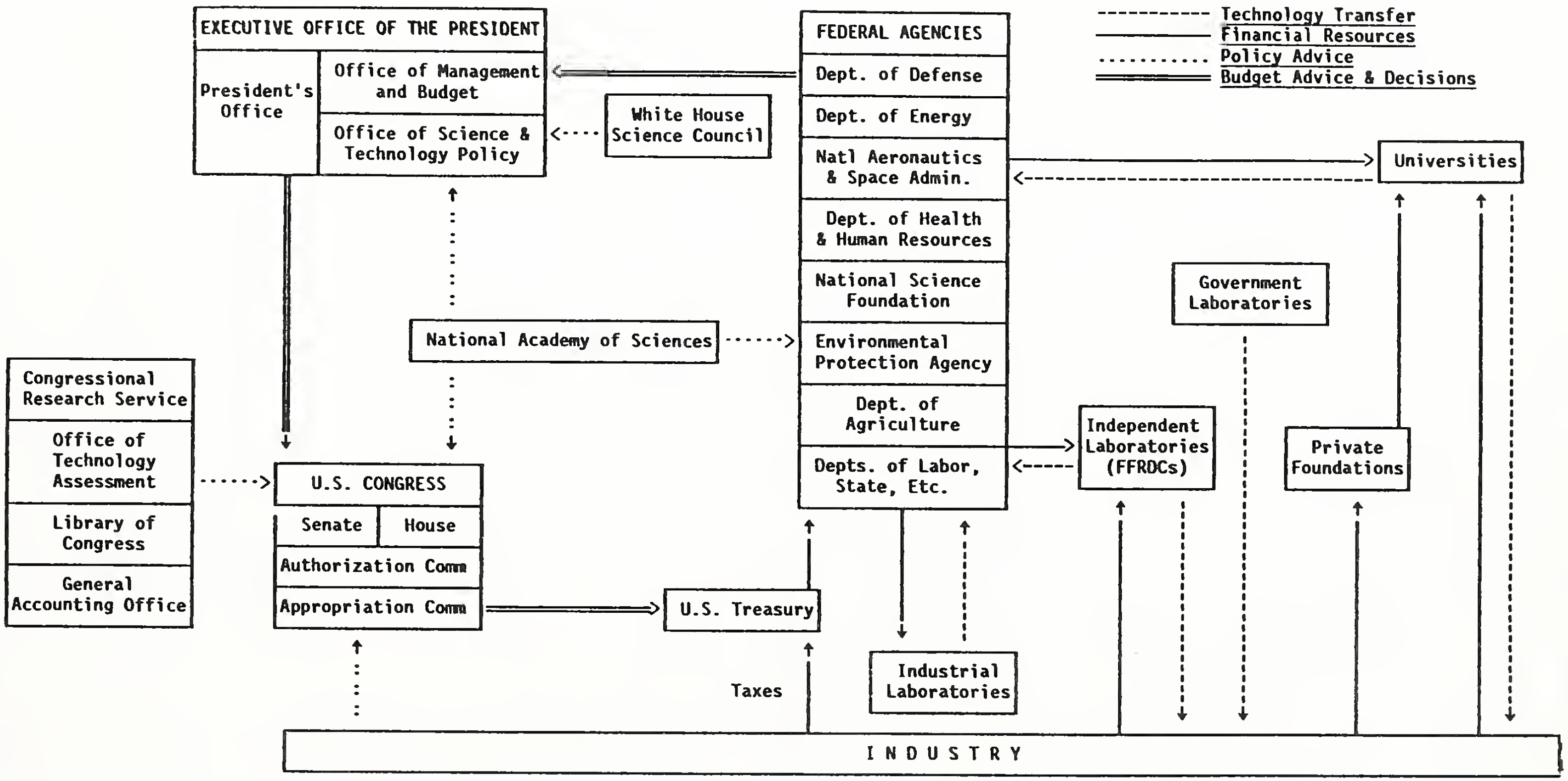
In 1980 the National Materials and Minerals Policy, Research and Development Act was passed after consideration by three sessions of Congress. This Act called for coordination by the President of the government's minerals and materials activities. This was followed by the passage in 1984 of Public Law 98-373 (Arctic Research and Policy Act), of which Title II, "National Critical Materials Act of 1984" called for (1) the establishment of a National Critical Materials Council and (2) the establishment of a national Federal program for advanced materials research and technology, and the stimulation of innovation and technology utilization in the basic and advanced materials industries. As of this writing implementation of the law by the Executive Branch is still in the early stages. In associated legislation, Congress addressed the issue of industrial research, also enacting the Cooperative Research Act of 1984. This law provided a more favorable environment (less antitrust penalties) for cooperative R&D between businesses, and under this Act, new research consortia such as MCC and others registered. (See Chart 17, Chapter 4).

The chronology of events described above reflects the discordant way science policy and programs in the U.S. have evolved with time, often changing in direction and emphasis with each major current event happening and each administration and Congress, indicative of the checks and balances inherent in the American political and free enterprise economic system. As a consequence the S&T (and MSE) system in the U.S., as aptly indicated by Chart 44, can be described as pluralistic and decentralized. No single department within government is responsible for its total R&D effort and the Nation's science and technology policies are the sum of all the policies of the individual parts making up the system. Coordination and control is agency-to-agency specific and national priorities emerge from the bottom up, rather than from the top down, reflecting an agency's perception of national needs and funding feasibility. For its planning, government relies on formal and informal advisory and study groups, the OSTP, OTA, NAS, and NAE being some representative examples. Due perhaps to the political system and year-by-year funding mechanism that involves about 160 separate budget approval steps, long-range planning is not a government forte.

The schematic representation given in Chart 44 is an approximation of the process by which U.S. resources are channeled to the various performers of R&D. Chart 45 indicates the total U.S. R&D budget between 1976 and 1988, and shows the division of effort in funding and performing research between government, industry, and others. Government provides about one-half of the $130+ billion (1988) currently devoted to research in the U.S. with about 1.7% allocated to MSE. Industry provides the balance; definitive statistics on industrial funding of MSE are not available, but may be as much as ten times the $1.1 billion spent by government. Government sponsored R&D is carried out by contract mechanisms in industrial laboratories, in university laboratories and in independent laboratories or research centers (often run by a university or a university grouping); and by direct Congressional appropriations in the government's own departmental laboratories and in Federally funded R&D centers (FFRDC), principally the National Laboratories.

CHART 44

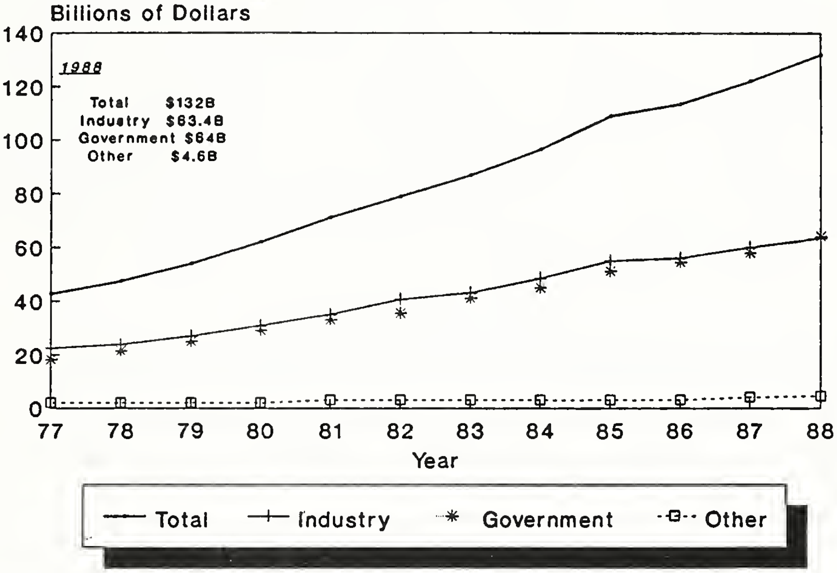
THE ORGANIZATION OF UNITED STATES SCIENCE AND TECHNOLOGY

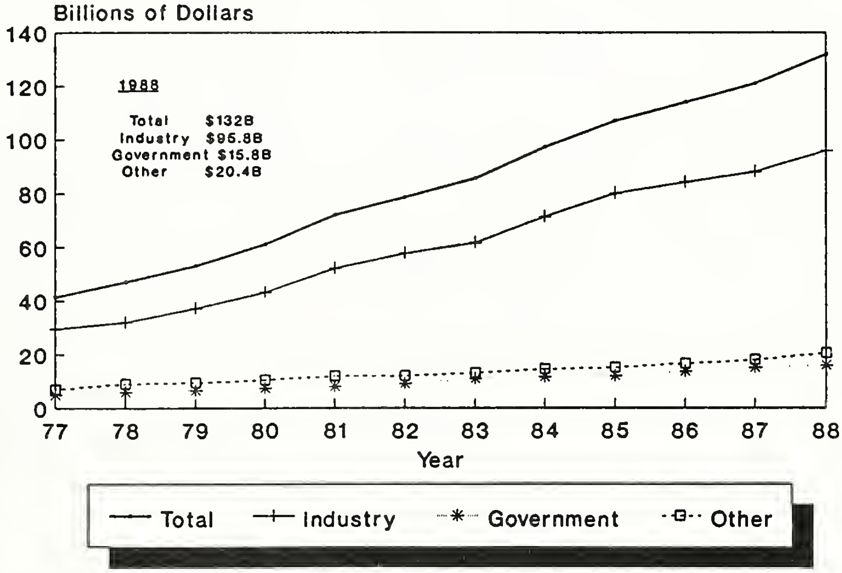


SOURCE: [Ronayne 1984]

CHART 45

FUNDERS & PERFORMERS OF R&D IN THE U.S.


FUNDING
Who Supplies the Money


PERFORMANCE
Who Spends the Money

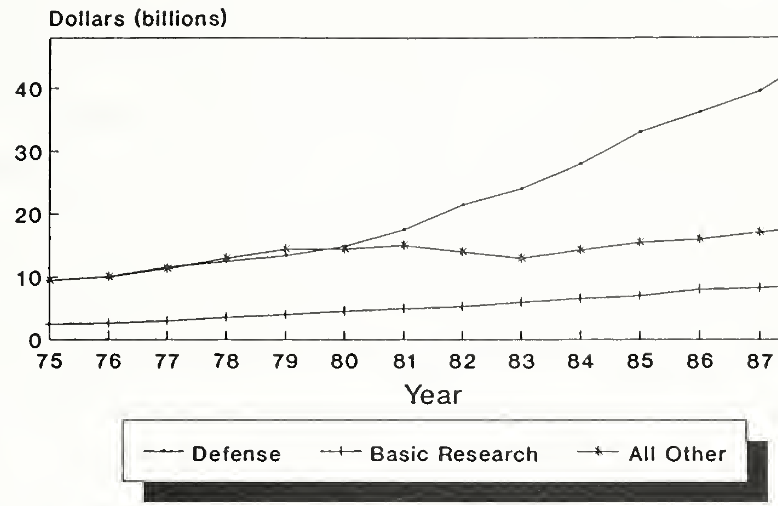
SOURCE: [Research & Development Jan. 1988]

By far the major fraction of Federal R&D funds go to defense related research and through this, the Department of Defense (DOD) has created one the finest integrated Research → Engineering → Manufacturing → Demonstration system in the world. U.S. defense technology is superior in most respects to all major competitors. Under present U.S. policy, it is viewed essential that DOD's R&D needs receive appropriate priority at every level, from the size of the Federal R&D budget, to issues such as access to faculty on the campus. The Defense Department has been and will continue to be a major sponsor and utilizer of materials R&D.

There is no uncertainty about the magnitude of the defense portion of R&D. Chart 3 (See Chapter 3) shows the total U.S. expenditure on R&D as a percentage of GNP. Using this measure, the chart demonstrates the rough parity with the U.S. in total effort which has been achieved by West Germany and Japan during the 1970's. By contrast, from analysis of nondefense-related expenditures, (Chart 4) it is evident that Japan and West Germany (with very limited national defense responsibilities) have pulled far ahead of the U.S. in R&D focused on basic science and industrial competitiveness. Chart 46 shows what has happened to the U.S. government R&D expenditures between 1975 and 1988 in terms of defense, basic, and other (industrial) allocations. Basic research funding has increased since 1975, but nondefense R&D has been slowed dramatically and defense R&D will have become about 72% of total government R&D by next year. Focusing specifically on materials and structures technology there will be significant expansion in all categories of DOD funded efforts (Chart 47) and from all service organizations.

Chart 46

U.S. Government Funded R&D



NOTE: 1986-1988 Estimated

Source: [Science Feb. 1986]

CHART 47

DOD MATERIALS AND STRUCTURES SCIENCE AND TECHNOLOGY PROGRAM FUNDING

Who, What, and How Much	$MILLIONS FY 1980	FY 1981	FY 1982	FY 1983	FY 1984	FY 1985	FY 1986	FY 1987 Est.
Materials Technology	106.0	118.8	136.4	145.3	155.3	186.4	230.0	261.1
Structures Technology	65.4	109.1	121.8	127.0	96.4	75.3	58.8	64.7
Research (6.1)	54.2	70.9	81.1	83.8	77.7	82.7	102.2	94.9
Exploratory Develop. (6.2)	94.4	115.7	128.3	120.0	132.4	141.0	142.2	163.2
Advanced Technology Development (6.3A)	27.8	36.5	45.1	63.4	63.7	46.7	40.4	57.2
Manufacturing Science	---	4.8	3.7	5.4	9.6	9.1	4.0	7.0
Information Analysis Centers (6.5)	1.5	1.0	1.5	1.8	2.0	2.0	2.0	2.0
University Research Initiative (URI)	---	---	---	---	---	---	26.0 -	---→
Army	33.3	39.9	49.2	48.6	69.2	73.6	51.9	60.5*
Navy	56.7	72.1	76.6	83.4	73.1	80.2	73.1	70.0
Air Force	66.0	94.3	106.3	111.3	109.4	107.9	122.3	152.1
DARPA	17.4	21.6	27.1	29.3	35.0	38.3	41.5	32.7*
DLA	1.5	1.0	1.5	1.8	2.0	2.0	2.0	2.0
TOTAL	174.9	118.9	259.7	274.4	288.7	302.0	315.8	317.3

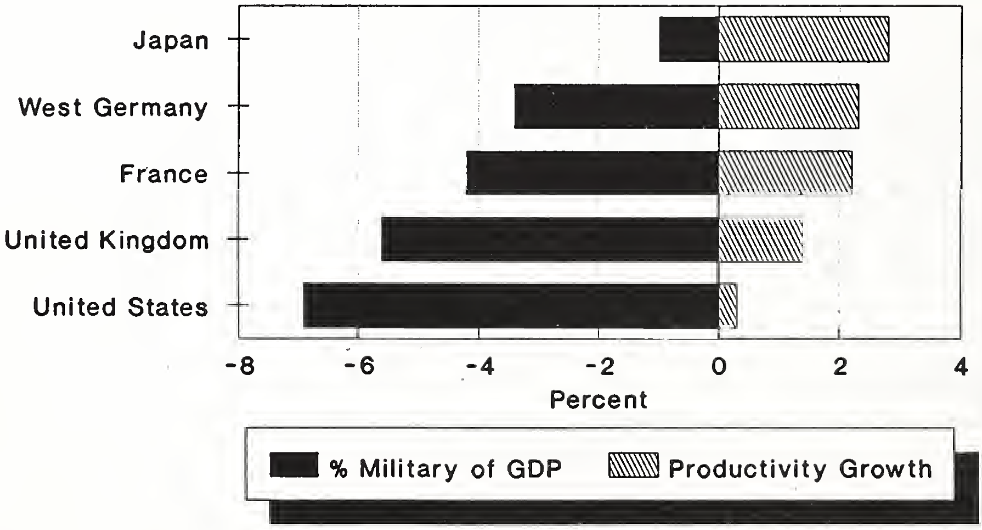
*Does Not Include Armor/Anti-Armor Funding

SOURCE: [Kerber 1987]

By all measures the U.S. outspends its industrial competitors in defense R&D. The sheer size of this effort has profound impacts in creating public awareness of science and technology, setting S&T directions, and in many important ways, in expanding the technical base of the U.S. Furthermore, in many well documented instances over the years, new materials and processes developed with defense R&D have led to major positive impacts on spin-off commercial products and productivity. However, cost of defense to an economy may be considered a drain on resources--both funds and the most precious of resources, skilled manpower. Moreover, there could be a strong negative correlation between improvement in national economic productivity and proportion of gross domestic product devoted to defense (Chart 48), depending upon the assumptions made in deriving this relationship.

Chart 48

Military Spending (1983) and Productivity Growth (1973-1983)



GDP = Gross Domestic Product
Per Employed Person
Source: [The Young Commission 1985]

Increasingly, defense R&D and R&D for commercial purposes are less interchangeable, as, for example, in the development of composite materials. Defense R&D has been justifiably credited with the introduction of organic matrix composites into military aircraft, and now, years later, into commercial aircraft. Currently, there is a similar, but apparently more restricted, development of commercial application of metal-matrix composites. The commercialization of the exotic carbon-carbon composites on which so much of defense spending on materials R&D is currently focused is a future question mark. Will automotive load-bearing composites come from these hard-to-manufacture, one-at-a-time lay-up materials, or more likely, from materials and processes developed specifically with ease of manufacturing and high production rates in mind from the beginning? In another area, high performance electronic chips, great credit can be given to defense and aerospace R&D for the early development and miniaturization of electronic microchips. However, many recent studies have emphasized the divergence in needs and associated R&D between specialized defense related chips and high volume commercial chips. The factors that drive technology for military applications are very different from those which drive technology for commercial application. Military specifications stress specific operational objectives. Commercial developments tend to emphasize operating efficiency, safety, reduced production costs, and high availability with low maintenance. Not surprisingly, in those industries which attempt to satisfy both needs, there is often parallel, non-interacting R&D activities.

Industry performs the bulk (about 73%) of all R&D (including defense) conducted in the U.S. It spends the majority of its own R&D funds within its own laboratories and the rest at independent research centers and the universities. Corporate R&D expenditures are often reported and analyzed as a percentage of sales and as such, R&D, particularly that of a long-term nature, may suffer from the vagaries of the near term economic climate.

R&D at the universities constitute less than 10% of the total conducted in the U.S. and only about 50% of all basic research. Government research funds go to a relatively small number of the 2000 or so four year and over colleges and universities. In 1982 the 50 largest university research institutions accounted for about 61% of all academic research and approximately 64% of Federal funds [Fusfeld 1986]. More and more the universities perform in a capacity as a research manager of large Federal programs, particularly defense related. The NSF is the government's largest sponsor of basic research at the universities; other government agencies also provide R&D funds, but activities may range from the basic to the applied. On the whole university research has a fundamental orientation with the current trend toward more applied. In 1982 there were 29 engineering graduates per 100,000 persons in the U.S. while in Japan there were 62 per 100,000. Engineering (particularly manufacturing) R&D at the universities has been identified as a true deficiency and support for this area is on the rise.

Industry and the universities provide S&T policy advice to the government essentially only through informal communication links. While many separate agencies have statutory advisory groups and Congress hears testimony from individuals and groups, there are no standing national councils involving industry-university-government participants for joint planning, coordination, and program critique. Dialogue between the public and private sector, and within sectors, is not on an organized basis and occurs more on a happen stance circumstance than by schedule.

Overall the civilian R&D system in the U.S. can be characterized as being comprised of two major structural and role elements, roughly equating to: Government support for science; and, industry support for technology. Herein defines the major difference between the U.S. S&T system and those of most other nations, especially the leading competitors of the U.S. This differentiation has been built over the years in the U.S. and is based upon the premise that the best way for government to enhance industrial technology is to foster a superior science base. This position was reaffirmed recently [Graham 1987] in a statement to a U.S. House of Representatives subcommittee by the Science Advisor of the President: "... and a firm recognition that a primary role of government is to support basic research at our universities and national laboratories, and that the role of industry in our private sector is to translate new knowledge into innovative technologies and bring high quality products to the global marketplace to the benefit of both the producer and the consumer". Thus the U.S. government has not developed a consistent, systematic set of S&T policies designed to aid industry more directly. While U.S. essentially has relied on domestic economic actions involving macroeconomic considerations, regulation(s) relaxation, and basic research funding, it has avoided promotion, planning, and S&T targeting at the government level--the common tools used by other nations. The laissez faire style of industrial policy in the U.S. has in the past led to extraordinary successes in both science and technology. In question now is whether this approach is appropriate to today's conditions where many competing nations have achieved near technological equality through nationally coordinated efforts. The recent U.S. record in world markets appear to say no.

Other nations have chosen a different pathway and rely heavily on government orchestrated industrial technology development programs. These directions depend upon collaborative R&D arrangements between government, industry, and universities. The complexity of R&D and the increasing need for interdisciplinary, systems-like organization of R&D is one of the profound trends of the last quarter century. The development of large interdisciplinary research laboratories to serve the needs of major industries is common practice overseas and encompasses most industrial sectors. It is clear from the source of funding of these labs that primary emphasis is placed upon medium to near-term time frames with the focus on product development and refinement. Few such laboratories have major programs in long-term basic research and virtually none in undirected basic research. The link between the innovation stage and the development chain necessary to bring new products to market needs nurturing as it is the effectiveness of this link upon which technology development depends. It is this link that many U.S. competitors have focused their R&D efforts.

Chart 26 (see FRG Profile) schematically shows the R&D spectrum for the U.S. In Japan, at the MITI labs, and in West Germany at the Fraunhofer labs, organized efforts are made to fill the gap between innovation and product development. The best of these labs are small in size, focused on relatively narrow topics, run by a strong administrator with great discretionary freedom and mid-to-long-term funding guarantees. When these labs are charged with industrial interaction they do so in coordination with industrial efforts, often engaging in programs jointly funded by industry and governments (both local and national) and guided by industrial advisory committees.

In the U.S., by contrast, there are no such laboratories of this kind charged with the general support of commercial industry. One does find some of the desirable features: in the National Bureau of Standards, which has the mission of assisting industry in the area of standards and development of measurement techniques; in the National and Federal laboratories which have been so successful in the development of the nuclear power industry and in the support of an extraordinary array of technologies associated with defense, energy, and aerospace; and in our private for-profit research laboratories which have worked so effectively with many industries.

In partial response to the need for such a link in the commercial sector, the NSF has initiated Engineering Research Centers. While filling an important need in orienting engineering education at our universities toward industrial needs, these centers do not fill the gap between university research and industrial product development, a gap which is partly filled by the MITI and Fraunhofer labs and by the U.S. DOD laboratories in the defense sector.

It is not obvious what additional steps will be taken in the U.S. since so much is already in motion. This is particularly true since no single format is appropriate to address all MSE needs in this gap between innovation and product. In some instances, additional Engineering Research Centers may be appropriate to address problems closer to the innovation stage. The ERC's with strong industrial involvement might best address fundamental issues of processing science, for example. Other laboratories are clearly needed to focus on the design and even prototyping of specialized materials production equipment. The MITI laboratories for mechanical engineering and electrooptics serve some of these functions. U.S. analogues are found to a limited degree at DOE laboratories, NBS, and private for-profit labs. New U.S. laboratories in this area might represent expansion of the roles of these aforementioned labs. Finally, there are laboratories studying actual product development in a pre-competitive atmosphere. Included here are all the processing techniques, as, for example, those necessary to carry out surface treatment of Si based devices in the sub micron processing scale. An industry-wide laboratory to address such questions in a manner leading to the development of appropriate new technology requires the intimate involvement of industry in planning as well as the contribution of industrial funds and personnel in a committed, full-time manner. The newly formed Sematech is an example of such a laboratory. The role of government here at a minimum is to assure that no legal or regulatory restrictions limit formation of such industrial partnerships, and at a maximum to participate in an active way in the planning and funding of long-term consensus research programs.

The activities within the private sector are key and central to the issue of competition. To begin with, Chart 45 indicates that the percent of R&D expenditures by industry has increased in the U.S. in the last 11 years to almost 50 percent for the first time, second only to Japan and Germany among major technological nations (Chart 10). Further, Chart 11 shows that nearly one-half of all government R&D funded in the U.S. is performed by business enterprises. This is in sharp contrast with other nations (except the U.K.). These two observations emphasize the role of industry in performing 73% of all R&D in the U.S. In many of the countries studied, mechanisms were in place for cooperative research to optimize the effectiveness of industrial R&D in the pre-competitive stages. In this environment, it is proper to consider the role, if any, the U.S. government will take in encouraging appropriate cooperation within industry. Chart 17 indicates that in the two years after the passage of the 1984 National Cooperative Research Act, which relaxed anti-trust regulations in the area of R&D, there were 49 filings of joint venture and multiparticipant R&D partnerships and that of these, about 26 appear to involve MSE-related efforts. However, most of these are bilateral. The future will tell whether MCC and SRC type precompetitive research interactions will find imitation, but note, for example, the newly formed Sematech and the recently announced cooperative efforts of the aerospace industry (in which MSE research will be a major identified component). It is not known whether the MCC, SRC, and Sematech models will work, but they represent the first substantial alternatives to the national MITI laboratories of Japan and the Fraunhofer Gesellschaft Laboratories of Germany. In these cooperative efforts the opportunities for strength through collaboration and economy via limited duplication of effort can be achieved. The President's

Commission on Industrial Competitiveness has already recommended further relaxation of the antitrust legislation to encourage such precompetitive comparative industrial R&D and legislation is under discussion.

U.S.S.R.

The famous quotation made by Churchill forty years ago still appropriately describes the Soviet Union today: ... "Russia is a riddle wrapped in a mystery inside an enigma" [Soviet Union 1981]. The U.S.S.R. is the largest country in the world, is well endowed in natural resources, ranks third in population, has a very good educational system steeped in science and math, and in terms of personnel, has the largest R&D effort in the world, amounting about 35% of the total worldwide activity. Yet, not withstanding these major attributes, the Soviet Union has achieved the status of a giant in military and space, but a dwarf in technological acumen and hence, currently is a non-entity in world trade and markets. Its major competitor is itself; it engages in world trade only to gain some political advantage, to obtain hard currency or to correct some internal remiss of the state controlled economy; e.g., low agricultural output or inability to manufacture mundane or high technology goods. Soviet science on the whole is highly rated and in some cases enviable, to be watched and built upon, as for example, Japanese advancement of the published U.S.S.R. materials and processing developments in the areas of low temperature diamond film deposition and electrodeposition of fibers for metal-matrix composites.* Soviet product design and manufacturing technology is inefficient and more often than not, characterized by reverse-engineering of Western made goods, a practice leading to a five to ten year 'to the market' lag between the East and the West [Taubes 1986].

The structure and operation of S&T within the Soviet Union is intimately linked and woven into the machinery of government, a

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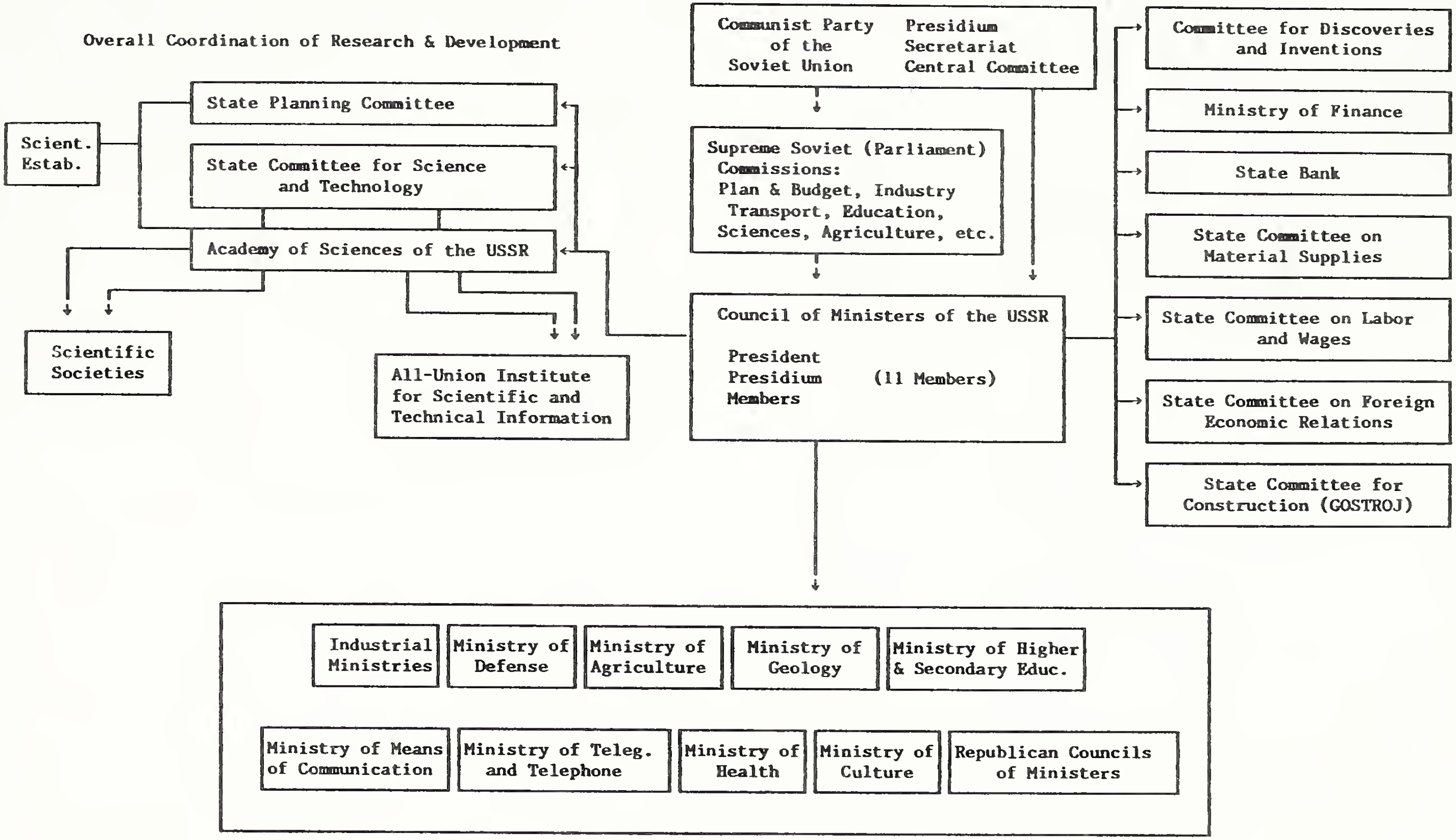
*Monitoring of foreign S&T for enchanced competitiveness has been the subject of concern in the U.S. This issue raises many questions, which requires a new look at U.S. policies and practices [ONR-NSF Workshop 1986].

single party system. The present form of government, called a federal union, was officially established in 1922 under Lenin and consists of three separate branches. The executive branch is the Council of Ministers; the legislative is the Supreme Soviet; and the judicial is the Supreme Court. The separation of powers is superficial as the Communist Party controls all functions of government, including its S&T. For almost every governmental organ, there is a parallel, but controlling party equivalent. Chart 49 gives the basic organizational makeup of the U.S.S.R. R&D establishment. It is the most highly structured, centrally controlled and unforgiving system in the world. Planning is a top down arrangement where the party policy is articulated into science and technology goals, generally through one of the governments's five-year plans. Goals set by head party leaders, equate to desired (required) scientific results to mandated levels of manufacturing of new technology products. The system is constrained by bureaucracy (party and government) and an elitist theme where rewards are high for success in S&T and national disgrace or worse for failure or disfavor.

The Soviet government started incorporating S&T into the fabric of government policy soon after the Revolution with the issuance by Lenin in 1919 of the "Outline of a Plan for Scientific and Technical Work"; this was the first formal declaration by any government that recognized that science was an integral part of the modern state. Operationally, S&T starts with the Communist Party and the Central Committee. Next in line is the Supreme Soviet and its functional body, the Council of Ministers, made up by the heads of the major ministries (like defense, industry, education, agriculture, etc.) and the State Planning Committee (Gosplan), State Bank, and the like. The real power of decision rests with the 11 or so member Presidium, chaired by the head of the Communist Party. This body proposes/considers/ approves S&T plans formulated by the Gosplan developed through a coordination process involving the Academy of Sciences, the State Committee

CHART 49

RESEARCH & DEVELOPMENT IN THE U.S.S.R. - ADMINISTRATIVE ORGANIZATION (DEC. 1966)



SOURCE: [White 1971]

for Science and Technology, and the various ministries. Within this organizational complex the Academy of Sciences carries the most influence and at one time guided R&D within the ministries. The Academy originated in 1725 by order of Peter the Great as Russia's main science establishment; it was modeled after Western academies and its first eight members were European. Today the Academy is the science side of Soviet S&T and the ministries the technology side. Higher science education is handled by both the Academy and by the Ministry of Higher and Secondary Education. The Academy and other educational institutions, as well as all the prime ministries operate an array of research establishments of varying size and sophistication, involving well over one million workers.

Overall, the S&T 'plan' (put forth by Gosplan) [White 1971] of the U.S.S.R. over any time frame is developed as an integral part of the National Economic Plan. It is detailed in almost every respect. It identifies the problems to be worked on, which research groups will do the work, and defines achievements expected. Finances are based on the number of R&D workers at an establishment, a number sometime over-estimated; capital expenditures are proposed separately. The subsection of the Economic Plan dealing with specialized branches of industry targets such items as the introduction of a new technology, automation, investments, and production goals, etc. More and more the industrial ministries are being allowed increased autonomy in their R&D, but still are subject to oversight by the Academy (and the Party). There is, however, no official tie between any major research grouping; thus many of the innovative basic ideas (including materials) generated by the Academy research institutes lie fallow because the ministries conduct about 90% of all engineering R&D and generally do not interest themselves in Academy business (and vice versa). While there is superficial coordination, there is no incentive for collaboration and Soviet industry opts for adaptation of Western technology rather than developing their own. As a consequence of this division MSE is treated as materials science on one hand, and materials engineering on the other, with the former generally excellent and the latter, duplicative.

Besides all the shortcomings, the Soviet Union has mounted extraordinary S&T efforts which have led to its superpower status as, for example, those connected with military weapons and space developments. These were (and still are) nationally mandated items falling under the Communist guiding doctrine of a large armed force, for controlling the masses internally, and gaining the control of those without. It remains to be seen how the new policy directions of "glasnost" (openness) and "perestroika" (restructuring) will impact their current low marks in industrial technology development; the Soviets most certainly have the capability to do otherwise.

5. COOPERATION

"The new patterns of cooperation will determine the new patterns of competition."
--Carmela Haklisch, New York University, 1986

5.1 Patterns of Cooperative R&D

Cooperative research entails the joining of resources, technical and financial, to pursue areas of collective interest in furtherance of specific individual needs. Recent times have seen the methodical creation and buildup of a plethora of new technical linkages among businesses and research organizations throughout the world, outstripping past efforts. These take many forms, and joint ventures, multinational corporations, national and international consortia, and an array of new types of collective industrial research associations now abound. More and more nations rely heavily on government orchestrated technology development programs in which collaborative arrangements between government, universities, and industry is integral to their strategic approach.

However, both "competition" and "cooperation" are twin elements in national policies--both private and public--which, in tandem, drive the engine of R&D to change technology to improve a country's position. The place of each of these motifs in a nation's cultural make-up varies greatly. In the U.S.'s culture at large, competition has been raised to a dogma status. From persons in athletic leagues to the struggles among corporate giants for marketshare, it is ingrained that the "best" will win in the competition. It is alleged universally that it is the competitive spirit which has been the cause of U.S. prosperity and wealth. In the immediate post World War II era, the very lack of effective competition and U.S. dominance of the world economy gave misleading data which appeared to confirm the 'competition is best' concept. Today, the situation is different, and genuine competition among near equals has emerged in the international industrial arena. Olympic competition is but one manifestation of the perception that nations compete with each other in economics, defense, technology, R&D, etc. Yet strangely enough, the U.S. is less accustomed to acting cooperatively, like a single competing unit in the economic sphere, than most other countries.

The cooperation motif internationally is relatively mixed in the Western developed world. While cooperation on defense--NATO, SEATO, ANZUS, etc.--has been actively pursued, cooperation in the civilian sector pales by comparison and for the good reason that in that arena it is believed, passionately, that competition in the marketplace must exist for free and fair trade. Science, especially basic science with its absolute commitment to openness and sharing is a quintessentially cooperative (across national boundaries) venture at one level, while retaining a fierce competitiveness at the individual level. The technological enterprise here as in much else, is radically different from science. A spirit of cooperation, co-laboring, in the common cause of creating excellence in a product is essential.

Such cooperation is as much a part of other cultures' fiber as competition is in the U.S. Japan is the prime example, but most of the Far Eastern cultures exhibit an ethnocentric cohesiveness built on traditional religious values. These generalities on the relative importance of cooperation and competition in different nations certainly affect R&D and S&T policies in general.

The policy of internationally shared technological (often mislabeled scientific) ventures was greatly advanced by the atomic weapon development. The resultant pattern persists in all Big Science. Particle accelerators, huge telescopes, major research facilities costing in the $10-100 million range, have all become focal points for research collaboration. And cooperation at the individual level continues through the myriad scientific conferences, through the literature where the spirit of individual competition creates a cooperative network at the next hierarchical level. Input-output studies on each country's performance in relating to this "information conduction band" are not generally available. The appropriate measures are: international conferences attended by each nation's engineers/scientists, number of papers presented, visits made by such scientists to other countries laboratories and use made of any reports from such visits, etc. Most observers agree that the Japanese have participated much more vigorously in tapping this resource than the U.S. and, moreover, that the U.S. participation has declined in the last decade or two [NSB 1985]. U.S. "market-share" of the science-output into the international science information conduction band is both very uneven across subfields of MSE [Roy 1987] and declining in certain fields (such as magnetic materials) with time. Part of this must be attributed to the obviously increasing R&D capabilities in the rest of the world, but organizing to cooperate more effectively can, without any question, be the most cost-effective improvement the U.S. can implement.

Both the concept and conduct of cooperative R&D involving private corporations are more common in Europe and Japan than in the U.S.* This difference derives partly from the earlier U.S. recognition and use of technical change as a deliberate tool for corporate growth**, and partly from the smaller domestic or

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*The discussions in this section are based in part on data presented in [Haklisch 1984; Fusfeld 1986; Fusfeld 1984-86, and Roy 1987].

**Organized industrial research started in the German chemical industry of the late 19th century, but the integration of technical planning with strategic planning emerged in U.S. corporations after World War II.

regional markets, hence smaller resources for R&D, in other countries. Importantly, there are distinct different philosophical convictions regarding competitive behavior vis-à-vis cooperation.

Whatever the reasons, cooperative industrial R&D plays a more active role abroad than in the U.S. Trade associations in the U.S. are well-established, but their budgets are modest and tend to fund activities in existing research institutions, most often universities. As examples, the R&D expenditures for several of these associations in the U.S. are [Haklisch 1984]:

Organization	Founded	R&D (1984) Est.
International Copper Research Assn.	1959	$ 1.6M
International Lead Zinc Research Assn.	1925	2.0M
American Iron and Steel Institute	1910	1.8M
Metal Powder Industries Federation	1945	.6M

A few exceptions do have their own facilities. One is the Portland Cement Association (formed in 1916) with estimated 1984 R&D expenditures of $5.34 million. Another is the Textile Research Institute (formed in 1930) with 1984 R&D at about $1.5 million. It is clear that materials research sponsored by trade associations in the U.S. is not intended to be a substantial part of the technical base. These activities can initiate exploratory research in new areas, they can provide modest assistance to small companies, and they can encourage faculty and graduate students at universities.

On a relative basis, however, it has been noted above that collective industry-wide funding of university MSE research has played quite a significant role. But individual companies often also invested large sums within university departments. 'Pioneer Corn', under Henry Wallace (once Vice-President of the U.S.), supported work at Washington University in St. Louis for decades. The Bethlehem Steel Corporation supported work on blast furnace slags for 27 years continuously at the Pennsylvania State University. Dozens of such arrangements existed. They were gradually weakened as the U.S. R&D budgets grew and made it easier to get money, and easier to do the work (since the relevance constraint was removed).

By the 1960's the U.S. Federal Government was aware of the problem and made sound attempts to do something about it. The biggest effort by far was in the MSE field. Starting in 1960 ARPA (Advanced Research Projects Agency--DOD) set up national centers (IDL for MR--Interdisciplinary Laboratories for Materials Research) both to build up the personnel base and the basic research base for industry. Coupling to industry was much in the air at presentations but stayed at that level in almost all these Centers. ARPA, in addition, started three explicit MSE industry-university coupled centers such as that between Monsanto and Washington University in polymers. The Defense Department had dozens of joint materials programs involving universities and industries in teams. In 1972, NSF assumed responsibility for the IDL program and the laboratories renamed Materials Research Centers. NSF, using a similar concept, followed on with the creation of ERC's (Engineering Research Centers). Ten ERC's were started in 1985. Plans for an additional 20 centers have been announced by NSF beginning in 1988.

Overall, the distinct feature of U.S. cooperative R&D activities is its diversity, but not its cohesive approach. Individual researchers, universities, private corporations, and all levels of government participate in different degrees, and at different times to meet specific, but individual needs. While the U.S. has no direct counterpart cooperative system or organizational framework, nor national policy in place comparable to its competitors, modest movement in this direction is evident. Antitrust laws have been modified and industrial consortia (e.g., MCC, SRC, and the new Sematech) are on the rise. Executive orders are in place to promote better utilization of the National Laboratories by industry. New NSF sponsored ERC's are being set up. State initiated technology incubator programs are appearing with regularity. Still lacking, however, are the government fostered national laboratories for cooperative applied industrial research, seen so effective in Japan through its MITI's labs and in West Germany by the Fraunhofer Institutes.

The picture is somewhat different in Europe and Japan. First, a number of industry-specific groups, many involving materials, have their own facilities, e.g., British Non-Ferrous Metals Research Association, the Fraunhofer Institutes in the FRG, and the JFCC in Japan. Second, there is usually a substantial government subsidy with some formal basis for industry funding. While specific figures are not known, the fact is that laboratories are operated by these collective associations. One outstanding example is the French metallurgical institution, IRSID (Institut de Recherche sur la Siderurgie), with approximately 600 people and annual expenditures in 1986 of FF 240 million [Fusfeld 1984-86]. IRSID is funded principally by the French metallurgical industry, with some research contracts from the government.

5.2 Representative National Activities of Foreign Countries

Most European countries and Japan encourage cooperative R&D that involves the participation of private corporations. These activities normally support established industries important to the particular country, including materials, with emphasis in recent years on such rapidly changing areas as semiconductor materials and advanced materials (e.g., ceramics and composites). The larger cooperative efforts are in the U.K., France, Germany, and Japan.

United Kingdom

One principal forum of cooperative activity in the U.K. is the Research Association (R.A.). More than forty of these exist. In materials, one is the British Non-Ferrous Metals Research Association. Funding of the R.A.'s comes from (1) voluntary (usually) membership subscriptions, (2) government grants, and (3) specific contract research. This last item can be for a single firm, or a program funded by a number of member firms.

The laboratories sponsored by the Department of Trade and Industry conduct a number of programs, each of which is supported by a group of companies with a common interest in that program. These groups are referred to as "clubs," and more than thirty are operating. While many of the programs are of an exploratory research nature, a number are highly technological including one on materials handling.

The concern with microelectronics led the British government to establish the Alvey Programme in 1983 (see also U.K. profile, Chapter 4.3), named for the chairman of the study group which considered the U.K. status in this field. The funding for R&D comes 50% from government, 50% from the companies which participate. Expenditures for this program are about in the hundreds of millions currently. Each approved project has two or more participants. At least one is a corporation, while the others can be a university or other research institutions. The overall "program" is the sum of activities of these small "consortia". While the Alvey Programme covers a wide range of research and techniques considered to be "pre-competitive," many are related to component manufacture, and a number are concerned with semiconductor materials. These include:

- ion surface interactions - GEC + university
- implant and diffusion - British Telecom, GEC, Plessey, STL
- impurity and defects - GEC, Plessey
- multilevel metal - British Telecom, Ferranti, STL

France

There is a system of Industrial Technical Centers, established in 1948, as one mechanism to provide a technical base for French industry recovering from World War II. These Centers are earmarked to support established industries such as textiles and metallurgy. The principal funding for each Center, from 50 to 90%, comes from a tax on the companies which make up each industry. The remainder comes partly from government subsidies, partly from contract studies for individual firms within the industry.

Perhaps the largest private research laboratory in metals is that of Pechiney. About 100 research scientists and engineers are engaged in materials research, including ceramics. This is out of a total R&D level of approximately 1400 people [Fusfeld 1984-86]. Pechiney is a major participant in cooperative programs in France and in Europe.

Federal Republic of Germany

Major cooperative industrial R&D activities in West Germany are aimed principally to support small and medium-size enterprises (SME's). There is a Federation of Industrial Research Associations (AIF), initiated in 1954, which coordinates the activities of roughly 80 research associations. Thirty-one industry sectors are represented by these associations, and they have a total of approximately 8000 SME members.

Projects funded by the research associations are carried out largely in facilities operated by an association but partly in outside research institutions. Since the objective of the AIF is to "enhance and maintain the technological potential of SME's," the projects tend to be more technological in nature rather than fundamental research. While total activity of the research associations is only a small percent of industrial research in the FRG, it is a more significant factor in the technical activity of SEM's. In mining, for example, research associations in 1975 accounted for 67% of R&D effort.

Individual major research programs supported by large companies on a cooperative basis are conducted by separate research institutions. The two largest in West Germany are the Batelle-Institut e.V in Frankfurt, and the laboratories of the Fraunhofer-Gesellschaft in different locations. (See also FRG profile, Chapter 4.3).

Japan

Japan probably has the most prolific system of cooperative research programs and organizations. The major categories consist of: 18 Government Centers; 600 Local Centers; and (many) Semi-Public Centers.

Chart 50 gives the functions and industry involvement of these different categories. The regional dispersion and emphasis on raising the technical level of small firms provide networks by which those firms can actually make contact with the local centers.

CHART 50

TYPOLOGY OF JAPANESE COLLECTIVE RESEARCH

ATTRIBUTES	GOVERNMENT CENTERS	LOCAL CENTERS	SEMI-PUBLIC CENTERS
Description	Eighteen government industrial technology centers that are attached to major technical ministries	Six hundred local centers which are attached to provincial & municipal authorities	Centers which are industry specific
Predominant Technical Activities	Applied R&D	Testing, R&D, Training (a unique feature, local centers provide training for staffs of small firms-involved 4000 people in 1976)	Testing, Technical Advice & Assistance Information and Documentation, Loan and Demonstration of Equipment, Research activities undertaken in collaboration with groups of companies
Sources of Funding	Public Sector Funds Financed almost totally by parent or other ministries	Public Sector Funds 90% from parent local authority, 1-7% from paid services to firms, 3-5% from MITI	Public and Private Sector Funds Industry provides "modest financial support
Government Role	Projects are directed by the administration and center directors	Projects are directed by administering local authority	(Not clearly defined)
Generic or Industry Specific	Generic	Generic and Specific	Specific
Level of Private Sector Involvement	No direct participation in decision-making or implementation. However, informal ties are well developed. Development project may be undertaken in collaboration with industry based on results of programs. Limited contract work	No direct influence on operation of centers, but influence is exerted through industry bureaus in local communities and technical committees in the centers	Representatives from industry comprise substantial fraction of each center's management and technical committees
Purpose of Projects	To support research programs of the technical ministries ranging from low budget, short-term (2 years) to high budget, long term (5-10 years) national projects	To provide direct assistance to local small firms (less than 300 employees)	To support activities directly related to specific needs of a given industry sector

SOURCE: Based on [Rothwell 1979]

The major industry-specific cooperative R&D, primarily funded through MITI, is conducted by Research Associations as authorized in the Industrial Technology Association Law. Under this, 54 associations have been initiated, of which 38 are still in operation. A great many of these are in microelectronics, one being the successful and highly publicized VLSI Research Association, with seven member companies.

MITI has established a New Materials Project (see also Japan profile, Chapter 4.3). As part of this, a Biotechnology Research Association was formed in 1981 with 14 member companies, and granted a contract to conduct research. The initiative to form the association was taken by the companies, but that could have come from MITI. The important point is that these Research Associations include the participation of important companies in the technical area.

5.3 International Cooperative R&D

After the war, especially in Western Europe (occasionally involving the U.S.) many organizations were formed to try to capitalize on the power of scale, by pooling the talents of the separate national bodies. Bodies such as the OECD, the EEC, GATT, and the standards organizations, are all efforts which share objectives and methodologies to varying degrees. Some (but not all) representative examples include:

OECD (Organization for Economic Cooperation and Development)

This organization, its roots stemming from the Marshall Plan following World War II, was formed in 1961 to promote economic and social welfare of its 24 member countries. The secretariat is located in Paris, France, which services OECD's special committees, about 200 in all concerned with diverse topical areas including S&T, trade, investments, energy, industry, education, and the like. OECD's primary outputs are in the form of studies and assessments and statistical data; a current study underway is on MSE. Within the framework of OECD, separate, autonomous or semi-autonomous organizations, often are set up to meet special needs of some or all of the member countries. One example is the International Energy Agency (IEA), formed in 1974 to foster and sponsor energy R&D in 21 of the 24 OECD nations. One current project of IEA involves advanced structural ceramic powder characterization and mechanical property determinations, a cooperative activity needed for ceramic heat engine development.

European Communities (EC)--Research and development conducted under the auspices of the EC represents perhaps one of the most extensive forms of international research cooperation in existence in the world today. Chart 16, Chapter 4, lists some of the special programs now underway. In 1979 it involved about 360,000 EC research workers (1,020,000 total employed in EC research activities); in 1984 R&D appropriations to the EC by its members amounted to about $4 billion or about 1.5% of the total R&D expenditures by the member states individually. Collaborative R&D in the EC had its origins from the Euratom treaty, one of three which provided the basis for the formation of EC. Under Euratom the Joint Research Centre (JRC) in Belgium was setup in 1957 to implement and coordinate joint research for the member countries; today JRC operates four major research establishments--GEEL in Belgium, KARLSRUHE in West Germany, ISPRA in Italy, and PETTEN in the Netherlands. The latter two institutions relate more directly to MSE technology, but all conduct materials research.

Actions undertaken by the EC, research or otherwise, must be approved by the EC's ruling body, the Council of Ministers. The operational arm of the EC for R&D and all other areas is the Commission of the European Communities (ECC). The ECC on S&T matters is advised by a network of committees comprised of representatives of national governments, national S&T experts, and independent specialists. The two most important committees are CREST (The Science and Technical Research Committee) for science policy and Codest (European Development of Science and Technology) for policy implementation.

In general the EC establishes R&D activities using somewhat cumbersome and time-consuming operational procedures. Using the committee system ECC develops R&D proposals which are reviewed by the Management and Coordination Committee (CGC) and by the European Parliament in an advisory fashion (although advisory it can use its budgetary powers to exert direct influence on decisions). The primary role of CGC is to coordinate and evaluate EC programs with the R&D separately conducted by individual member states. Upon approval by ECC, the proposals are submitted to the Council of Ministers for final decision. If approved the ECC implements the program by making project selections (based on its advisory committee recommendations), allocates funds, monitors progress, and sees that the results are published and disseminated. The actual R&D is handled by utilizing three routes:

1. Through the JRC using its inhouse research centers at Petten, etc. (Direct Action Route).

2. Through research under contract-cost shared projects (Indirect Action Route-may be coordinated by JRC).

3. Through coordination of research by JRC or others (Concerted Action Route).

The principal cooperative R&D programs in Europe are conducted under the auspices of the EC. One of the earliest intended to support industrial R&D was COST, for European Cooperation in the Field of Scientific and Technical Research, initiated in 1970. Corporate involvement varied by project.

In 1973 the Council approved a proposal by ECC for a general European S&T strategy and plan, to be funded and implemented under a overall program termed Framework. This program (Chart 51) for its second phase (1984-1987), had an overall budget of

CHART 51 FRAMEWORK PROGRAM FOR 1984-87
(INCLUDING PLANNED VOLUME OF FUNDING)

		Million ECU[1]	%
1.	Promoting agriculture competitiveness:	1303.5	
	(i) developing agricultural productivity and improving products:		
	• agriculture	115	
	• fisheries	15	
*2.	Promoting industrial competitiveness:	1060	28.2
	(i) removing and reducing barriers	30	
	(ii) new techniques and products for the traditional industries	350	
	(iii) new technologies (including Esprit, biotechnology, telecommunications)	680	
3.	Improving the management of raw materials	80	2.1
*4.	Improving the management of energy resources	1770	47.2
	(i) developing nuclear fission energy	460	
	(ii) controlled thermonuclear fusion	480	
	(iii) developing renewable energy sources	310	
	(iv) rational use of energy	520	
5.	Stepping up development aid	150	4.0
6.	Improving living and working conditions:	385	10.3
	(i) improving safety and protecting health	190	
	(ii) protecting the environment	195	
*7.	Improving the effectiveness of the Community's scientific and technical potential:	85	2.3[2]
	(i) horizontal action	90	2.4
		3750	100.0

[1] At 1982 constant values
[2] Corresponds to 5% by the end of the period
* Direct relevance to MSE

SOURCE: [ECC-5 1987]

about $3.15 billion (in 1984 dollars, based on 1982 ECUs, the monetary unit of the EC). Of the seven program areas under the Framework program, three have general relevance to MSE but the program element on Promoting Industrial Competitiveness ($890 million in 1984 dollars) has direct impact.

In recent years, considerable attention has been focused on cooperative R&D with the direct participation of private firms. Two of the more important are the ESPRIT and BRITE programs, each containing some projects related to materials. Another highly MSE relevant program is EURAM:

- ESPRIT

ESPRIT--European Strategic Program for Research and Development in Information Technology--is perhaps the most successful model of cooperative international R&D on a large scale. It will spend roughly $1.25 billion over a five-year period begun in 1983, but with a second five-year program anticipated. The EC funds 50%, and participating large corporations, the remaining 50%.

The uniqueness of the program lies partly in its size, but also in the active role of very large research-intensive companies in the planning, conduct and coordination of projects. Universities and smaller companies are involved in projects to the greatest extent possible, so that a network is established that transfers know-how throughout all sectors.

Most of the effort covers devices, circuitry, and software. Some of the R&D projects and companies participating on semiconductor materials are:

Submicron CMOS--Bull, STET
SC Materials and IC's--Philips, Plessey, Siemens, Thomson-CSF
GaAs Monolithic IC's--Siemens
Silicon MBE Layers--AEG, GEC

ESPRIT is intended to improve the competitive status of European firms vis-à-vis those of Japan and the U.S. The programs are considered "pre-competitive" by considering technology leading to, but short of, product development.

- BRITE

BRITE--Basic Research in Industrial Technologies for Europe--is for general industry support, not a particular one. The "priority themes" for BRITE are:

(1) Reliability, Wear, and Deterioration
(2) Laser Technology
(3) Joining Technologies
(4) New Testing Methods
(5) CAD/CAM and Mathematical Modelling
(6) Polymers, Composites, Other New Materials, Powder Technology
(7) Membrane Science and Technology
(8) Catalysis and Particle Technology
(9) New Production Technologies Suitable for Products Made From Flexible Materials

Most of these areas contain projects related to materials and/or materials processing. Each project must be proposed and conducted by a team endorsed by two or more member nations. At least one team member must be a corporation. Universities and research institutes may be the other members. Again, 50% of the funding is from the EC, the rest from corporate participants.

Total funding for BRITE from 1985 to 1988 was over $150 million. Thus, annual expenditures are not enormous, but can provide general support, particularly for SME's. The overall objective of BRITE is "to promote technological research which, although not yet related to the development of marketable products or processes, pursues clear-cut industrial objectives."

- EURAM

This program, European Research in Advanced Materials, falls under the Framework element on Promoting Industrial Competitiveness. EURAM had an initial phase 1 budget of 30 million ECU (about $36 million) [Fusfeld 1984-87] for three years, also with a 50-50 division between the EC and the corporate participants. While BRITE is more technological in its orientation, EURAM is concerned more with properties and basic processes and covers metallic materials, engineering ceramics, and composites in its 1986-1989 phase. The budget for this second phase has not been set, but will be at the multi-tens of million dollar level. The program is designed to be several steps removed from competitive products. Another distinction is that EURAM has among its corporate participants some of the largest European corporations. These include Pechiney, ICI, Hoechst, Montedison, and many others.

Outside direct control of the Commission of the European Communities, a number of other European cooperative activities have been initiated. These include:

- Experimental Safety Vehicle (later Research Safety Vehicle)

This has little direct materials R&D, but is a good example of focused non-proprietary cooperative industrial research. It began in 1970, and has as participants, automakers from seven countries. Although it began as an effort to set systems specifications for safety technology, the activity evolved with a data exchange program to include those engineering advances contributing to fuel economy and costs. Conferences are held about once a year, and include representatives from government, professional societies, and insurance companies. This serves to identify problems and suggest approaches.

- Private Ventures

A growing number of situations involve R&D programs among two or three companies, but with a business plan to exploit the results. These are specific joint ventures, dependent on the successful completion of R&D. The biggest are in the semiconductor area, and involve semiconductor materials. One is the so-called Mega-Project between Philips and Siemens. The two firms plus the Dutch and German governments have committed $900 million for the period 1984-1989. The R&D includes a focus on CMOS, SRAM's, and DRAM's. Another is the European Computer Industry Research Center (ECRC) owned by International Computers Ltd. (ICL), Bull, and Siemens. It is in the field of artificial intelligence, and has little or no direct materials R&D, but can influence specifications. It is an example of a private collective research laboratory (in Munich).

- Eureka

This program began as a concept in 1985 for stimulating cooperative R&D among two or more European companies. The name stands for "European Research Coordinating Agency." By 1987, it has emerged as a framework for providing funds from the member European countries to approved projects on an ad hoc basis.
A proposed R&D program is submitted to a Eureka secretariat, which circulates it to all members. It is first approved as an acceptable Eureka project. If the partners are two very large corporations, there may not be any government funds added,

depending on the subject matter. However, a successful Eureka project, when exploited in the form of a new product, will presumably have greater market access throughout Europe.

In many cases, particularly for SME's, there will be funds added. Thus, new developments can be stimulated. Most important, however, the program encourages corporations throughout Europe to consider working together by the project or by the market, without the need to merge or establish a permanent relationship. It is an attempt to bring home the potential of a truly "common market", using the attraction of common resources, possibly augmented by governments.

The total amount of collective materials research conducted in Europe or Japan is modest relative to the in-house corporate research (e.g., Pechiney, ICI, Hoechst) or to the national government R&D programs. The West German government supports approximately $500 million in materials R&D [Fusfeld 1984-86]. It is therefore unrealistic to anticipate revolutionary scientific or technical advances from these collective efforts. They do, however, account for a significant amount of R&D in dispersed industries.

Cooperative R&D overseas serves two functions that are not stressed or pursued successfully in the U.S.:

- there seems to be a reasonably effective use of cooperative programs and facilities by SEM's (small and medium-sized enterprises);
- the EC programs (BRITE and EURAM) provide seed money for exploratory R&D that is not intended to be completed under those programs.

U.S. trade associations have these functions in principle, but do not have the resources or the company traditional procedures to do this adequately.

Thus, cooperative research plays a different role abroad than in the U.S. in that it approximates the vertical integration achieved by large companies. It is not clear that duplicative activities would be equally useful in the U.S. A number of interesting (but constrained) mechanisms are being explored within the U.S., such as in the semiconductor industry, e.g., Semiconductor Research Corporation (SRC), the Microelectronics and Computer Technology Corporation (MCC), and the new Sematech. These are comparable with ESPRIT in that they are expected to provide concepts and knowhow for large research-intensive companies in rapidly-changing fields.

<u>GATT (General Agreement on Tariffs and Trade)</u>--This cooperative agreement was designed to facilitate and promote a system of free trade between its some 90 signatory nations. Unfair trade practices, like product dumping and import/export quotas, fall under GATT. In addition to its other numerous guidelines and rules, GATT also includes an "Agreement on Technical Barriers to Trade," commonly termed the Standards Code. This was made effective January 1, 1980, with the intent to remove standards as a basis for a competitive advantage by one nation over another. The Code requires a consistency between national and international standards and a mechanism for complaint and redress for violations. Commercial standards, those used to buy/sell (trade) manufactured products, devices and systems are considered a must within a nation and a necessity in international markets. MSE is critical to the development of these standards. Although government and universities may be involved, the major funder (by far), performer and recipient of standards developments is industry, and industry alone. No other segment benefits more.

International standardization as a whole represents the world's largest nongovernmental system for voluntary industrial and technical cooperation and collaboration. For comparative purposes, ASTM (previously named the American Society for Testing and Materials), one MSE oriented professional standards organization in the U.S., has a membership of about 30,000 individuals and 2200 organizations. National organizations, like ASTM and ANSI (American National Standards Institute) in the U.S., BSI (British Standards Institute) in the U.K., JISC (Japan Industrial Standards Committee) under MITI in Japan, (DIN Deutsches Institut) in West Germany, AFNOR (l'Association Francaise de Normalisation) in France, and CEN (European Committee for Standardization) in the EC, work through the 89 member-country organization, ISO (International Organization for Standardization) for development and acceptance of international standards.

Overall standards development requires significant R&D and involves both pre-standards and direct standards type research. The latter involves commercialization with the ASTM/ISO interaction, perhaps being a representative activity. An example of pre-competitive, international cooperative research is VAMAS (Versailles Project on Advanced Materials and Standards). This collaborative effort had its origins at a Summit Meeting of the heads of states in 1982 and was set up by the Summit Working Group on Technology, Growth, and Employment. Today it is separately organized through a memorandum of understanding agreed upon by its eight participants: U.S., Canada, Japan, France, West Germany, Italy, the U.K., and the EC. Technical working areas include: Wear Test Methods, Surface Chemical Analysis, Ceramics, Polymer Blends, Polymer Composites, Superconducting and Cryogenic Structural Materials, Bioengineering Materials, Hot Salt Corrosion Resistance, Weld Characteristics, Materials Databanks, Creep Crack Growth, Efficient Test Methods for Polymer Properties, and Low Cycle Fatigue.

In summary, international (as well as national) cooperation is on a large scale and takes many forms. The principal objectives [Fusfeld 1984] of traditional international/national technical agreements impacting industry and world markets generally include the following:

- **Cost Sharing** (e.g., all cooperatives)

- **Standardization** (e.g., ISO, VAMAS)

- **Strengthening Basic Science** (e.g., NATO Science Committee program to increase mobility of scientific personnel; large scale facilities for research-CERN (ECC)).

- **Improving International Political and Economic Relations** (e.g, GATT, OEDC, ECC)

- **Solving Specific International Technical Problems** (e.g., IEA programs)

The specific roles and motivation affecting the decision making-process for participation in international technical agreements, particularly industry, includes numerous arrangements and considerations, some of which include:

- **Nature of Agreement**

  - **Public** (e.g., research associations like EPRI (Electric Power Research Institute) or trade associations like the International Copper Research Association; professional societies like MRS (Materials Research Society, ASTM).

  - **Private** (e.g., MCC (Microelectronics and Computer Corporation)) o **Nature of Company Participation**

- **Money** (e.g., MCC, ECC)

- **People** (e.g., Any joint venture or multi-client activity)

- **Joint Research** (e.g., Large complex programs like the Concorde or Airbus development)

Thus cooperation and competition go hand-in-hand and **"The new patterns of cooperation will determine the new patterns of competition"** (Quote by C.S. Haklisch, New York University, cited in [Fusfeld 1986]).

6. IMPACT OF FOREIGN MATERIALS SCIENCE & TECHNOLOGY ON INDUSTRIAL TECHNOLOGIES

> **"It is the ability to commercialize or operationalize new ideas before its competitors that America is losing its lead, even while it leads in the origination of new ideas."**
>
> **--Harvey Brooks, Harvard University, 1985**

International competition affects various industries in differing ways and at rates and to degrees which depend on such factors as targeting by competitors, captive markets, defense related procurement policies, technical lead time, etc. No single set of parameters can describe the impact of foreign MSE on U.S. industrial technologies. Nor is a comprehensive and exhaustive analysis required to learn those lessons that are to be learned. The approach taken here and elaborated upon below involved consideration of case studies on selected industries, surveys of national S&T (MSE) policies and directions, and a compendium of information gleaned from other sections of this volume. This provided the basis for an assessment of the U.S. competitive status vis-à-vis other nations in the international industrial arena.

6.1 Characteristic Trends

Case Studies Summaries*

In each of four representative industrial sectors, specific materials issues were selected, and the international R&D status examined in some depth. Industrial sectors chosen were Primary metals (steel making); Information/communication (manufacture of

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*Draft case studies from which the summaries were prepared are on file at the Institute for Materials Science and Engineering, National Institute of Standards and Technology (formerly The National Bureau of Standards), Gaithersburg, MD 20899.

VLSI and magnetic storage); Transportation (light weight composites in commercial aircraft, ceramics in heat engines, and engineering plastics); Energy (zeolites as catalysts).

Another way to view the areas chosen for study focuses on the U.S. competitive position: mature industry with significant lost market share (steel making; magnetic storage); areas of current contention in which our competitors are rapidly moving ahead (manufacture of VLSI, ceramic heat engines); areas in which U.S. technology is a clear leader at present, but threats from abroad may be seen (lightweight composites in commercial aircraft, engineering plastics, and zeolites as catalysts).

Several general comments may be made in summary:

- With the exception of steelmaking where the material is the product, MSE is rarely the driver in industrial success. However, in all the areas studied, MSE is critical in areas of changing technology. In all of these critical areas, competition now exists, with our major industrial competitors catching or exceeding our capabilities in the production of materials--i.e., in the development of production technology.

- The principal drivers in these competitive markets are specific industries, not countries, but in some instances (e.g., VLSI, ceramic engines), coordinated government sponsored R&D efforts can have a significant impact on industrial capabilities to compete.

- Technology transfer from one nation to another is often by licensing and international joint ventures, contributing to an inevitable world wide proliferation of technology. In this environment, leadership in science doesn't guarantee leadership in engineering or technology.

Each study has specific lessons to teach:

MANUFACTURING OF STEEL

The U.S. steel industry, despite recent cuts in production, is still a major economic factor, and currently is making headway in sales, due in part to the recent devalued dollar. It is the fourth largest industry in the U.S. employing in excess of 200,000 people. In all countries surveyed (Japan, West Germany, Canada) the steel industry is considered vital, not only for its direct effect on the economy, but also on related industries. The U.S. position is somewhat unique in that it relies more heavily on scrap than its major competitors (and has a large scrap surplus as a "natural" resource), and it lags the world in implementation of continuous casting and thus would benefit most from implementation of a new, more economical casting process. However, while these opportunities for future continued industrial competitiveness are present, the U.S. may be unable to take advantage since the number of researchers and trained technical people in the U.S. relative to production is low compared to other countries. In other countries there is more cooperative and collaborative research, and other countries have identified long term research goals and are funding research while the U.S. has only begun this process. It appears that the best, and possibly the only way long term research can be carried out in the future in the U.S. is on a collaborative basis with the government possibly acting as a catalyst, and partially funding the work.

VLSI

The international market in semiconductor devices is expected to exceed $50 billion by 1990, the great prepondence of which involves Si based devices. It is generally expected that a tenfold decrease of size must take place over the next decade in order to accommodate needs for increased device density and speed with reduced power requirements. The race to develop effective means for surface processing on this 0.1-0.3 µm length scale will play an important role in determining the future configuration of the electronics industry world wide.

One example of the required surface processing technology is the area of optical lithography. Until 1985, U.S. manufacturers dominated the production of equipment in this area, but Japanese companies have now taken the major market share. The recognition of goals at 0.1 µm definition has led to active programs in Japan and Europe to design and market compact synchrotron sources for commercial lithographic application. No comparable developments exist in the U.S., although initiatives centered in DOE (where design expertise resides) and DOD (where strategic VLSI needs are yet to be met) are under serious consideration at the time of this writing. The impact of the newly formed Sematech is yet to be determined.

The success of the Japanese effort in this VLSI processing field is attributed to the organization of their resources towards the technical goals required for commercial success. As a nation, they have made a commitment to develop new processing technologies and to apply them to semiconductor structures conceived for future applications. MITI has identified projects for continued effort that require ten years or more of research and development to bring to the market place. The cooperative system they use integrates the efforts of national laboratories, universities, and most importantly, industries, into an effective and creative organization for developing new processing technology. Critical to achieve such a result is an organization with decision-making capacity and long term stability of resources.

MAGNETIC RECORDING MEDIA

Magnet recording media is a classic example of materials as the enabling technology. The actual value of the magnetic particles in a tape or disk medium may be only 10%, and the medium may be only 10% of the value of drive--yet it is certain that the goal of high density storage cannot be reached without the achievement of high coercivity in particles of ever decreasing and ever more uniform size. Currently, a complex array of decisions by individual companies had led to a U.S. focus on the manufacture of professional electronic equipment with consumer electronics being assembled from equipment that could be made more cheaply in Asia. Consumer media manufacturers are then driven to follow more closely the standards set by the Asian manufacturers. Now, in the last step in this trend, media are increasingly manufactured off shore, diminishing justification for R&D to develop new products which creates a vicious circle causing the demise of the U.S. industry. In the magnetic pigment area, some hope is seen as the re-evaluation of the yen makes American pigment a bargain in Japan, and U.S. companies may see an increasingly favorable environment for sales.

In this area, there is not an announced coordinated government policy to control the direction of Japanese industrial choice--rather the driving force came from individual companies, but their efforts were supported by the government. It is important to note the degree of cooperation between companies in Japan. One example is the creation of a world wide standard for the new 8-mm consumer machines and tape. This standard was created and agreed upon in 12 months. In recent years the Japanese government has played a more direct role in the recording industry through a MITI focus on perpendicular recording including a coordinated research program involving the efforts of 12 universities, 15 industrial laboratories and at least two government research laboratories.

One final point raised in this study could be equally appropriate for other areas of electronic and optical materials. The U.S. is ill-prepared to compete in magnetic technologies. There are only two universities in the U.S. that offer magnetic engineering. The U.S. has only feeble research efforts in magnetooptics and the nation would be completely unprepared should the Japanese revive magnetic bubble technology as they are contemplating, by developing the "Vertical Bloch Line" concept. A stronger academic and research base must be one of the U.S.'s first priorities to regain competitiveness in magnetics.

COMPOSITES IN COMMERCIAL AIRCRAFT

Commercial aircraft will increasingly be constructed from organic matrix composites (OMC) rather than metals, but this conversion will be slowed by safety and financial risk questions. However, it is estimated that by the year 2000 about one-fourth of the structure of commercial aircraft will be composites. Aluminum is the metal most at risk in the shift to composites; however, the impact on the aluminum industry would be only about 1% of total volume. The success of the European consortia produced Airbus and its capture of about 36% of commercial plane production is not associated with composites; however, it broadens the base of users considerably and opens up organic matrix composite suppliers outside the U.S. Somewhat compensating for this is the fact that 30% of Airbus is American. The success of Airbus has added emphasis to the trend (especially in Europe) to form joint efforts. This trend for world-wide manufacturing of commercial aircraft seems to be the way of the future.

The materials manufacturing system supporting OMC has a broad base of U.S.-Europe-Japan corporations. Most of the major suppliers are international corporations which can function effectively across the national borders. The basic technologies appear to be diffused across the free world with no one country having a strong lead. The possibility of establishing a unique scientific advantage in OMC is deemed extremely difficult due to the diffuse nature of both the OMC and commercial aircraft businesses. It is on the engineering questions of design, fabrication, and quality control of composites which the competitive lead will depend. It is in these areas where a coordinated national effort to ensure leadership is required. Barring this, one may readily envision a situation in which increasingly large fractions of U.S. commercial aircraft are manufactured in those countries in which quality assurance, fabrication control, and design capability can be optimized.

CERAMICS IN HEAT ENGINES

A detailed survey of worldwide activities in this field indicates that several countries, including the U.S., Japan, Germany (FRG), Sweden, and the U.K. have been active in this field, and several others are beginning to become active.

Pioneering work had been carried out in this area by the U.K. in the 1960's. Experimentation using some of the processes developed in the U.K. started in the U.S. shortly thereafter, aimed at gas turbine applications. The U.S. work, initially funded by industry, expanded greatly in the 1970's when various government agencies provided more substantial funding. By the late 1970's the U.S. was believed to have a general leadership position in some aspects while Britain led the science and other countries, particularly Germany and Sweden, excelled in specific areas.

Subsequently, Japan adopted the development of structural ceramics for heat engines as a part of its national technological development in ceramics and made huge strides. Currently, Japan appears to have become the world leader in terms of the capability of producing ceramic engine components (and other ceramics) commercially. Some of the components currently in production in Japan are ceramic diesel engine prechambers, and ceramic turbocharger rotors. These are appearing in autos marketed in Japan. Much additional technological and manufacturing progress, however, is needed before ceramic components attain a major role in heat engines. Improvements are needed in terms of reliability and reproducibility, as well as of cost reduction. Indeed, newer analyses of the potential advantages of ceramic engines do not present as bright a near term future as had driven the initial R&D effort.

Japan is sufficiently far ahead, that only a concerted coordinated effort by all sectors in the U.S. would allow this country to compete for a major share of the market. This is beginning to happen, but it is too early to judge the success of these joint ventures, research consortia, etc.

This case study illustrates four major points with regard to general U.S. national R&D policy.

- Continual monitoring of foreign technology is necessary to determine the status of U.S. technology before the commitment of resources for particular targets.

- The second is the insufficient or ineffective government planning and coordination so that resources are utilized efficiently. Wide fluctuations in level of effort on a two to three year cycle are fundamentally and inexorably incompatible with good technological development.

- The third is the insufficient attention to national personnel resources needs which have long time constants.

- The fourth--which encompasses the bulk of the technical (as distinct from policy) component of this case study--is that in the chain of science-engineering technology - manufacturing of ceramics for heat engines, the U.S. and Europe (which started ahead in the same areas) may be competitive in the earlier stages, but both have lost the lead in manufacturing to Japan.

ENGINEERING PLASTICS

As in the case of aircraft, materials substitution is a major trend in automotive manufacture. The inevitability of replacement of the metal auto skin by some form of reinforced plastic is unquestioned; however, the rate of substitution is slowed by several factors, both technical and other. Increasing liability and warranty requirements generate the need for more extensive and expensive test evaluation. The most pressing technical need is the reduction of cure temperature for paints and/or increase of high temperature tolerance by the structural plastics--both factors are required to assure continued utilization of enormous capital investments in paint ovens.

The influences of governments throughout the world on this materials substitution issue have been indirect, through legislated technical requirements--the most notable of which include emissions limits on hydrocarbons, crash worthy bumpers, less hazardous windows, and fuel economy. One thing present in Japan and Europe and missing in the U.S. is formal and visible interlocking of materials producers and users. In some areas, however, U.S. automotive companies appear to recognize the advantages of fewer but more dependable suppliers of higher quality resins, technology and service. This is seen as a beginning of a step in the right direction.

Japan's efforts in this area are roughly on a par with those of the U.S. with limited production models being produced by Nissan with other manufacturers poised and watching Nissan. Wider use of plastic bodies will come with lower resin prices and satisfaction of the on-line paintability requirement. Korea is not developing this technology, but can be expected to obtain it through joint ventures with more technically advanced partners. In France, the U.K., and Italy, the situation is similar to that of the U.S. and Japan.

This study concludes by raising, but not answering some tantalizing questions which are included in "Is there a role for the U.S. government to take in order to enable a U.S. partnership aimed at establishing a national leadership position in this area of technology change?"

CATALYSTS

The subject of zeolites as catalysts was selected as a deliberate counterpoint to the doom-and-gloom character anticipated and found in many of the other case studies. The U.S. has developed and maintained a clear lead in this area, both scientifically and technologically. Zeolite cracking catalysts with sales of about 700 tons per year in the U.S. can be shown to produce a savings in gasoline yield equivalent to over $2 billion a year at current ($20/bbl) fuel costs. The importance of zeolite chemistry and engineering is evidenced by the fact that the number of publications and patents in the field has increased geometrically each year since the 1960's. Research is being done in this field all over the world, but thus far, all commercial processes are based on U.S. inventions and licenses.

As strong as is the U.S. lead in this area, complacency is not justified. Strong competition from abroad (Japan, Germany, France, and the Netherlands) is apparent in areas of science and development of new zeolites. More than one-half of current publications and patents come from abroad. Most zeolite catalyst patents will expire in the late 1980's and early 1990's, and one can expect that many foreign catalyst manufacturers will begin to offer these catalysts, although process patents will continue to be enforced for some time to come. Leadership in this field will require discovery and synthesis of new microporous crystalline materials and development of new applications for them in chemical catalysts, selective absorption, and related fields. There is already ample manufacturing capacity and know-how in Japan, Germany, and in the Netherlands in this field to pose serious threats to the U.S. dominance.

National Surveys

A survey* of the nations studied revealed a consistent picture of each country's national goals, strategies, and implementation tactics in S&T in general, and MSE in particular. Analysis of the survey questionnaire provided the following conclusions:

- There was unanimity among all nations surveyed in identifying the same three areas for emphasis in the years 1976-1986, with expectations of continued emphasis in the following ten years. Materials Science and Engineering, biological (and behavioral) science and computers (information) have been and will increasingly be the central foci of S&T funding in all nations surveyed.

- When the government role in foreign countries is explored, it is evident that the views of industry, universities and government are sought and received; but in the U.S., by contrast with almost all other nations, this input is informal. S&T directions are set by all governments to

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*Section 8.2 provides a summary of questionnaire responses.

assist specific industrial areas. MSE is not so directed in the U.S., while most other nations set MSE directions in a manner intended to target specific industrial market areas. It is particularly noteworthy that in the U.S., there is no official MSE strategy, while in most others surveyed, a specific national plan does exist. We noted parenthetically that the U.K. considered just such a plan (Collyear Plan), and while apparently rejecting it has now begun to adopt elements of that plan (See U.K. profile in Chapter 4.3). Canada has engaged in an extensive study of its MSE funding which may lead to a more comprehensive and coherent plan for MSE. The U.S., while engaged in the comprehensive study of MSE, of which this document is one part, is unlikely to emerge with a national plan.

- There is a universally accepted role of governments in attempting to ensure the coupling of R&D with commercial exploitation of research results. However, the use of government laboratories in this role is found to be common to most nations, with the general lack of such activity in the U.S. a significant difference.

- The availability of adequate trained manpower to carry out the needed MSE is certainly a concern of all nations, but there is a high degree of variability in control of the educational system among the countries surveyed. The extremes in control are the U.S. with its vast decentralized local region dominated higher educational system and Korea in which levels of educational funding are directly tied to the GNP and technical training areas are emphasized as part of the national economic plan. All countries surveyed indicate that emphasis in MSE has increased during 1976-1986 relative to other areas of education, with further emphasis expected in the next ten years.

- Similar to the U.S., MSE is taught academically in a variety of departmental settings in all nations surveyed and that in all countries but Japan and Korea the trend is toward more multidisciplinary MSE. Research in academic departments is similar the world around, with 30-50% of the research of an applied nature while the remainder is basic. Korea is a striking exception, with 80% of the university research identified as applied. There seems to be a general trend toward more applied research at universities although not in Japan (where university/industry links are traditionally not close), Korea (where there could hardly be a more applied activity) and W. Germany, where the more applied work is conveniently carried out in the Fraunhofer Laboratories, only loosely tied to the universities.

- Government policy and funding for MSE education are viewed as marginal to only moderate. This conclusion might be dismissed, since only MSE knowledgeable respondents were polled, but the unanamity amongst representatives of universities, governments and industries, as well as the near unanamity among countries suggest an important issue here. Moderate attention to and funding of education in materials, one of the three targeted areas of S&T by all nations surveyed, may be a strategic oversight of major proportions.

- Techniques for implementing national goals for MSE are similar among foreign nations with centralized program planning and implementation along with targeted S&T and cooperative mechanisms being favored tools.

6.2 Comparative Analysis: U.S. and Foreign MSE/S&T

All nations must engage in international trade at some level as no country has the complete complement of natural and other resources to fully sustain its economy and assure the well being of its populace. As populations grow the necessity for trade increases even more. These are truisms for the larger, more endowed free nations like the U.S., the equally rich countries having state controlled economies such as the U.S.S.R., and particularly for the under or less developed countries where national existence depends upon trade and/or foreign aid. World trade is an absolute mandate. Political systems influence only how and when trade occurs, not whether it will happen.

Competition is the elemental premise upon which world trade is based. Trade flourishes in a free and unencumbered environment with S&T being one root factor to new or expanding markets, and conversely to declining positions. Since a significant fraction of the GNP of industrialized nations stems from manufactured goods, durable products and related services, MSE is a particularly important segment of the S&T system and thus to a nation's competitive posture. While other disciplines, physics, chemistry, or others may have profound effect on multiple industrial/manufacturing market areas, and may be the dominant factor in a single market development, MSE intersects and impacts many industrial areas, alone or in combination with other fields. Thus the health and competitive status of a nation's MSE must be maintained and nurtured through a continuing process of assessment, evaluation and action, as appropriate and needed.

This section presents an analysis of the competitive status of MSE in the U.S. vis-à-vis other nations. Countries specifically covered in the comparative analysis include representative trading partners of the U.S. (Japan, France, U.K., W. Germany, Korea) viewed as having, or might have in the longer term, a competitive advantage in world markets impacted by MSE. China and the U.S.S.R. are not included because their MSE is operative under such a different political system. MSE in Canada, and some N.I.C. nations, like Brazil, Hong Kong, and the like, are typified by covered nations and therefore not individually assessed. The intent of the analysis is to illustrate different MSE systems and the efficacy with which the system works to achieve their respective MSE status, good or bad. Whenever possible the analysis of individual countries is generalized with others to highlight an important facet, trend, problem, etc. Since S&T and MSE are so inter-related, much like a parent-child relationship, a major fraction of the comparison is based on S&T characteristics.

Chart 52, Comparative Analysis: U.S. versus Foreign Competitive Positions, is the result of a very small but meaningful survey. It shows the responses of a small group of U.S. materials industrialists, scientists, and engineers who are intimately familiar with the state of the field abroad. The analysis has been grouped under three headings that influence the U.S. competitive position in materials:

1. **INDUSTRY FACTORS**
2. **TECHNOLOGY FACTORS**
3. **GOVERNMENT FACTORS**

Clearly, such factors are not completely mutually exclusive and, hence, the location of some of the subheadings in the chart is a matter of emphasis judgment. Similarly, the chart represents a snapshot in time--as of 1987--and some of the allocations and trends may (indeed hope they will) change in the near future.

Despite these caveats, the chart contains some messages that are important for government planners, industrial leaders, and those engaged in materials science and engineering.

INDUSTRY FACTORS

Industry factors were analyzed under seven headings:

A. Comparative Advantage in Major Markets
B. Comparative Advantage in MSE
C. Productivity
D. Industry Structure
E. Innovation to Commercialization Capacity
F. Resource Factors
G. Capital and Financial

In the first five of these, with a few exceptions, primarily involving Japan, the U.S. was seen to either be at parity with or to have a clear current advantage over the five comparison countries (Japan, France, Germany, the United Kingdom, and Korea). It was, however, the perception of the experts that in all but two of the sixteen subcategories contained in categories A through E, the U.S. position was static or deteriorating.

In categories F and G, by contrast, the U.S. was seen to have an advantage in only one of the five subcategories and to have a declining or static position in all of them. In sum then, the U.S. can be viewed as being in a disadvantageous position in both resource factors and capital/financial factors influencing our industry capability--and things are worsening. These perceptions are clearly related to some of the subcategories in the Government Factors section (e.g., national debt, trade policy, and government/industry financial incentives). They are, of course, important in themselves both as guides to governmental policy makers and to technologists struggling with strategies that seek to reverse the other declining trends through new capital equipment investment. Will the needed capital be available is a major question.

TECHNOLOGY FACTORS

The picture under the rubric of Technology Factors is more complex. Here, this category was assessed under four subgroupings:

A. MSE R&D Emphasis (by task)
B. R&D Emphasis by Material
C. MSE Resources
D. Interactions and Interfaces

In the first of these the U.S. is seen to have a clear advantage (and to be holding it) in the area of basic research. In application, development and manufacturing, the U.S. is less well off. Japan, our prime current competitor, leads in each of these areas that presage the development of new products and processes. Worse, the U.S. relative position in each of these areas is deteriorating. This phenomenon clearly relates to the very poor competitive position the U.S. has vis-à-vis competitors in the field of Government-Business Relations reported under Government Factors later in the chart. The U.S. has a long tradition of government support for basic research but essentially no tradition in direct support of nondefense industrial technology. These three declining positions should carry a strong message to those in government concerned about our future in the field.

The picture under heading B is less clear. The U.S. currently has advantages in each materials area and a clearly improving position in composites. In the other areas, despite the apparent declining positions, the headings (metals, ceramics, and polymers) are too coarse-grained to reflect some of the more focused strategies in industry and government activity (e.g., rapid solidification, low temperature cements, electronic polymers). Indeed, the same comments are relevant to C-MSE Resources including education, facilities, and funds.

Nonetheless, this perception of a deteriorating position of leadership warrants a continuing watch.

GOVERNMENT FACTORS

Declining or improving positions cannot be rated as either bad or good in the absolute. To be meaningful, they have to be compared to what would be appropriate under the U.S.'s national materials strategy. Unfortunately, under the Government Factors heading, the first three subcategories (Structure/organization, Government Business Relations and Strategy itself) show the U.S. at a significantly, worsening disadvantage with respect to competitors. The first two of these, of course, are contributors to the third. The U.S. has neither the structure nor the relationships that can lead to a national materials strategy that is respected by both business and government. As a result of not having a MSE in place, several questions are open to conjecture, as for instance -- Is our declining position in technology, (e.g., steel) for example, appropriate to a country at our stage of development, or is it a result of a lack of strategic thinking and advanced planning?

Despite the caveat that Chart 52 has no significance as a statistical survey, it has major significance as the combined perception of experts and actors in the field of materials. The portrait it paints is, overall, one of a developed nation which has yet to adopt strategies, structures or mechanisms to defend its declining leadership in the world of materials. The very existence of this report, however, may be a sign that the picture is up for a change.

CHART 52

COMPARATIVE ANALYSIS: U.S. VERSUS FOREIGN COMPETITIVE POSITIONS (1987)

-Symbols-

J - Japan
F - France
G - Germany
UK - United Kingdom
K - Korea

-Trends-

<------ Declining U.S. Position
------> Improving U.S. Position
═══ U.S. Position Not Changing

THE U.S. COMPETITIVE POSITION IS:

COMPETITIVE PROFILE	Disadvantageous		At	Advantageous	
	Major	Minor	Parity	Minor	Major
1. INDUSTRY FACTORS					
A. Comparative Advantage in Major Markets:					
o Aerospace <-----				F	J,G,K,UK
o Motor Vehicles <-----	J		F,G		UK,K
o Electrical/Electronic <------		J		K	G,F,UK
o Instruments ═══				J,G	UK,K,F
o Machinery <-----		J	F,G,UK	K	
o Chemical/Allied Products <-----		K	J,F,G		UK
B. Comparative Advantage in MSE:					
o Metals <-----			J,G,UK	F,K	
o Ceramics <-----		J	G,UK	F	K
o Polymers ═══			UK,G		J,F,K
o Composites ----->			J,G,F		UK,K
C. Productivity					
o Current <-----			J,G	UK	F,K
o Growth Rate <-----	J,K		F,G		UK

CHART 52 (CONTINUED)

THE U.S. COMPETITIVE POSITION IS:

COMPETITIVE PROFILE	Disadvantageous		At Parity	Advantageous	
	Major	Minor		Minor	Major
D. Industry Structure:					
o Integrated ----→			J,F,G	UK	K
o Size (Big, Small, Niche) ═══			J,F,G	UK	K
o Multinational ═══			J,F,G		UK,K
E. Innovation to Commercialization Capacity ←----	J		G	F,K	UK
F. Resource Factors:					
o Labor Costs ←----	K	J	F,G,UK		
o Labor Quality ←----		J,G	F,K	UK	
G. Capital and Financial:					
o Capital Costs ←----	J,K		F,G,UK		
o Long Term R&D Investments ←----	J,K	F,UK	G		
o Financial/banking Environment ═══	J,K	F	G,UK		
2. <u>TECHNOLOGY FACTORS</u>					
A. MSE R&D Emphasis					
o Basic ═══			G	J,F,UK	K
o Applied ←----		J	F,G	UK	K
o Developmental ←----	J		F,G	UK	K
o Manufacturing ←----	J	K	F,G	UK	

CHART 52 (CONTINUED)

THE U.S. COMPETITIVE POSITION IS:

COMPETITIVE PROFILE	Disadvantageous		At	Advantageous	
	Major	Minor	Parity	Minor	Major
B. Materials R&D Emphasis					
o Metals ←----			G,J	UK,F	K
o Ceramics ═══		J	UK,G	F	K
o Polymers ←----			G,UK		J,K,F
o Composites ----→			G,J,F		UK,K
C. MSE Resources					
o Funds					
- Metallurgy ←----			UK	J,F,G	K
- Ceramics ----→		J		F,G,UK	K
- Polymers ═══		G	UK	F	J,K
- Composites ----→		F	J,G		UK,K
- Electronic Matls ←---		J		F,G,UK	K
- Optical Matls ═══			J	F,G,UK	K
o Manpower Education					
- MSE ----→			J	F,G,UK	K
- Metallurgy ←----			G	J,UK	F,K
- Ceramics ----→		J	F,UK	G	K
- Polymers ═══		G		J,F,UK	K
- Composites ----→		F	J,UK	G	K
- Electronic Materials ------→			J,G	F,UK	K
- Optical Materials ------→			J,G	F,UK	K

CHART 52 (CONTINUED)

THE U.S. COMPETITIVE POSITION IS:

COMPETITIVE PROFILE	Disadvantageous		At Parity	Advantageous	
	Major	Minor		Minor	Major
C. MSE Resources (Continued)					
o Facilities & Equip.					
- National/user ═══			F,G,UK	J	K
- Regional/local ←----	J	G	F,UK,K		
o Funds					
- Government (Non-defense) ←----	J,K		G	F,UK	
- Industrial Investment ═══	J,K		F,G	UK	
D. Interactions & Interfaces					
o Cooperation (Science)					
- Inplace Mechanisms ═══		J,F,G UK			K
- Mechanism Utilization ═══		F,G,J	UK		K
o Cooperation(Technology)					
- Inplace Mechanisms ------→	J,G	F,K	UK		
- Mechanism Utilization ------→	J,G	F,K	UK		

CHART 52 (CONTINUED)

THE U.S. COMPETITIVE POSITION IS:

COMPETITIVE PROFILE	Disadvantageous		At Parity	Advantageous	
	Major	Minor		Minor	Major
3. GOVERNMENT FACTORS					
A. National Industrial Policy					
o Structure/organization ←-----	J,K	F	G	UK	
o Government-Business Relations ←----	J,F,G,K		UK		
o Strategy ←----	J,K	F	G		UK
B. Industrial Development					
o Financial Incentives ←-------	J,F,K	G	UK		
o Defense Related Barriers ←----	J,G,K	F	UK		
o Government Services (patents, information, statistics) ═══			J,G, F,UK		K
C. National Factors					
o Exchange Rate ----→		J,G,UK	F,K		
o National Debt ←----	J	G,F,UK		K	
o Employment ═══	J	UK,K	F,G		
o Inflation ----→			J,F,G, UK,K		
o Trade Policy ═══	J,K	F,G	UK		
o Competitive Attitude/ National Prestige ═══	J,K	G	F		UK

7. CONCLUSIONS AND RECOMMENDATIONS

> **"There must be, somewhere, a mechanism for looking at the problem as a whole, for keeping track of changing situations and the interrelation of policies and programs."**
> **--Resources for Freedom, The President's Materials Policy Commission, 1952**

The decline of the U.S. position in industrial world markets vis-à-vis many of our trading partners has taken center stage in the political debate of the late 1980's. Quoting from Global Competition, The New Reality [The Young Commission 1985], "Since 1960 our productivity has been dismal--outstripped by almost all our trading partners." "For this entire century--until 1971, this nation ran a positive balance of trade. Today, our merchandise trade deficit is at record levels." "In industry after industry, U.S. firms are losing market share." As we note in previous sections, the origin of these negative trends are many, but the technological issues - particularly those related to MSE, are paramount to industrial advancement. MSE in the U.S., viewed as an enabling technology, will suffer as the economic and technological bases are diminished and must flourish if the technological base is to do so.

The objective of this study was to examine activities in MSE in other lands, and to identify root differences and similarities. This has been done in the context of the national debate on how to maintain the U.S.'s competitiveness in manufacturing, and the observations, conclusions, and recommendations stated here are inevitably impacted by this context.

Foremost, among the observations, gleaned from the questionnaire sent to national leaders in MSE, and from the reported national plans for science and technology, is the strong commitment to industrial growth by all major nations, stimulated by coordinated R&D in which MSE is a featured element. Indeed, of all industrial areas in which growth is anticipated for the next decade, MSE ranks along with biotechnologies and computers/information as targeted by all nations sampled.

As demonstrated by the case studies, with the exception of materials producing industries, MSE is rarely the driver in industrial advancement, but it is critical in areas of changing technology. In all of these critical areas, competition now exists with the major industrial competitors of the U.S. catching or exceeding our capabilities in the production of many materials and materials systems--i.e., in the development of manufacturing technology. The principal drivers in these competitive moves are specific industrial businesses, not governments, but in the general case (e.g., VLSI and ceramic engines among the reported case studies) coordinated government sponsored R&D efforts can have a significant impact on industrial capabilities to compete. Notable examples from U.S. history illustrates this impact; focused Federal funding on aerospace related R&D, funded by DOD and NASA and carried out in universities, government laboratories, and industry, have been highly influential in the development of a national eminence in commercial aircraft manufacturing. Cooperative mechanisms, fostered by government involvement more and more are being used the world over as a prime vehicle to enhance industrial competitiveness.

The complexity of modern manufacturing has led inevitably to interdependence amongst industries. This trend is on the upswing, taking the form of joint ventures, licensing and outsourcing of manufacturing via long term contractual agreements, and increasingly, cooperation in the long term research and development of technologies for improved manufacturing capability. In Japan, such cooperation is most advanced, mediated by government funding and often carried out in government laboratories in collaboration with industry. In the U.S., the earliest examples of such industrial cooperation in pre-competitive research may be seen in the funding efforts of such industry sponsored research granting organizations as the Electric Power Research Institute (EPRI), the Gas Research Institute (GRI), and the Semiconductor Research Corporation (SRC), in R&D laboratories such as the Microelectronic and Computer Corporation (MCC), and in numerous industry/university centers. Noticeably lacking in the U.S. and found to a greater degree in all countries studied, is a national agency charged with stimulating and assisting industry and, where appropriate, to ensure that cooperative activities are coordinated and that their impact on industrial development is optimized.

The recognition of MSE as a subject for focused national support is common to all nations, but the organizational structure and funding mechanisms are as varied as are the cultures and governments of those nations. There are, however, some important features to be noted in comparing the U.S. with Japan, and to a lesser degree, West Germany (countries which have been enormously successful in recent years in converting innovative concepts into technological advantage): (1) Education has been focused strongly on engineering rather than science (this is changing in Japan as the Japanese recognize that while they must maintain engineering acuity, they must also contribute more to the body of knowledge required for future progress); (2) Coordinated planning of targeted industrial development is stimulated by a government whose policies and expenditures are aimed at fostering the competitiveness of private industries; and (3) National laboratories are specifically charged with service to industry as a significant component in the complex process of transforming innovation to practice and product. These laboratories have almost no counterpart in the U.S., since with the exception of the National Bureau of Standards, U.S. National and Federal laboratories are not charged with the mission of service to the commercial sector.

These observations lead to the following guiding recommendation:

The government of the U.S. must assume a pro-active role in assuring a proper and more favorable environment for technological development by private industry in a cooperative framework involving both the private and public sectors.

This recommendation is consistent with the sentiments and recommendations of The Young Commission. It also leads to several explicit recommendations with particular impact on MSE.

(1) The government should assure the presence of a network of laboratories in which pre-competitive research on materials can be accomplished. This assurance might take one of several forms: further relaxation of regulations and laws inhibiting industrial cooperative research and development; development and funding of new laboratories and/or changing the mission of existing ones by giving them the mandate to support industry where and when appropriate.

(2) The government should recognize the separate paths of technology development characterizing defense and non defense technology, and devote focused attention and allocate financial support of the non defense sector in collaboration with private industry and universities.

(3) The government should acknowledge the role played by MSE as an enabling technology required for the success of other industrial technologies and coordinate the already extensive funding of MSE to achieve maximum impact. Funding should be increased where appropriate to assure development of this important field, and transfer of the technology to private industry. This coordinative role should include, but not be limited to: maintenance of accurate information about MSE markets, R&D funding levels, topical coverage and manpower

allocation in MSE in the U.S., and in major competing nations; ensurance of translation of technical information from those major contributors to new technology including those advanced in commercial applications (Japan, Korea) and those which are not (U.S.S.R., China).

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8.2 Summary Response to Questionnaire on International Cooperation and Competition in the Field of Materials Science and Engineering

This section compiles a summary of majority responses to a questionnaire on national goals, strategies and implementation tactics in S&T in general and MSE in particular. The questionnaire was constructed in an iterative manner, with input from the study committee and from a few science attaches, and selected respondents to earlier versions who were helpful in refining the questions and clarifying their intent. Distribution of the final version was to leading persons in the nations studied knowledgeable about S&T and MSE affairs. The mailing list was compiled from suggestions provided by the NRC-MSE panel members as well as the science attaches of those nations. The list included representatives from government, universities and industry. One hundred and twenty questionnaires were sent to the foreign nations identified; 42 responses were received, several of which represented combined replies for two or more persons. In all, a 40-45% return was achieved. An identical questionnaire was distributed to Panel members and associates (20) for a comparable assessment of U.S. S&T/MSE. Recipients were requested to limit their replies to their nation alone, so that answers are believed to be representative only of that particular country.

The results of the questionnaire are tabulated in the following pages by country, representing a somewhat arbitrary "average" of the opinions expressed by all respondents for that country. Although the questions asked were not constructed in a manner allowing for quantitative assessment of "standard deviation", responses from each given country were so tightly clustered that the results are believed to be significant to within the course grain of the measures used. Appreciation is expressed to the many respondents worldwide, whose careful attention to the requests in filling out this questionnaire have led to these interesting areas of commonality and differences among our several nations.

QUESTIONNAIRE
ON
INTERNATIONAL COOPERATION AND COMPETITION IN THE FIELD OF MATERIALS SCIENCE AND ENGINEERING

ANSWER BY COUNTRY

QUESTION	UK	FRANCE	FRG	EC	JAPAN	KOREA	CHINA	CANADA	US
1A. * **Change in S&T Funding Emphasis between 1976-86 in the field of:**									
a. Astronomical, Atmospheric, Earth & Ocean	-	=	+	=	+	=	=	=	+
b. Biological and Behavioral	+	+	+	+	+	+	+	+	+
c. Social	-	+	=	-	=		+	-	-
d. Physics	=	=	=	=	+	=	=	=	=
e. Chemistry	=	=	=	=	+	=	=	=	=
f. Materials	+	+	+	+	+	+	+	+	+
g. Mathematics	=	=	=	=	=	=	=	=	+
h. Computer	+	+	+	+	+	+	+	+	+

* + increased
- decreased
= no change

ANSWER BY COUNTRY

QUESTION	UK	FRANCE	FRG	EC	JAPAN	KOREA	CHINA	CANADA	US
1B. * **Expected change in S&T funding emphasis between now and 1996 in the field of:**									
a. Astronomical, Atmospheric, Earth & Ocean	=	=	+	+	+	=	+	+	=
b. Biological and Behavioral	=	+	+	+	+	+	+	+	+
c. Social	=	-	=	-	=	+	+	=	=
d. Physics	+	=	=	=	+	+	=	=	+
e. Chemistry	=	=	=	=	+	+	=	=	=
f. Materials	+	+	+	+	+	+	+	+	=
g. Mathematics	=	=	=	=	=	=	=	=	=
h. Computer	+	+	+	+	+	+	+	+	+

* + increase
- decrease
= no change

ANSWER BY COUNTRY

QUESTION	**UK**	**FRANCE**	**FRG**	**EC**	**JAPAN**	**KOREA**	**CHINA**	**CANADA**	**US**
2. ** **Organizations expected to perform R&D in emphasized S&T Areas:**									
a. Astronomical, Atmospheric, Earth & Ocean			G,U	G	G		G,U	G,U	
b. Biological and Behavioral		G,U	G,U,I	U,I	G,U,I	U	G,U	U,I	
c. Social						U	G,U		
d. Physics	U,I				G,U,I	U			G,U
e. Chemistry					I	U			
f. Materials	G,U,I	G,U,I	G,U,I	U,I	G,U,I	G.I	G,I	G,I	
g. Mathematics									
h. Computer	U,I	U,I	I	U,I	G,U,I	G,I	G,U,I	G,U,I	G,U,I

** G = Government Labs
U = University Labs
I = Industrial Labs

	ANSWER BY COUNTRY								
QUESTION	UK	FRANCE	FRG	EC	JAPAN	KOREA	CHINA	CANADA	US
3A. **Govt. Funding is Targeted For:**									
Biotechnology	X	X	X	X	X	X	X	X	X
Advanced Materials	X	X	X	X	X	X	X	X	X
Information Technology	X		X	X	X	X	X	X	X
Transportation				X					
Basic Industries							X		
3B. **Targeted Areas Having MSE Impact Are:**									
Biotechnology				X					
Advanced Materials	X	X	X	X	X	X	X	X	X
Information Technology	X		X	X	X				
Transportation		X		X					
Basic Industries							X		

ANSWER BY COUNTRY

	QUESTION	UK	FRANCE	FRG	EC	JAPAN	KOREA	CHINA	CANADA	US
4A.	**For targeted areas there is a government level mechanism in which the views of industry, universities and govt. are heard and acted upon? Y=Yes; N=No**	Y	Y	Y	Y	Y	Y	Y	Y	Y
4B.	**The mechanism is: (F) formal or (I) informal?**	F	F	F	I	F	I	F	F	I
5A.	**S&T directions are set by government to assist specific industrial market areas? Y=Yes; N=No**	Y	Y	Y	Y	Y	Y	Y	N	Y
5B.	**MSE directions are set by government to assist specific industrial market areas? Y=Yes; N=No**	N	Y	Y	Y	Y	Y	Y	N	N
5C.	**Current Emphasis Areas in Industrial S&T and MSE are:**									
a.	Information/ Communications	X	X	X	X	X	X	X	X	X
b.	Transportation			X	X			X		
c.	Machinery						X			
d.	Chemical & Allied Products		X	X		X		X		
e.	Energy		X	X	X	X		X	X	
f.	Defense	X	X				X	X		X

ANSWER BY COUNTRY

	QUESTION	UK	FRANCE	FRG	EC	JAPAN	KOREA	CHINA	CANADA	US
6A.	**Strategies most applicable to MSE are:**									
	Broad based support					X	X			
	Specialization	X	X	X	X			X	X	X
	Importation of Foreign MSE								X	
6B.	**Specialization or Importation Strategy Applicable to:**									
	Metals			X	X					
	Ceramics			X	X			X		X
	Polymers		X	X	X			X	X	
	Composites	X	X	X	X			X	X	X
	Electronic Materials	X	X	X	X			X	X	X
	Optical Materials	X								

ANSWER BY COUNTRY

QUESTION	UK	FRANCE	FRG	EC	JAPAN	KOREA	CHINA	CANADA	US
7. **For national MSE Strategies:**									
A. **There is a national plan? Y=Yes; N=No**	N	Y	Y	Y	Y	Y	Y	N	N
B. **The period of time MSE programs are planned? (Years)**		3-5	10	3	5-10	5	5		
C. **Participants in the planning include: (1 = highest influence)**									
Government		1	2	1	1	3	1	1	
University		3	2	1	2	2	2	3	
Industry		2	1	1	1	1	3	2	
D. **The implementation of the national MSE plan is structured? Y=Yes; N=No**		Y	Y	N	Y	N	Y		
E. **Implementation includes a combination of government, university and industrial groups? Y=Yes; N=No**		Y	Y		Y		Y		
F. **In order of rank (1=high), the implementation is guided or controlled by:**									
Government		1	1		1		1		
University		3	3		3		3		
Industry		2	2		2		2		

ANSWER BY COUNTRY

	QUESTION	UK		FRANCE		FRG		EC		JAPAN		KOREA		CHINA		CANADA		US	
8A.	In order of rank (1=high) principal funders of (B)Basic and (D)Developmental R&D are:	B	D	B	D	B	D	B	D	B	D	B	D	B	D	B	D	B	D
	Government	1	2	1	2	1	1	1	2	1	2	1	1	1	1	1	2	1	2
	Industry	2	1	3	1	2	1	2	1	2	1	2	2	3	2	3	1	2	1
	University	3	3	3	3	3	2	3	3	2	3	3	3	2	3	2	2	3	3
8B.	In order of rank (1=high) principal performers of (B)Basic and (D)Developmental R&D are:																		
	Government	1	2	2	2	2	2	1	3	3	2	2	2	1	1	2	1	2	2
	Industry	2	1	3	1	2	1	3	1	2	1	3	1	3	1	3	3	3	1
	University	1	3	1	3	1	2	2	3	1	3	1	3	2	2	1	2	1	3

	ANSWER BY COUNTRY								
QUESTION	UK	FRANCE	FRG	EC	JAPAN	KOREA	CHINA	CANADA	US
9A. **The government attempts to ensure the coupling of R&D with commercial exploitation of research results? Y=Yes; N=No**	Y	Y	Y	Y	Y	Y	Y	Y	Y
9B. **The mechanisms for ensuring coupling are:**									
1. Direct funding of R&D at industry	X	X	X	X	X	X	X		X
2. Purchase by govt. of commercial products from govt. sponsored industrial research						X			
3. Joint funding of R&D at industrial labs by government and industry	X	X	X	X	X	X	X		X
4. Joint funding of R&D at university labs by government and industry	X	X	X	X		X			X
5. Joint funding of R&D at government labs by government and industry		X	X	X	X	X			
6. Government funded labs committd to industrial research	X		X	X	X	X	X		
7. Industrial funded labs for cooperative R&D	X			X	X				

ANSWER BY COUNTRY

QUESTION	UK	FRANCE	FRG	EC	JAPAN	KOREA	CHINA	CANADA	US
10A. **Mechanisms in place to ensure cooperation between your country and other countries in MSE R&D are?**									
1. Jointly funded instrumentation projects	X	X	X	X	X				
2. Jointly funded research projects	X	X	X	X	X	X	X	X	X
3. Travel funds provided for people exchanges	X	X	X	X	X	X	X	X	X
4. Membership in international consortium which funds research in MSE (e.g., EC)	X	X	X	X					
5. Membership in volunteer organizations	X			X	X			X	

ANSWER BY COUNTRY

	QUESTION	UK	FRANCE	FRG	EC	JAPAN	KOREA	CHINA	CANADA	US
11A.	There are strategies to assure adequately trained manpower in MSE? Y=Yes; N=No	N	Y	N	Y	N	Y	Y	Y	N
11B.	The required educational levels needed are decided by:									
	Government				X			X		
	Industry									
	Universities									
	Consensus		X				X		X	
11C.	Educational levels are tied to some economic indicator Y=Yes; N=No	N	N	N	N	N	Y	N	N	N
11D.	The indicators are:									
	G = GNP						G			
	O = Other									

	ANSWER BY COUNTRY								
QUESTION	UK	FRANCE	FRG	EC	JAPAN	KOREA	CHINA	CANADA	US
12A. **Emphasis in MSE education from 1976-86 relative to other areas of education has:**									
Increased	X	X	X		X	X	X	X	X
Decreased									
Not Changed									
12B. **MSE education between now and 1996 relative to other areas of education is expected to receive:**									
Increased Emphasis	X	X	X		X	X	X	X	
Decreased Emphasis									
No Change									X

ANSWER BY COUNTRY

	QUESTION	UK	FRANCE	FRG	EC	JAPAN	KOREA	CHINA	CANADA	US
13A.	**MSE Academic departmental settings which are in use include:**									
	Metallurgy	X	X	X	X	X	X	X		X
	Ceramics	X	X	X	X	X	X			X
	Polymers	X	X	X	X	X				X
	Chem. Engineering	X						X		X
	Mech. Engineering	X		X				X		X
	Elec. Engineering	X				X				X
	Multidisciplinary MSE	X	X		X	X	X	X		X
	Chemistry	X	X	X	X	X				X
	Physics	X	X	X		X				X
	Geology									
13B.	**Trend for multidisciplinary MSE is:**									
	Increasing	X	X	X	X	X			X	X
	Decreasing									
	Not Changing						X	X		

ANSWER BY COUNTRY

	QUESTION	UK	FRANCE	FRG	EC	JAPAN	KOREA	CHINA	CANADA	US
14A.	University research in MSE includes both basic and applied work Y=Yes; N=No	Y	Y	Y	Y	Y	Y	Y	Y	Y
14B.	The % of university research which is applied is:	30-50	10-20	30-50	30	30	80	50	30	25
14C.	There is a trend toward more applied research at universities Y=Yes; N=No	Y	Y	N	Y	N	N	Y	Y	Y
15.	The government has a separate program to address MSE educational/training needs Y=Yes; N=No	N	N	N	Y	N	Y	N	N	N
16.	Government policy and funding for MSE education viewed as:									
	High									
	Moderate	X	X	X		X	X	X		X
	Marginal	X							X	

ANSWER BY COUNTRY

	QUESTION	UK	FRANCE	FRG	EC	JAPAN	KOREA	CHINA	CANADA	US
17.	**Techniques for implementing national goals for MSE**									
A.	**Overall MSE program includes:**									
1.	Centralized program planning, coordination and implementation		X	X	X	X	X	X		
2.	Decentralized planning with coordination	X				X			X	X
3.	Increased Govt. funding	X		X	X	X	X	X	X	X
4.	Govt. incentives other than direct funding									
	- trade benefits									
	- tax allowance		X	X	X	X			X	
	- antitrust									
	- favorable legis.				X	X				
	- others									
5.	Targeted R&D Areas	X	X	X	X	X	X	X	X	X
6.	International collaboration	X	X	X	X	X	X	X	X	
7.	Internal collaboration and joint programs between government, industry and university	X	X	X	X	X	X	X	X	X

ANSWER BY COUNTRY

QUESTION	UK	FRANCE	FRG	EC	JAPAN	KOREA	CHINA	CANADA	US
Question #17 Continued									
8. Increased funding of:									
- basic research			X	X	X				
- applied research	X	X	X	X	X		X	X	X
- developmental research			X	X			X		
- manufacturing research			X						
9. Increased education and training		X	X	X	X			X	
10. Establishment of national facilities	X	X	X	X	X		X	X	
11. Others									
B. **MSE educational programs include:**									
1. Broadly based coverage	X	X	X		X	X	X	X	
2. Centralized program planning, coordination and implementation	X							X	X
3. Decentralization program planning, coordination and implementation		X	X		X				
4. Promotion of centers of excellence	X	X	X	X	X	X	X	X	X

ANSWER BY COUNTRY

QUESTION	UK	FRANCE	FRG	EC	JAPAN	KOREA	CHINA	CANADA	US
Question #17 Continued									
5. Curriculum emphasizing special areas					X		X	X	
6. Importation of educators from other countries					X		X	X	
7. Importation of students from other countries									X
8. Increased research and educational facilities at universities			X		X		X		X
9. Increased university student body capacity					X				
10. Increased funding in national budget			X	X	X	X	X		
11. Subsidized training to meet industrial needs				X					
12. Others									
C. **Science and Engineering programs include:**									
1. Increased funding in the national budget			X	X	X				X

ANSWER BY COUNTRY

QUESTION	UK	FRANCE	FRG	EC	JAPAN	KOREA	CHINA	CANADA	US
Question #17 Continued									
2. Increased importation of information							X	X	
3. Participation in international collaboration	X	X	X	X		X	X		
4. Emphasized areas of expected high early pay-off	X								
5. Expanded areas of existing strength	X		X						
6. Support programs to maintain or increase international industrial competition	X	X	X						
7. Others									
D. **Technology is:**									
1. Bought from other countries			X				X		X
2. Government developed					X				
3. Guaranteed govt. support of developments by industry			X		X	X	X		

ANSWER BY COUNTRY

QUESTION	UK	FRANCE	FRG	EC	JAPAN	KOREA	CHINA	CANADA	US
Question #17 Continued									
4. Primarily developed by private industry	X		X		X				X
5. Developed in fields involving local comparative analysis	X		X					X	
6. Emphasized in fields to maintain or increase international competition	X	X	X		X	X			
7. Others									
E. **Materials Technology is:**									
1. Developed through broad-based competencies		X	X		X	X			X
2. Targeted by individual materials classes/types for development	X		X	X	X		X	X	X
3. Bought from other countries							X	X	
4. Others									

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11. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)*

In 1986, the National Research Council (NRC) commissioned a Committee on Materials Science and Engineering (COMMSE) to conduct a comprehensive study of this field, to define its progress, assess needs and opportunities and provide policy guidance at the national level. A Summary Report of COMMSE was published in 1989, and was based primarily on informational inputs generated by five separate panels, each charged to investigate a different aspect of Materials Science and Engineering (MSE). This report documents the results of the individual study conducted by the COMMSE Panel 3 on International Cooperation and Competition in MSE. It deals with many facets of MSE, as practiced in other countries, and in the United States. It surveys national policies and programs for science and technology (S&T) and MSE, elaborates on administrative structures to carry out R&D, and provides comparisons between the United States and the major industrial nations of the world. Much of the content revolves around the theme of industrial competitiveness as influenced by cooperative R&D.

12. KEY WORDS *(Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)*
cooperative R&D; industrial competitiveness; materials science and engineering (MSE); MSE in Canada, China, FRG, France, Korea, Japan, U.K., U.S., U.S.S.R.; national MSE policies and programs;

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