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FOREIGN APPLIED SCIENCES ASSESSMENT CENTER
INTEGRATION REPORT III

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THE SOVIET APPLIED INFORMATION SCIENCES IN A TIME OF CHANGE

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July 1991

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PURPOSE

- The Foreign Applied Sciences Assessment Center (FASAC) is operated for the Federal Government by Science Applications International Corporation (SAIC) to improve U.S. knowledge of foreign applied science and to increase awareness of new foreign technologies with military, economic or political importance. Such knowledge can reduce technological surprise, can support estimates of the consequences of technology transfer, and can provide a background for U.S. research and development decisions.

The Center directs leading U.S. scientists in the preparation of technical assessment reports and provides continuity as a national forum for periodic reviews of foreign science research activities.

REPORTS

Although FASAC examines world applied science, emphasis is placed on research in the Soviet Union. The Center reports on what the Soviets call exploratory research (akin to Department of Defense 6.1 and 6.2 research), which seeks to translate developments in fundamental research into new technology. The Center generally does not report on technology already being incorporated in engineering applications.

In addition to an assessment of the quality and emphasis of foreign research, a Center report provides milestones for monitoring subsequent progress. It also provides elements of a net technical assessment of the balance with U.S. science, without being an out-and-out comparison.

ORGANIZATION

The permanent Center staff includes the Center's Director, two Senior Scientists, a Senior Editor, a Technical Information Specialist, and an Assistant Editor. FASAC panels consist of expert consultants from academia, industry, and government, typically six to eight members per panel.

Each panel assesses the status and potential impacts of foreign applied science in a selected area. Panel members are selected by the following criteria: leading authority in the field; recent "hands-on" experience; knowledge of foreign research; and knowledge of the direction of U.S. research programs.

The panels review broad areas of applied science and then focus on particular activities of interest to their assessment. At intervals, panels are convened to revisit some of the same topics. Periodically, an Integration Report effort draws together the Panel Chairmen, Center staff, SAIC scientists and engineers, and government representatives. Together they produce a comprehensive report that describes the trends in foreign research including pervasive issues, such as instrumentation, which affect research capabilities.

The Director and Senior Scientists help select the topics to be assessed, select the Panel Chairmen, guide and assist in the preparation of panel reports, and write the Integration Report, which provides a comprehensive multidisciplinary assessment of foreign applied science.

FOREIGN APPLIED SCIENCES ASSESSMENT CENTER

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ABSTRACT

The Foreign Applied Sciences Assessment Center (FASAC) conducts reviews of selected areas of foreign basic and applied science by US scientists who are technically expert and active in the fields reviewed. Several of the FASAC assessments of Soviet science have involved various aspects of the information sciences, including enabling technologies and applications, as well as the core information sciences. This report draws upon those FASAC assessment reports, the expert judgment of some of the authors of those reports, and other public sources to characterize the current state of the information sciences in the Soviet Union and the effects of information science capabilities upon other areas of Soviet science and technology. This report also provides estimates of the likely effect of the political and social reforms underway in the Soviet Union on future Soviet progress in the information sciences and, at a more general level, in science and technology.

As in other areas of science, Soviet researchers are better in the theoretical aspects of the information sciences than in the applications. Moreover, the Soviets are unable to match either the quality or quantities of the tools of the applied information sciences that are produced in the West.

Soviet microelectronics capabilities continue to lag the West (and Japan) by several years, and there is no indication that Soviet scientists will be able to compensate for that lag by the development of other, more advanced technologies. The Soviet telecommunications infrastructure remains inadequate to support effective information networks.

Soviet scientists remain unable to produce computers of any size in the desired quantities. Moreover, their most successful computers are generally functional copies of Western designs, and thus Soviet computers lag those in the West of the same age by several years. Moreover, Soviet-manufactured computer hardware continues to have severe reliability problems. Correlated with the lag in hardware is a corresponding Soviet lag in software development.

The consequences of the Soviet shortage of computer capabilities vary with the application area. Computer-controlled experiments are beginning to be

undertaken in some disciplines (for example, tokamak experiments, particle accelerator control). Complex simulation and modeling calculations appear to be limited to those relatively few researchers who have access to very capable computers (often imports from the West). The lack of capable computers is a serious impediment to computer-aided design of very large-scale integrated circuits, while the Soviet microelectronics industry lacks both automated test equipment and automated controls for processing equipment.

Soviet research in robotics and artificial intelligence appears very good in theory, but the level of applied work in these areas is poor. Other areas in which Soviet research and development is severely impeded by lack of access to highly capable computers include computer vision, image processing, and pattern recognition.

The progress of *glasnost* in the Soviet Union is leading to greatly increased freedom of information and freedom of travel, including emigration. While this new freedom should lead to much more effective information transfer, both internally and internationally, a serious "brain drain" from the Soviet Union appears to be in progress.

New and evolving economic policies are creating confusion in Soviet science and technology, though they may make the Soviet research environment more dynamic and flexible in the long run. The decreased emphasis on military power in the Soviet Union is likely to lead to less total funding for Soviet science in the near future.

The decrease in military confrontation with the West is leading to a relaxation of COCOM regulations, and the new economic environment is leading to the establishment of joint ventures between Soviet and foreign firms, as well as forms of Soviet enterprises (notably cooperatives). Although these developments hold the promise of accelerating Soviet progress in acquiring the tools of the applied information sciences, progress is likely to be slower than the Soviets may desire in the near term. The first potential area for improvement is in

wider availability of personal computers. This is likely to have a positive influence in many areas of research, as well as in some industrial applications. However, there are other, more computationally complex high technology areas (such as computer vision) for which these tools would be inadequate.

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FOREWORD

This is the third in a series of Integration Reports (IRs) prepared by the technical staff of the Foreign Applied Sciences Assessment Center (FASAC). This IR is intended to assess the state of the applied information sciences in the Soviet Union today, and to predict what one might expect in the near future. The report draws upon the results of FASAC Technical Assessment Reports (TARs) dealing with various aspects of the information sciences, as well as relevant contemporary information obtained from many sources, including FASAC panelists who were authors of the relevant TARs. The FASAC TARs drawn upon for this IR have dealt with topics ranging from the "enabling technologies" (such as microelectronics) on which the information sciences depend, through the core information sciences (such as computer science), to technical areas in which information science support is important (for example, oceanography, where the tools provided by information science are used to collect and process experimental data and to develop theoretical models). The intent of the report is to identify and illuminate some of the cross-cutting issues in the Soviet development of and use of the applied information sciences. Inevitably, the report addresses, to various levels, related broader issues facing Soviet science, and indeed Soviet society, as a whole. The report does not address all of the historic problems of Soviet science, but rather accents some of the actual and potential developments related to the dramatic changes that are underway in the Soviet Union.

The panelists who contributed to the preparation of this third FASAC IR, along with the titles of their previous TARs, are listed below.

Panelist (Affiliation)	Title(s)
Dr. Jagdish K. Aggarwal (University of Texas, Austin)	<i>Soviet Image Pattern Recognition Research</i>
Dr. Harley Balzer (Georgetown University)	<i>Soviet Science and Technology Education Research</i>
Dr. Michael Conrad (Wayne State University)	<i>Soviet Molecular Electronics Research</i>

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Soviet Computer Science Research

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Dr. Robert Jameson
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*Soviet Exoatmospheric Neutral Particle
Beam Research*

Dr. Oscar S. Rothaus
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Soviet Applied Discrete Mathematics

Dr. Harry Sello
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*Recent Soviet Microelectronics Research on
III-V Compound Semiconductors*

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System Software for Soviet Computers

CHAPTER I

INTRODUCTION AND SUMMARY OF PRINCIPAL FINDINGS

A. THE INFORMATION SOCIETY

This report focuses primarily on the status of the information sciences in the Soviet Union and the effects of that status on Soviet science and technology in general. There is an inevitable interaction between the health of the science and technology enterprise in the Soviet Union and the broader issue of the health of Soviet society. Soviet Communist Party spokesmen have for more than two decades talked of the "scientific-technical revolution" to describe the situation in which science is creating the opportunity for rapid change in the technological basis of a country's economy. (Early on, much of the discussion was wrapped up with assertions that the technology would be put to better use by a Marxist society.)

The "information sciences" to be considered in this report are broadly those that can be applied in support of organizing, storing, and disseminating information. This definition includes research in support of computers and communications. Computer development is so rapid that it is given the most attention.

Much of the more recent Soviet discussion of the scientific-technical revolution has centered on the impact of the various components of information processing technology on the Soviet economy, but the context now is more in terms of the serious problems in catching up with the West. Gorbachev, already in 1985, expressed the importance of microelectronics, computers, and the information industry in general to Soviet economic progress (see discussion in Dobson, 1988).

Despite the expressed importance of the information sciences, Soviet researchers have had considerable difficulty in making progress in the key information technologies, as will be discussed later in this report. There are real questions as to whether a Soviet centrally planned system can ever provide a fertile ground for developments in such rapidly moving fields as computer hardware and software. Also, many social and political factors that are implicit to the

tradition of central control of information in Soviet society are clearly antithetical to the information society as it is understood in the West.

The end of repression that appears to have come to Soviet citizens with *glasnost* has unleashed strong expression of popular discontent. Along with strong condemnation of the leadership for the poor standard of living relative to the West have come strikes, ethnic strife, and even calls for secession of republics from the Soviet Union. The Soviet central leadership has attempted to respond to the discontent with structural changes, some quite dramatic, but generally not as radical as desired by many. The political situation is nearly chaotic, and how it will all play out is anybody's guess. Soviet information science and technology cannot be considered in a vacuum, but this paper will not address the broad political and social themes in any depth, but will consider the potential effects of the political process on Soviet science and technology. As of this time (June 1991), central planning appears to be continuing, though mixed with some tentative attempts at limited free enterprise, while information control has suffered great setbacks but not total defeat. As will be discussed below, the proclaimed changes related to the information sciences cannot be considered as accomplished, and the effects of the changes inevitably will be slow in coming.

There is every possibility of further dramatic developments in Soviet society. In view of the importance attached to the scientific-technical revolution and the applications of the information sciences by the Soviet leadership, such changes would likely have (or be intended to have) impact in these areas. However, this paper will deal primarily with the situation as it has evolved up to now, without a lengthy shopping list of possible "options" for further Soviet changes.

B. OVERVIEW OF SOVIET SCIENCE AND TECHNOLOGY

Soviet achievements in both science and technology certainly have been mixed, with results in both areas that must be viewed as disappointing by the Soviet leadership and informed public. In-depth assessments of specific science and technology areas have illuminated relatively isolated examples of outstanding Soviet achievements, comparable or superior to those in the West. An overview of several of these assessments and a discussion of some of the reasons for the spotty results can be found in Bengston et al. (1989).

Some of the areas of Soviet excellence can be explained as due to the high priority afforded them because of military requirements, and sometimes political visibility (for example, the aspects of space science supportive of man in space). Others may be due to a long-standing tradition of scholarship (for example, areas of applied mathematics). Still others are due to the strong influence of prestigious scientists (for example, laser science and technology, because of the influence of Nobel laureates Basov and Prokhorov). These areas of distinction appear to be the exception rather than the rule. Despite the greater manpower generally available in the Soviet Union in almost all areas of science, their work usually lags that of the West.

The reasons for the generally low output of Soviet science have been a matter of considerable interest for Westerners, and a real concern for both Soviet scientists and the leadership. The structure and sociology of both Soviet science and Soviet society at large contain many elements impeding progress. Both external and internal observers appear to agree that a scarcity of material resources is one of the important factors (scarcities are endemic to the Soviet system).

Included among the scarce resources are some of the "information technology" products that we take for granted in the United States such as supercomputers on the high-technology end of the spectrum, and also PCs, printers, telephones, computerized databases, and electronic mail networks, as well as such simple things as copying machines. Information technology products are not the only items in short supply in the Soviet Union: scientists and engineers working with experimental or developmental hardware do not have available to them the infrastructure of vendors of equipment and supplies taken for granted in the West; in fact, they are unlikely to have decent air-conditioned buildings in which to place their equipment.

When we enter into discussions of the effectiveness of the Soviet Union in harvesting the fruits of the scientific-technical revolution for their society, the reasons for failure can most simply be attributed to fundamental problems in the organization of Soviet society. The "system" discourages individuals from tak-

ing risks, and there are always risks of failure in developing products. In general, there can be penalties for failure, and only limited rewards for success.

The task of planning what and how much is to be produced resides in the several industrial Ministries, and the safe course is to plan on producing more of the same, even if the product just ends up in a warehouse. But the Soviet manufacturer usually does not have to worry about competition. He usually has a monopoly and his performance is judged by quantitative output, as dictated by the "plan," rather than qualitative considerations. So why improve the product? The organizational links between R&D establishments and industry are poor, and research scientists and engineers have great difficulty in interesting industry in potential new products. Argumentation about how to improve this situation is clearly a large part of the current ferment in the Soviet Union.

Part of the slow progress in Soviet science as well as technology can be attributed to attitudes: there are many influences on the individual to be conservative and to avoid risks, perhaps because of the perils of living in an unpredictable authoritarian society. Intertwined with this are traditions of bureaucracy and secretiveness, some of which extend back to Tsarist society. In the case of Soviet scientists, there is the added thread of elitism; knowledge is perceived to be important for its own sake, and there is felt to be no reason to put it to practical use. Theoretical knowledge is obviously very important, often because it makes clearer the full range of possible applications. However, some of the Soviet scientists' tendency to disdain applications may be based upon the anticipation of very real difficulties.

In this report, we will focus on the role of the information sciences in the work of Soviet scientists and engineers (thus including at least some consideration of manufacturing as well as designing products), but will inevitably stray into limited consideration of the impact of information technology on Soviet society in general.

C. THE STATE OF THE INFORMATION SCIENCES IN THE SOVIET UNION

As in other areas of science, Soviet researchers are better in the theoretical aspects of the information sciences than in the applications. Moreover, the usual

Soviet difficulty in manufacturing reliable products, especially those incorporating high technology, is a pervasive problem for the equipment required by the applied information sciences. Soviet attempts to produce computers in desired quantities have been essentially unsuccessful in every size from micro- to super-computer. They are very slowly improving a grossly inadequate internal telephone system. In both cases, substantial improvement will require large-scale importation of equipment built in the West (or Far East) or establishment of Western-managed joint ventures for production in the Soviet Union (or a combination of the two approaches). There is now a limited number of VAX-11/780 clones available to Academy of Sciences institutes, and imported PCs are becoming more common, though a definite shortage exists.

The Soviet lack of computer hardware has impeded research in support of as well as design and manufacture of more advanced microelectronics. Soviet research in optical processing includes good materials development but has not resulted in the development of good device fabrication techniques. The lack of acceptable components has limited Soviet hardware demonstrations of optical processing technology.

The long-standing lack of state-of-the-art hardware has had an impeding effect even on Soviet progress in the more theoretical aspects of the information sciences. The Soviet scientists' training and innate theoretical capabilities are superb, and in some areas they are pre-eminent. However, they are not likely, in the near future, even to begin to tackle some of the more complex problems in theoretical computer science and artificial intelligence being worked on in the West, since many of the problems are inextricably linked with the use of the much more capable computers available in the West.

D. THE CHANGING CLIMATE FOR SOVIET SCIENCE AND TECHNOLOGY

The Gorbachev era of *glasnost'* (openness) and *perestroyka* (restructuring) has had dramatic effects on the working environment as seen by Soviet scientists and engineers. In capsule form, these effects include:

- **Replacement of aging institute directors and academicians.** This development may lead to an improvement in the intellectual climate and research agenda for Soviet science.
- **Internal openness (*glasnost*).** There has been a dramatic relaxation in censorship. This is also bound to lead to an improved intellectual climate and more efficient transfer of knowledge within the Soviet Union.
- **International openness.** This change is illustrated by the sharp increase in travel by Soviet scientists to the West (particularly Western Europe). This is certain to result in more rapid assimilation of ideas from the non-communist world.
- **Easier emigration.** This is likely to result in a "brain drain," at least in the short run. Minority scientists fearing persecution are the most highly motivated to emigrate, but others also will leave if they despair of a significant improvement in both the research and "human" environment, or are attracted by opportunities in the West.
- **"Self-financing" of institutes.** This step is likely to have the short term effect of disrupting the ongoing activities of the institutes. In the long run, it might have the beneficial effect of bringing institute activities more in line with societal needs. At present, the effect is primarily one of confusion.
- **Project financing.** If extensively implemented, this will break the iron grip of the directors on the activities within their institutes. This is bound to eliminate some good activities along with the bad, but could be helpful for the strength of Soviet science in the long run.
- **Defense industry conversion and decreased military funding.** This is likely to lead to less total funding for science in the Soviet Union, unless extraordinary efforts are made to maintain R&D competitiveness with the West.

- **Cooperatives.** These new small organizations may provide an opportunity for competent, ambitious individuals. They may be able to fill some niches in the technical infrastructure, although the overall result of this new option plus the general atmosphere of less dogma in the social sciences and humanities may be to make the conventional scientific career less attractive to Soviet youth.

E. PROBABLE FUTURE DEVELOPMENTS

Although the Soviet Union allegedly has placed high priority on the production of computers since at least the early 1980s, success has not been forthcoming. The most recent restructuring has not attacked the core of the problem: the failure of the would-be manufacturers in the industrial ministries to produce the designs of the Academy scientists. The industrial ministries naturally suffer from the familiar "not-invented-here" syndrome, but they also have no motivation, financial or other, to adopt new designs produced by Academy scientists.

The loosening of COCOM regulations and the increased competition in the Western computer industry should make it possible for Soviet scientists to achieve a significant increase in their microcomputer capability by import, augmented by joint venture factories in the Soviet Union in the long run. This process will be slowed because of the Soviet lack of the needed hard currency.

There will be a role for Soviet computer scientists in software joint ventures with groups in the West, but the volume of activity will be insufficient to produce the quantity of foreign exchange needed to import the large volume of PCs required. Other "personal services" cooperatives capable of earning Western money will also arise, such as a service to produce scientific databases. There is also the possibility that a significant number of Soviet computer software specialists will find employment in West European (for example, German) firms.

The improvements in Soviet computer capability, should they occur, would significantly enhance Soviet research abilities in many areas, and also lead to improved industrial process control and quality assurance. PCs by themselves are inadequate, however, to lead to greater Soviet progress in some important

high technology areas, such as pattern recognition and similar areas of artificial intelligence.

CHAPTER II

ENABLING TECHNOLOGIES

A. SUMMARY

In this chapter we discuss the status of the Soviet technology base in areas supportive of the information sciences: silicon microelectronics, the basic building blocks for contemporary digital computers; potential building blocks of future computer concepts, ranging from III-V compounds to "molecular electronics"; and the communications technologies that facilitate information transfer from one location to another.

Soviet research activities are robust in several of these information science and technology areas, but lag those of the West in most cases. However, the results of these research activities have not been transferred effectively into products of the quality or quantity needed.

B. MICROELECTRONICS

There is robust Soviet research in many technical areas supportive of microelectronics development and manufacture (Sello and Kirkpatrick, 1988). For example, Soviet research on X-ray lithography (potentially important for use in producing integrated circuit [IC] devices with sub-micron feature sizes) appears generally first-rate. Soviet researchers appear to have a thorough understanding of both the X-ray sources and also the resists and masks. A pilot line was claimed to be in operation in 1984 at the Nuclear Physics Institute in Novosibirsk (Skrinskiy, 1984). However, there is no information available as to the integrated circuit device dimensions attained in production (or the precise nature of the devices being produced).

While Soviet scientists have good knowledge of X-ray lithography, the status of their equipment for optical and E-beam lithographies (the dominant IC manufacturing technologies outside the Soviet Union) is not evident from the technical literature.

Soviet scientists are known to be self-critical about the low quality and productivity of their microelectronics production equipment in general (for example, Kondalev and Khomenko, 1989), and Soviet computer designers associated with the Academy complain about the inability of the Ministries to produce computers to their design specifications. The Soviet Union appears to have inadequate, non-automated test equipment in their IC production facilities, and it also lacks computers for process control.

The poor quality control in Soviet manufacture of computer chips is indicated by estimates of 25 to 50 percent bad chips in a typical DRAM shipment (Langa, 1991). It is also common for Soviet microprocessor chips to be shipped with a list of defects: the instructions the chip will not perform.

The Soviet Union clearly lags the West in the development and use of computer-aided design (CAD) techniques for microelectronics. This is one of several areas in which the Soviet lack of computer capabilities impedes the development of microelectronics, further slowing the Soviet advance in computers and other information processing equipment.

In the West, pre-production modeling and simulation of computer chip designs is performed on high-performance supercomputers; we know of no such activity in the Soviet Union. The Soviet Union does not seem to have implemented the use of computers for process control in microelectronics manufacturing; in this case, access to machines equivalent to the IBM AT would be adequate. On the other hand, CAD could best be done on graphics workstations. There is no indication in the S&T literature that the Soviet Union has graphics workstations, though there are reports that Sun 3/60 clones are being assembled at the ZIL plant (with 68020 clones imported from Southeast Asia). Nevertheless, all indications lead one to believe that there is a distinct lack of graphics and display equipment in general.

The computer chips produced in the Soviet Union may be based as much on Western technology as on indigenous Soviet developments. In any case, there appears to be a five- to seven-year delay between the introduction of a computer chip in the United States and the introduction of a Soviet equivalent. This is illustrated in the comparison of microprocessor chips in Table II.1. The table also

lists East German chips (there has been a significant contribution from East Germany and other Council for Mutual Economic Assistance [CEMA] countries to various facets of Soviet computer development and manufacture). The Soviet microelectronics production capability in 1989 appeared to be at the 64 K DRAM and 16-bit microprocessor level. There are reports of substantially better capabilities in (former) East Germany: the VEB Carl Zeiss combine in Jena has reported development of a 1-Mb DRAM, and is producing an automatic optical wafer stepper for its quantity production (*Neues Deutschland*, East Berlin, 12 June 1989). The impact of this capability on the Soviet Union is uncertain in view of the unification of Germany.

Table II.1
EAST-WEST CHIP COMPARISON

US		Soviet/East German Equivalent	
Name	Year of Appearance	Name	Year of Appearance
INTEL 4004 OR Z-80	1971-72	U808 (GDR)	1978
INTEL 8080	1973-74	K580	1978-79
AM2900 Series	1975	K1804	1982-83
ZILOG Z8000	1978-79	U8000 (GDR)	1983-84
INTEL 8086/88	1978-79	K1810	1983-84
INTEL 80286	1982-83	? (GDR)	1989(?)
INTEL 80386	1985-86	No equivalent yet seen	

Source: National Research Council (Goodman et al., 1988)

Soviet research on the fabrication and characterization of III-V semiconductors has long appeared to be oriented toward fundamental physical understanding and not particularly motivated by device considerations. In fact, there is no announced Soviet effort, short-term or long-term, to manufacture GaAs integrated circuits. Soviet scientists are active in laboratory-scale preparation of GaAs (or GaAlAs) discrete devices, such as field effect transistor structures, but there is

no indication of Soviet processes in the manufacture of either discrete GaAs devices or GaAs ICs. However, the Soviet efforts in crystal growth technology have become more competitive with Western work in the last few years, and Soviet and East European institutes have been approaching US and West European distributors offering crystal samples and inquiring about possible sales of these materials in the West.

C. OPTOELECTRONICS AND OPTICAL PROCESSING

Optoelectronics and optical processing are viewed by some experts as potential means for the Soviets to overcome some of the limitations imposed by their lag in microelectronics. Optoelectronics deals with electronic devices for emitting, transmitting, modulating, and sensing light, while optical processing involves manipulation and transmission of information by optical means, including but not restricted to optoelectronic devices.

There is a significant Soviet research effort in optoelectronics which could be directed toward computers and other information systems (for example, communications networks). An intriguing aspect of the Soviet literature is the persistent discussion of the concept of all-optical computers. This discussion carries some weight because it appears to have originated with N. G. Basov, the Nobel Prize winner who was director of the Lebedev Physics Institute for more than a decade. In particular, Basov has made much of the notion of control operator optical elements as a means of producing massively parallel computer architectures. However, the Soviet research hardware in general involves only individual components, such as spatial light modulators (SLMs), and there is no indication that there is a credible Soviet program to develop an all-optical computer in the near-term.

Soviet research on optical components is robust. Their efforts in SLMs are particularly vigorous, with development groups active at the Lebedev Physics Institute, the Ioffe Physical Technical Institute, and elsewhere (Klinger et al., 1989). They also appear to have analog optical signal processors (comparable to those originated earlier in the United States, and described in the published Western literature in the early 1970s) for their synthetic aperture radars (Held et al., 1990).

Through at least the mid-1980s, there was a strong Soviet program in holographic memories, an area in which there has been little US work since the 1970s. Holographic memories are candidates for large volume, relatively slow access storage. In the West, the dominant new technology being developed for this application is the optical disk. While there is Soviet work in the material technologies supportive of optical disk development, this work is far behind that of the West and Japan.

In addition, there is significant Soviet research in LEDs and semiconductor diode lasers and also optical fibers. This could be useful in future optical computers as well as components of local area computer networks or telephone and other data transmission lines. The Soviet basic work in semiconductor diode lasers has been creative and of high quality, but practical devices lag similar Western products by three to six years (VanderLugt et al., 1991). Soviet researchers have been attempting to produce optical fibers in large quantities for communications networks, but have had difficulties in quality control. A Soviet newspaper article (Panasenکو, 1989) states that there are 860 kilometers of installed fiber-optic communications lines in the Soviet Union (as compared to 1.5 million kilometers in the United States).

Soviet capabilities in devices and systems for optical processing are limited by at least three factors. The first is inadequate fabrication techniques for optical devices such as spatial light modulators, laser diodes, and photodetector elements. The second is a lack of computer hardware and software for the design of optical systems. Thirdly, since most optically implemented processing functions still require interfacing into a larger system with microelectronics, Soviet shortfalls in very large scale integration (VLSI) electronic circuitry impact the capability to produce effective optical processing systems. The Soviet Union apparently is well aware of these shortcomings.

D. MOLECULAR ELECTRONICS

Molecular electronics must be considered a new field of research, though the term molecular electronics predates the transistor. Molecular electronics is a family of potentially powerful emerging technologies in which engineered single

molecules or molecular aggregates play a central role in performing a computing, sensing, or measurement function.

In the late 1980s, molecular electronics research activity intensified significantly in all major countries engaged in development of high technology, including the Soviet Union. In conjunction with a number of other CEMA countries, the Soviet Union has developed well-organized research programs in the related areas of molecular electronics, molecular computing, biocomputing, and biomolecular information processing. Some of these programs are at the idea stage, others involve study of basic biomolecular processes, and a few are tailored to eventual specific applications in molecular electronics.

The roots of molecular electronics research are somewhat different in the Soviet Union than in the United States. Investigators in the United States largely have been motivated by a desire to overcome limitations imposed by the logical complexity of conventional computation and by the physical limits on the performance of conventional electronics. These considerations also motivate Soviet researchers, but Soviet weakness in conventional integrated circuit technology has been at least as important. Soviet researchers have attracted support based upon the hope that molecular electronics ultimately will allow the Soviet Union to "leapfrog" its present limitations in conventional microelectronics.

Molecular electronics research is vigorous in the Soviet Union, and Soviet researchers have had some notable successes. Certain relevant areas of biophysics and physics research are particularly strong. Scientists at the Pushchino Biological Physics Institute have built prototypes of state-of-the-art molecular optoelectronic memory storage and retrieval systems based on membrane preparations containing the light-transducing molecule bacteriorhodopsin. The proprietary organic photochromic materials these developers used are promising potential substrates for advanced non-photographic holographic information storage. Biophysicists at Pushchino have also carried out notable experimental investigations of molecular mechanisms in biological neurons, pertinent to understanding of information processing in the brain. A joint development effort involving the Soviet Union and East Germany has produced a unique prototype analog system for extraction of features from images, based on self-excitable (autowave) chemical reaction processes.

Separation of molecular electronics from neurocomputing and from the study of information processing in biological systems impedes progress in the Soviet Union; pressure for premature technological realizations is also likely to have negative effects. Although the vast majority of Soviet molecular electronics research is basic rather than applied, the goal of leapfrogging conventional integrated circuit technology has a strong influence. Work on electron transfer systems, molecular monoelectronics, organic switches, self-assembly, and soliton signal transfer are all strongly colored by this goal, which may be inhibiting the most effective scientific and technological exploitation of the model systems being studied.

The main architectural paradigm pursued in the Soviet Union is the classic sequential programmable digital (von Neumann) architecture used in present computers, even though the model systems studied may be better adapted to implementing alternative, non-von Neumann architectures (such as special purpose parallel, neural, analog, or hybrid designs). Organic materials are nowhere close to being competitive with silicon in conventional architectures at this point in time. Most likely, such materials will demonstrate any competitive advantage they enjoy sooner in one or more of the alternative architectures.

The competitiveness of molecular electronic materials (in any architecture) strongly depends on the technological infrastructure potentially available for implementation and production. Pertinent technologies include recombinant DNA and protein engineering, self-assembly, enzyme immobilization, Langmuir-Blodgett films, bioreactors, biosensors, applied molecular evolution, computer technology, and robotics. Several excellent protein crystallography and genetic engineering groups are active in the Soviet Union, but they are handicapped by a lack of access to the high-performance protein engineering workstations that have recently multiplied the productivity of competing protein engineering groups working in the United States, Japan, and Western Europe. Soviet biotechnology should be able to use imports to help them advance more rapidly, especially as the basic technologies required for protein engineering become standardized and commercially available (as is currently happening). In assimilating this foreign technology, Soviet scientists will be able to draw upon

an excellent tradition of (non-computational) theoretical research on protein folding, structure, and stability.

Soviet weakness in conventional electronic computer technology is a major disadvantage in molecular electronics research and development because computer modeling and robotics are critically important tools in this field. Soviet molecular electronics research has some notable strengths, but the Soviets have far to go before this field makes important contributions to remedying their weakness in conventional microelectronics and computer technology. No leap-frogging is imminent.

E. COMMUNICATIONS

Use of communications technology is essential for many applications of advanced information sciences. Examples include rapid remote access to databases, timely dissemination of geophysical measurements, and electronic mail transfer, as well as the remote use of central computing facilities. The PC and modem for connection to external sources (and depositories) of data are a pervasive feature of the information society in the United States and Japan, and are supported by high-quality, highly reliable communications links.

There is Soviet research in a variety of areas related to communications, but their efforts in equipment development and manufacture appear grossly inadequate to the need (except possibly within the military services). The most obvious example is the Soviet telephone system.

The Soviet national telephone system continues to significantly hinder data communications in general. Establishing connections in the switched telephone network takes a long time; there is a significant probability of a wrong number, connections are easily broken, and lines are often unavailable. The Soviet telephone system is a serious impediment even to voice communications. Satisfactory transfer of digital information requires higher quality and reliability than voice (or compensating redundancy in transmission, with attendant penalties in transfer rates). The Soviet Union is well aware of the deficiencies in its telecommunications, and is struggling (though not all that effectively) to upgrade.

The Soviet telephone system suffers from the pervasive inefficiency of Soviet industrial production. Incompatibilities have continued among communications equipment made by the several Ministries involved. As with computers, it has been impossible to enforce standardization of the peripheral equipment for communications systems, and shortages are commonplace. For example, an article in *Pravda* (13 November 1989) ridicules the proposed launching of an 18-ton communications satellite into synchronous orbit when there is not even an adequate supply of handsets and telephone wire.

Despite much Soviet talk over the years and recently about the urgency of improvement of telephone service for the public, the rate of advance is still modest. Only a small percentage of rural or urban households are added to the phone network per year, as illustrated in Table II.2.

<p>Table II.2 HOUSEHOLD TELEPHONE SERVICE</p>		
	1985	1989
Urban	23%	~ 30%
Rural	7%	10-12%

It is estimated (Panassenko, 1989) that there are about 12 telephone sets per 100 inhabitants of the Soviet Union, while the comparable ratio is about 90 per 100 for the United States. Because of the limitations of the general purpose telephone system, a separate dedicated network for data transmission has been set up. Designated PD-200, it has about 130 main switching nodes, but initially had a capability of transmitting only 200 bits/sec. It is being upgraded to 1,200 to 2,400 bits/sec (McHenry, 1988). There are also (expensive) leased lines capable of 2,400 bits/sec or sometimes better. Meanwhile, there are ambitious plans for the installation of a digital network eventually supporting bit rates of up to

19,200/sec (Campbell, 1987), but even today most installed Soviet telephone switches are electromechanical.

Installation of fiber-optic cable, as was first done on a limited local basis in Moscow in 1984, and more recently in Leningrad (Berlin and Brisker, 1988), could be useful for local area networks, but improvement of the Soviet long-distance communications infrastructure will be a Herculean task. A fiber-optic link between Moscow and Leningrad has been in the planning stage since at least 1986 (Krupnov, 1987). There have also been newspaper reports that both US West and the British firm Cable & Wireless have been negotiating (separately) with the Soviet Union on the installation of a transcontinental fiber-optic line along the route of the Trans-Siberian Railroad; at last report, the US and UK governments have denied export licenses to both firms.

The most logical way to upgrade the antiquated Soviet telephone network would include importing switching centers and a large amount of other equipment from the West. Many discussions and negotiations are known to have taken place between Soviet officials and Western phone equipment suppliers about turnkey central offices and phone equipment plants; but not much has come from these discussions, with the possible recent exception of Alcatel signing an agreement that could eventually provide approximately \$1 billion in telecommunications equipment to the Soviet Union.

The Alcatel agreement (*Financial Times*, 6 March 1989) would involve an initial importation of 250,000 lines of their Bell Telephone Manufacturing (BTM) subsidiary System 12 digital exchanges; then, BTM would set up a joint venture with a Soviet company to build an assembly plant near Leningrad to produce 1 to 1.5 million lines per year. The Belgian government has asked COCOM for approval of the joint venture arrangement, but it is still uncertain whether the deal will be consummated.

The supporting software for Soviet data transmission networks and communication facilities remains more than a decade behind that of the United States (Wegner et al., 1989). The Soviet centrally planned system has resulted in such peculiarities as the non-availability in 1985 of any software to support the YeS-8561 remote entry terminal that had been introduced in the mid-1970s,

though more recently Soviet telecommunications software has been developed to address such problems by design (for example, modularity and ease of modification).

The validity of the theory that the Soviet government is reluctant to have a good telecommunications system (because information control would be harder if there were better telecommunications) was probably always exaggerated in the West, at least as it applies to *internal* communications. Internationally, there is no (and, in the foreseeable future, there is not likely to be) direct-dial-out telephone service (a major problem is how to compensate the foreign carriers!), and direct dial-in has only recently (late 1989) been possible, and only to Moscow. The Joint Institute for Nuclear Research in Dubna has access to a 2,400 bits/sec link to CERN in Geneva through the All-Union Scientific Research Institute for Applied Automatic Systems (VNIIPAS). VNIIPAS appears to have been set up to be the telecommunications "window" to Western databases and Western scientists (McHenry, 1988).

Regarding Soviet telecommunications efforts specific to trying to assist science and technology research activities, Akademset' (the Academy of Sciences of the Soviet Union's analog to ARPANet) is a basketcase. To the extent that it functions at all, it and the underlying host hardware are so unreliable that they are not a useful tool for communication or for remote access to data or computing resources. While the use of electronic mail by scientific workers is growing, it is still considered a curiosity. Potential users display unexpectedly little interest, though they are often pressed by Western collaborators to try the idea. With the new "self-financing," some institutes are failing to maintain their links.

As an example of inefficient Soviet use of electronic mail, a Digital Equipment Corporation VAX computer assigned to the International Thermonuclear Engineering Reactor design activity at Garching, West Germany, can send electronic mail to VNIIPAS in Moscow via Vienna, Austria (International Institute for Applied System Analysis). A serious shortcoming of the system is the necessity of notifying the recipient to pick up a hard copy of the mail at VNIIPAS, since messages are not forwarded (electronically or otherwise) to other locations!

It comes as no surprise that the Soviet "civil" satellite programs are limited in space-to-ground communications capabilities. For example, the Fragment infrared satellite system has a 5.6 Mbit/sec transmit capability, more than an order of magnitude less than the US Landsat. On the other hand, the direct (though low bandwidth) transmission of side-looking radar images from the *Kosmos-1500* class satellites to many users throughout the Soviet Union (including those wishing to navigate the often-frozen northern waters) must be viewed as a successful practical application of information technology. However, this is a use involving a small, select number of recipients, rather than a mass market. The Soviet Union has launched hundreds of communications satellites since the early 1960s (and the satellites generally fail after two to three years in orbit). The first priority has gone to the military. The major civil use has been broadcast of the Soviet central television programs, and the satellites have also been used to distribute audio broadcasts and newspaper images. Nevertheless, it is estimated that about half the long-distance telephone traffic in the Soviet Union is via satellite. The total transmission rate of one of the current Soviet civil communications satellites is typically 40 Mbits/sec, usually spread across the several uses.

Although discussion is currently underway concerning a joint venture to install a fiber-optic cable across the Soviet Union, the great distances involved suggest that satellite communications may make more sense economically, until the traffic volume gets very large. The apparent low data transmission rates of present Soviet satellites imply some limitations to this approach.

CHAPTER III

COMPUTER HARDWARE DEVELOPMENT AND AVAILABILITY

A. SUMMARY

Despite pronouncements by Soviet leaders that have identified computer manufacturing as a top national priority for at least the past two decades, the Soviet Union has been unable to develop a computer industry that is adequate, in either technical or production capability, to meet national needs for computer hardware. Because COCOM controls (and scarcity of hard currency reserves) have effectively blocked computer imports until the late 1980s, the shortcomings of the domestic industry have left the Soviet Union with inadequate computer hardware to support development of the information sciences, other areas of science and technology that depend heavily on computational capability, and (in a vicious circle) next-generation computer design and manufacturing activities.

Shortfalls in the last area—and, in general, Soviet manufacturing capability when high quality and high volume are required—have caused and are likely to continue to cause the Soviet computer industry to fall further and further behind the rest of the industrialized world. Large-scale imports of computer hardware will probably be necessary to break the cycle and allow the computer industry (and those other segments of Soviet society that are now severely impeded by computer hardware limitations) a decent chance to catch up. Although the COCOM restrictions have been lifted for the lower-end machines, hard currency remains in short supply in the Soviet Union, and first priority appears to be going to imports of consumer products.

This chapter outlines the present situation in Soviet computer hardware technology. It emphasizes the capabilities of products available for delivery to users (including the rest of the Soviet information sciences community). Our discussion of prototypes produced at the frontiers of laboratory research is limited by a paucity of reliable information about these prototypes and by a history of exaggeration in Soviet reports of their capabilities. Highlight indicators of the current state of Soviet computer hardware capability include:

- At the close of the 1980s, the Soviet Union began serial production (in limited quantities) of 8/16-bit microprocessor chips first introduced there in 1983-1984. These chips are comparable to the Intel 8088 (key component of the first IBM Personal Computer), which was available in quantity in the United States in 1978-1979.
- In 1987, the Soviet Union made the first dozen or two serially produced SM-1700s. These minicomputers perform approximately the same functions as the early 1980s Digital Equipment Corporation VAX-11/780, but their speed and memory capacity are closer to the less capable VAX-11/730. They are functional—not technological—equivalents, based on veteran Soviet central processor chips rather than on new ones especially designed to run the new instruction set efficiently.
- In 1989, the Soviet Union reached a rate of production of 163,000 PCs of all types, including 71,000 8-bit school computers of limited capability. Quality is still a major problem.
- A workhorse of Soviet scientific computing at the end of the 1980s was the BESM-6, a second-generation (transistors-on-boards) scientific mainframe first shipped in 1965. Recently, some scientific users have managed to get time on large institutional general-purpose mainframe computers like the ES-1060, ES-1061, and ES-1065, which became more common in the late 1980s. The latter are similar in capability to the large IBM 370s of the mid to late 1970s.
- Soviet-built computers continue to be plagued with defective and unreliable components, and there is no effective infrastructure for repair.

During the late 1980s, much-needed laboratory minicomputers made in the Soviet Union and Eastern Europe (such as the SM-1420) appeared in significant numbers in scientific research laboratories with high priority and international visibility. Imported personal computers (with varying degrees of capability) have also begun to appear in significant numbers. Some of these have been microcomputers purchased by Soviet scientists (and other tourists) traveling abroad. That

there is still a shortage of PCs in the Soviet Union can be deduced from Soviet newspaper stories about large profits earned by individuals who resell PCs they have managed to import.

Many reorganizations of the Soviet computer industry have taken place over the years, but a substantial improvement in Soviet production of computers has not occurred. The computers are produced in insufficient quantities, lag the world state of the art, and suffer from an unreliability that would be intolerable in the West.

There has been a relaxation of the COCOM regulations governing the allowable capabilities of computers exported to the Soviet Union, so that as of the summer of 1989, PCs up to the level of the IBM AT could be exported by COCOM countries to the Soviet Union without a license. More capable mini- and microcomputers (as well as mainframes) may be exported to the Soviet Union by COCOM members only after approval on a case-by-case basis. For example, Control Data Corporation has asked US government approval for a sale of six Cyber 962 mainframes. These machines would be installed at Soviet nuclear power plants, and Control Data would be required to inspect the Soviet facilities and build in software safeguards to prevent diversion of machine use to military projects.

The Soviet Union is trying to solve some of its computer problems by large-scale importation of PCs or their components (deals being discussed would involve several hundred thousand PCs over a few years, with initial import of completed units, followed by assembly in the Soviet Union in later years). If these imports actually occur, their impact on Soviet society could be profound. However, past experience indicates that most of these deals will get entangled in the problems the Soviet Union has in obtaining hard currency for the purchases (or in arranging for compensating exports). The apparent deterioration of the Soviet civilian economy has put purchases of consumer products (food, cigarettes, etc.) from abroad at the top of the priority list.

B. PROCESSORS AND RAM

Table III.1 summarizes the history and present state of development of Soviet microprocessors. The most advanced Soviet manufacturing effort presently produces CPU chips of the Intel 8088 class, with 8-bit external data paths and 16-bit internal data paths. This relatively low-volume operation produces products comparable to microprocessor chips available in the West in 1979.

Table III.1 SELECTED SOVIET MICROPROCESSORS					
Device	Year of Appearance	Technology	Bus Width (Bits)	Clock Speed (MHz)	Comparable US Device (Year of Appearance)
K-536*		PMOS	8	0.1	INTEL 8008
K-580	1978-79	NMOS	8	2-2.5	INTEL 8080 (1973-74)
K-581*	1978-79	NMOS	16	2.5-3.3	DEC LSI-11
K-586	1984(?)	NMOS	16	2	INTEL 8086 (1978-79)
K-1810	1983-84	NMOS	8/16		INTEL 8088 (1978-79)
* Two-chip processor set.					

Source: Information in this table is extracted from Table III.12 of *Soviet Computer Science Research* (C. Hammer et al., 1984), and Table VI.3 of *Global Trends in Computer Technology...* (Goodman et al., 1988). Those tables were constructed from data in an extensive database on Soviet computer technology maintained by the Management Information Systems Department of the University of Arizona. Literature citations to support the entries may be found in the cited reports.

Soviet factories became able in the late 1980s to maintain medium-volume production of 64-kilobit dynamic random access memory (DRAM) chips, which can now be incorporated into Soviet electronic equipment. Table III.2, which lists Soviet RAM chips available in the late 1980s, indicates that the 64-kilobit DRAMs and possibly 256-kilobit DRAMs can now be designed into Soviet equipment. This represents an advance that will allow Soviet production of more capable computerized equipment than was possible until recently. However, volume production of 256-kilobit DRAMs "this year" has been an unrealized goal of the Soviet electronics industry for the last several years (see Section II.B). This goal is not likely to be realized until late 1991, when advanced computers in the rest of the world are expected to be using 4-megabit memory chips. Of course, the 256-kilobit chips are likely to be available from the Far East.

Table III.2
SOVIET MEMORY DEVICES

Device	Technology	Function	Size
K-565 RU-1A	NMOS	DRAM	4 kb
K-565 RU-1B	NMOS	DRAM	8 kb
K-565 RU-2	NMOS	SRAM	4 kb
K-565 RU-2A	NMOS	SRAM	1 kb
K-565 RU-3A, B	NMOS	DRAM	16 kb
K-565 RU-5	NMOS	DRAM	64 kb
K-565 RU-7*	NMOS	DRAM	256 kb
K-573 RF-1	NMOS	EPROM	8 kb
K-573 RF-2	NMOS	EPROM	16 kb
K-573 RF-5	NMOS	EPROM	16 kb
K-573 RF-6	NMOS	EPROM	64 kb
K-573 RF-7*	NMOS	EPROM	256 kb
KM-537 RIJ-1	CMOS	RAM	1 kb
K-556 RT-5	TTL	PROM	4 kb
K-1801 RYe-1-00	NMOS	ROM	64 kb
KM-132 RU-10	NMOS	SRAM	64 kb
K-1809 RU-1	NMOS	SRAM	16 kb

* Limited mention, not yet in volume production.

Source: Much of the information in this table is extracted from Table VI.4 of *Global Trends in Computer Technology...* (Goodman et al., 1988). That table was constructed from data in an extensive database on Soviet computer technology maintained by the Management Information Systems Department of the University of Arizona. Literature citations to support the entries may be found in the cited report.

The Mars-T project, part of the Soviet Union's most visible effort to research and develop advanced processors and architectures, has recently designed the 32-bit Kronos processor. Early descriptions of this processor indicated a processing speed goal of 4 MIPS; later reports mention 1.5 MIPS. The instruction set of the processor has been described in some reports as minimal, similar to the reduced instruction set computer (RISC) concept now popular in Western microprocessors; in other reports, the Kronos instruction set is described as similar to that of the high-level processor in N. Wirth's Lillith computer, with additional features to facilitate interprocessor communication. The version that has been built is a multi-board processor; though a single chip version has been designed, no one has volunteered to produce it. Soviet researchers have not published results of performance tests, so it is difficult to estimate the true status of these efforts, but the processors do not appear to be in production.

C. MINI- AND MICROCOMPUTERS

Table III.3 lists the major Soviet minicomputers. The most advanced indigenous model is the SM-1700, a minicomputer similar in its instruction set to the Digital Equipment Corporation VAX-11/780, with memory size and processor speed comparable to the (less capable) VAX-11/730. The SM-1700 uses a relatively old 4-bit-slice processor, the K-1804, to implement the new architecture. This minicomputer is being made available to the laboratory research community from the initial serial production, which is, however, limited in volume. A few dozen were made in the first year of serial production, 1987, and the rate subsequently increased to a few hundred a year. There are also recent (1990) reports of an SM-1702 which is twice as fast and one-fifth the size of the SM-1700.

The Soviet Union has been making clones of older, less capable PDP-11 computers for years. The fact that few of these machines appeared at the Soviet Academy of Sciences or State Committee for the Utilization of Atomic Energy experimental installations before the mid-1980s probably reflects assignment of higher priority to industrial applications than to advanced research prior to that time. Evidently, that order of priorities has now been modified or reversed. However, a 1989 report by scientists at the showcase Pushchino Computer Research Center that they must share the Data General minicomputer on which they do

parallel processing research with other groups indicates that capable machines still are not widely available.

TABLE III.3
SOVIET MINICOMPUTERS

Model	Approximate Western Equivalent*	Date First Installed	Processor Operating Speed (K ops/sec)	Primary Memory Capacity (KBytes)
SM-1	HP-21xx	1978	134-200	8-64
SM-2	HP-21xx	1978	154-400	32-256
SM-3	PDP-11/05	1977	30-200	8-84
SM-4	PDP-11/34	1979	130-500	32-256
SM-1210 (53/50)	HP-21xx	1986	1000-2200	4096
SM-1420 (51/20)	PDP-11	1983	350	256-1024
SM-1600 (53/14)	PDP-11+ PDP-8	1983	500-770	256-1024
SM-1700	VAX-11/780	1987	300	1024-5120

* Comparability with Western models is only approximate. No Soviet model matches the corresponding Western computer in all technological parameters.

Source: Information in this table is extracted from Table III.10 of *Soviet Computer Science Research* (C. Hammer et al., 1984), and Table VI.8 of *Global Trends in Computer Technology...* (Goodman et al., 1988). Those tables were constructed from data in an extensive database on Soviet computer technology maintained by the Management Information Systems Department of the University of Arizona. Literature citations to support the entries may be found in the cited reports.

Despite much lip service to its importance and priority, the Soviet Union still has not met its announced goal of several years: large-scale serial production of a microcomputer of acceptable performance and quality. This is an area of surprising, continuing weakness. Observers estimate that there were between 100,000 and 300,000 personal computers in the Soviet Union in early 1989.¹ (Most of the estimates are in the lower part of the range, and a significant fraction of the machines

¹ As is the case for other scarce goods in the Soviet Union, distribution is uneven. One 1988 visitor to a showcase laboratory reported that PCs were plentiful there.

are thought not to be operational.) Table III.4 lists of some of the more important Soviet microcomputers.

<p style="text-align: center;">Table III.4 SOVIET MICROCOMPUTERS</p>	
Computer	Processor
<p>General Purpose</p> <p>ISKRA-222</p> <p>ISKRA-555</p> <p>SM-1800</p> <p>Elektronika 60</p> <p>ES-1840</p> <p>ES-1841</p> <p>ISKRA-1030</p> <p>SM-1810</p> <p>NEYRON I9.66</p> <p>ES-1842</p> <p>Educational</p> <p>KUVT-86</p> <p>BK-0010</p> <p>Elektronika MS 0202/KUVT-UKNT</p> <p>AGAT</p>	<p>K-580 (8080 equivalent)</p> <p>K-580 (8080 equivalent)</p> <p>K-580 (8080 equivalent)</p> <p>(LSI-II equivalent)</p> <p>K-1810 (8088 equivalent)</p> <p>K-1810 (8088 equivalent)</p> <p>K-1810 (8088 equivalent)</p> <p>K-1810 (8088 equivalent)</p> <p>K-1810 (8088 equivalent)</p> <p>K-1810 (8088 equivalent)</p> <p>(Multichip 80286 equivalent)</p> <p>(PDP-11 equivalent)</p> <p>(PDP-11 terminal for KUVT-6)</p> <p>(PDP-11 equivalent + 12 8080 equivalent terminals)</p> <p>K-588 (8 bit)</p>

Foreign purchases and joint ventures for assembly may be the quickest ways for the Soviet Union to overcome its personal computer deficit. The July 1989 issue of *Electronics* reports the import into the Soviet Union of about 27,000 microcomputers from East Germany's *Kombinat Robotron* in 1988. Thousands of personal computers, mostly IBM PC clones from (South) Korea and Taiwan, are now being imported into the Soviet Union each year, though scarcity of hard currency is probably severely limiting these imports.

Soviet researchers traveling abroad have also been sources of imports. Until recently, Soviet researchers who visited Western laboratories for extended periods bought PCs while abroad, and then took them home at the end of their visits,

could make handsome profits by selling their scarce, duty-free imports. Other innovative approaches to acquiring PCs have included collaboration requests by Soviet scientists that include suggestions that personal computers in both countries would be an appropriate contribution from the Western partner, and suggestions to medium- to long-term Western visitors to Soviet research centers that they leave their Western PCs behind when they go home. Whether this is pre-planned or spontaneous seems to vary from case to case.

Soviet collaborators in international scientific activities based abroad have told their Western colleagues of plans to buy PCs in quantity in the West to support the Soviet part of the effort back home. They indicated (or at least implied) that they had access to funds to make these purchases. Whether these purchases were in fact made is not known.

In 1989, Siemens signed an agreement with the Soviet Union to provide up to 300,000 personal computers with roughly the capability of the IBM PC-XT model over the next three years. This could produce a quantum jump in the availability of computers in the Soviet Union if the full purchase is made. There are also reports (*New York Times*, 1 October 1989) that a small US firm, Phoenix Group International of Irvine, California, has signed a joint venture to set up a micro-computer factory in Pensa, to manufacture what is reported to be a "simplified" copy of the IBM PC-AT. However, neither deal has produced much as of yet.

These commercial developments, in addition to recent changes in US and COCOM policy with respect to exporting computers and other high technology equipment to the Soviet Union, significantly increase the possibility that Soviet researchers will soon have reasonably advanced microcomputers for at least some applications. Other sections of this report try to identify the likely consequences of this on Soviet science and society.

D. MAINFRAMES, SCIENTIFIC COMPUTERS, AND SUPERCOMPUTERS

Table III.5 lists the major Soviet mainframe computers. While their level of capability has risen over the years, they continue to lag non-Soviet computer technology standards by about 10 years. Compared to US mainframes, they have also been built and distributed in very small numbers. The first ELBRUS-2s (1985 12.5 MIPS-per-processor machines with up to 10 processors) and ES-1087s (~ 15 MOPS machines with 8- to 16-Mb memories, scheduled for first installation in 1989 or 1990) may be in place now.

The BESM-6 (a machine roughly equivalent to a Control Data 3600 that was first installed at Soviet scientific institutions in 1965) is still the workhorse of Soviet scientific computing. As ES-1060 and ES-1065 general-purpose mainframes (functional equivalents of high-end IBM 370 models of the late 1970s and early 1980s, with ~ 16-Mb main memories and 5- to 7-MIPS central processing units) have been distributed to some institutions as organizational computers, researchers occasionally have been able to obtain time on these administrative machines for research computing.

There are no known Soviet supercomputers in production (a critical deficiency that makes reports of importation of Convex minisupercomputers very significant). Although this class of computer has been found to be invaluable in the West for many important high-fidelity modeling and simulation tasks, and stringent and generally effective Western export controls have created strong incentives for indigenous Soviet production, the Soviet Union has not developed the ability to build machines of this class. When the Soviet Academy of Sciences established a Department of Informatics, Computer Technology, and Automation in 1983, one of its top priorities was supercomputer development. Machines with appropriate levels of performance were designed and built in prototype, but could not be built in quantity because the industrial ministries responsible for production could not meet the Academy designers' specifications (Wolcott and Goodman, 1988).

Table III.5
SOVIET MAINFRAME COMPUTERS

Model	Series	Approximate Western Equivalent*	Date First Installed	Processor Operating Speed (K ops/sec)	Primary Memory Capacity (MBytes)
ES-1020	ES-I	IBM 360/30	1972	10-25	0.064-.256
ES-1030	ES-I	IBM 360/40	1973	55-100	0.120-.5
ES-1050	ES-I	IBM 360/65	1975	500	0.128-1
ES-1022	ES-I+	IBM 360/30-40	1976	60-107	0.128-1
ES-1033	ES-I+	IBM 360/50	1976	140-250	0.256-1
ES-1052	ES-I+	IBM 360/65-75	1980	700	1
ES-1035	ES-II	IBM 370/135	1977	100-180	0.256-1
ES-1045	ES-II	IBM 370/145	1979	400-870	0.256-3
ES-1060	ES-II	IBM 370/165	1979	1000-1500	0.256-8
ES-1061	ES-II	IBM 370/165	1984	650-2000	≤ 8
ES-1065	ES-II	IBM 370/168	1984	4500	4-16
ES-1036	ES-III	IBM 43xy	1985	300-600	4-16
ES-1046	ES-III	IBM 303x	1985-86	1300-3600	4-8
ES-1066	ES-III	IBM 303x	1987	2000-12500	8-16
ES-1068	ES-III		1988	10000	32
ES-1037	ES-III	IBM 4341	1988	650-1000	2-16
BESM-6	BESM	CDC 3600	1965	1000	0.256-1
ELBRUS-1	ELBRUS	Burroughs 7700	1979	1500-15000	4-8
ELBRUS-2	ELBRUS		1985	12000-120000	
M-10	-	-	1979?	5000	5

* Comparability with Western models is only approximate. No Soviet model matches the corresponding Western computer in all technological parameters.

Source: Information in this table is extracted from Tables III.3, III.4, and III.5 of *Soviet Computer Science Research* (C. Hammer et al., 1984), and Table VI.6 of *Global Trends in Computer Technology...* (Goodman et al., 1988). Those tables were constructed from data in an extensive database on Soviet computer technology maintained by the Management Information Systems Department of the University of Arizona. Literature citations to support the entries may be found in the cited reports.

E. COMPUTER PERIPHERALS

Soviet disk storage manufacturing capability is developing slowly. Published Soviet magnetic materials research indicates a strong interest in topics related to

magnetic data storage, but does not seem to reflect experience in applying these materials in industrial settings.

Indigenous 200-Mb hard disks are now regularly installed at Soviet mainframe computer installations. Indigenous 317-Mb hard disks are occasionally encountered.² This state of affairs is a vast improvement over that of five years ago (see Hammer et al., 1984). Nevertheless, Soviet computer centers suffer in general from unreliable input/output peripherals, uneven and unreliable sources of electric power, and even paper shortages! Among the items in short supply are floppy disks, and, in a familiar pattern, there are joint ventures in negotiation to set up new floppy disk production facilities in the Soviet Union (one such UN/Soviet facility is said to be operational in Kiev).

² In the United States, disks of this size are attached to mini- and microcomputers used by department-size work groups within offices. They are routinely available for a few thousand dollars.

CHAPTER IV SOFTWARE

A. BACKGROUND

Software provides the instructions that control and direct the operation of computer hardware so as to accomplish a task. The operating system is an essential mediating agent in application of the formidable raw arithmetic and logical capabilities of digital computers to problems posed by humans. Application-specific software allows logically similar general-purpose digital computers to control experiments, vehicles, or weapon systems; to manage scientific, financial, or general information in databases; to supervise efficient high-speed, high-capacity communication systems; to assist in engineering, design, and manufacture of complex products; and to provide human decision-makers (in board rooms and command posts) with expert support.

System software establishes and maintains the environment within which the applications programmer and the end user perform their work. It allows application programs to use efficiently (or inefficiently) the numerical and symbol-processing capabilities of a computer system's hardware, and can be as important as the underlying hardware in determining a computer system's utility. The quality and convenience of the environment created by system software are critical determinants of the quantitative and qualitative productivity of application programmers. In this chapter, we discuss Soviet computer system software development while application-specific software is discussed in Chapter VI.

The Soviet decision to duplicate Western computers functionally (apparently starting with the decision in the late 1960s to duplicate the IBM-360 series mainframes) was probably influenced by the availability of large bodies of software, either "free" or at nominal cost. Thus, the Soviets got into a "copy and try to catch up" mode of software development. To this day, they appear to be cavalier about the intellectual property rights associated with Western software. The failure to date of all attempts to provide legal protection to software rights in the Soviet Union is an impediment not only to international cooperation with the Soviets in software development but also to the development of a software industry in the Soviet Union.

B. OVERVIEW

As documented in three earlier FASAC reports (Hammer et al., 1984; Despain et al., 1985; Wegner et al., 1989), Soviet system software research has made considerable progress during the 1980s. However, no significant closing of the gap between Soviet and Western computer system software technology is evident. Lack of capable hardware, and persistent systemic factors such as burdensome bureaucracy, management structures which restrict the flow of information within an organization, poor information flow among research centers, and lack of effective incentives for shared multiperson projects have played a large role in maintaining the gap.

If significant progress in closing the gap is to occur, a change in the structure of Soviet society to provide a climate conducive to the development and distribution of high-quality, user-oriented systems for cooperative work on large long-lived systems will be required. Such change is consistent with the objectives of *perestroika* (restructuring). However, changing the infrastructure of society is slow, and while the research and development climate may improve somewhat in the near future, broad-based, rapid improvements in the overall state of Soviet system software are not expected in the near future.

C. SPECIFIC TOPICS

The topics evaluated here include programming languages, operating systems, networks, software engineering and programming environments, software tools, databases, and artificial intelligence tools.

1. Programming Languages

Soviet research in programming languages is much less innovative than comparable Western work. Much of the Soviet activity is an attempt to reproduce or emulate Western hardware and software products. In addition to work on Fortran and ADA, this includes continued work on implementation of languages that have fallen into disuse in the United States such as Algol, Simula-67, and MIX. Much Soviet language design work reflects an apparent

lack of feedback from pragmatic experience. There appears to be active work on languages for parallel programming, but much of the work seems theoretical, without actual implementation. In the absence of a richer hardware environment (faster machines, larger memories), no change in the pace of Soviet work in languages is likely to occur. The problems that leading-edge Western designers are trying to solve cannot even be encountered in the hardware environment that the Soviet literature reveals. The well-known Soviet mathematical strengths have not had a visible impact on software technology and language design. Soviet researchers are likely to continue to follow Western language design efforts and adopt the more successful ones (presuming that their implementation is within the capabilities of the Soviet hardware).

2. Operating Systems

Inadequate Soviet hardware restricts operating system development more seriously than programming language development. The bulk of Soviet operating system articles discuss the use of systems in which the hardware is in the IBM-360/370 class or the DEC PDP-11 class. Soviet papers describing specific operating systems often contain inadequate performance data and are difficult to evaluate.

Hardware resources that are taken for granted in the West are scarce in the Soviet Union and Eastern Europe, and Soviet operating systems are therefore often concerned with entirely different resource utilization issues than faced in the West. In contrast to Soviet neglect of powerful operating systems (such as UNIX) in the early 1980s (Hammer et al., 1984), there is increasing mention of UNIX as an environment used by Soviet researchers in system development. Current Soviet practice in operating systems is at least 10 years behind that of the West. Soviet operating system research will not enter the mainstream of international activity until more capable machines (with 32-bit processors, more memory, and decent networks) become available to Soviet operating system developers.

3. Networks

In network software, Soviet researchers have proven to be capable systems developers. The leading work in the areas of most concentrated research does not trail Western work by many years. The noticeable deficiencies of Soviet networks (as compared to those of the West) are the result of deficiencies in hardware availability and performance, a poor telecommunications infrastructure, and a number of systemic and organizational factors.

In the Soviet Union, most network developments have focused on hierarchical links between computers. The most advanced development efforts have produced networks based on the open systems interconnection model advocated by the International Standards Organization. These technologies are the foundation of the Soviet academic wide-area network, Akademset'. Development has been constrained by difficulties in the acquisition of specialized hardware for network research, and use has been hampered by the lack of serially produced network hardware.

The gap between Western and Soviet capabilities in network software is likely to widen in the foreseeable future, largely because of the much larger and more vigorous research and development in the West.

4. Software Engineering and Programming Environments

Soviet software engineering is 10 to 15 years behind that of the West because the infrastructure for programming is so underdeveloped. Hardware resources and software aids are lacking, and no strong tradition of cooperative system development exists. A growing body of Soviet software engineering literature pays lip service to stepwise refinement, top-down design, chief programmer teams, development, and testing. However, there is little information that indicates application of these techniques in the design of large systems or about the limitations of these techniques in building large systems.

In the future, Soviet progress in software engineering probably will be slow and steady, and is likely to continue to lose ground relative to the West. As in other engineering disciplines, in software production there is no substitute for

actual experience. In the United States, most of the software engineering "technology" lies in the cumulative experience of the people and organizations that build software. There are no "silver bullets" that will quickly result in quantum improvements in the software engineering area as a result of breakthroughs or technology transfer. Progress in Soviet software engineering will occur only as experience is accumulated. Initiatives and crash programs promoted by the Soviet government may help in some narrow area, but they are unlikely to result in dramatic improvements in the near term.

5. Software Tools

The overall level of software tool development in the Soviet Union and Eastern Europe does not match that of the West. Some Soviet tool development projects were undertaken under severe hardware access constraints. Nevertheless, there has been considerable research on software tools in the 1980s. Compared with tool development in the West, in the Soviet Union there is more emphasis on program construction and generation tools, and a lack of emphasis on analysis and testing tools and on software management, control, and maintenance tools. However, it is clear that during the last 10 years there is steady progress in the sophistication, functional capability, and degree of use of software tools.

The Soviet Union is beginning to explore joint venture opportunities with Western software developers. If successful, such contacts may expose Soviet organizations to Western software development practices and tools and improve the degree of tool use, increase the awareness of the need for sophisticated tools covering all phases of the software development process, and raise the level of tools research. Profound changes in the legal framework surrounding software and software development are now under discussion in the Soviet Union, though up to now no actual changes have taken place. If software were to be protected as property, it would result in improved software development due to closer ties between users and developers, improved monetary incentives, and greater legal protection for software authors.

6. Databases

Databases (automated or otherwise) should play an important role in a planned economy like that of the Soviet Union. Problems with the complexity and/or the inconsistency of existing manual record keeping systems, ineffective utilization of equipment, and lack of effective management, technical personnel, and ancillary equipment have restricted the implementation of computer management of Soviet records. The dominant database management systems cited in the Soviet literature are CODASYL and IMS, which are Western technology from the early 1970s. Specialized systems (such as MUMPS, initiated in 1968 at the Massachusetts General Hospital) are used in many medical and some general applications. These old systems are less demanding of computational resources than modern relational database technology, and therefore are appropriate to Soviet hardware. However, these systems are not as easily modifiable or adaptable to new applications as newer systems.

Restructuring (*perestroyka*) in the Soviet Union could change the level and focus of activity in the database field. The focus is likely to change from the needs of large databases serving centralized planning to the needs of more local units. New efforts are likely to focus on small computers and modern database software technology. The technology to support these efforts will come in part from the present infrastructure, though substantial importation of Western PCs and modems would accelerate the process. The development of adequate communications among smaller computers will be prerequisite to obtaining many of the benefits which information technology can provide.

7. Artificial Intelligence Tools

Present Soviet technology appears to lack both the hardware and software tools needed to develop serious artificial intelligence products. Soviet work in this area still appears to be in the simplified "toy" problem stage, not yet approaching the complexity of the "real world" problems being tackled in the West. Lack of timely access to Western journals and primitive hardware have caused Soviet researchers to concentrate on circumventing hardware and software limitations, rather than dealing with the substantial problems of artificial intelligence. Tool design efforts are stuck at the level of improved assembly lan-

guage and graphical interface support, rather than on the structure of artificial intelligence applications. Current Soviet publications emphasize *desiderata* rather than accomplishments; claims that theory is applicable to practice are often inadequately substantiated and therefore are not credible. Soviet artificial intelligence researchers are sufficiently familiar with the underlying concepts and application areas to learn to produce concrete results, should adequate hardware and incentives become available. Unless the Soviet research community can obtain Western-style development systems based on networks of workstations with sophisticated programming environments featuring languages like LISP or PROLOG, it is unlikely that they will soon begin to contribute to international efforts at solving artificial intelligence problems of realistic and thus interesting complexity.

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CHAPTER V

THEORETICAL DEVELOPMENTS RELATED TO INFORMATION SCIENCES

A. SUMMARY

In this chapter, we consider a group of theoretical topics directly related to information science. These include theoretical computer science, selected areas of applied mathematics, and theoretical aspects of artificial neural networks.

The simplistic assessment is often made that Soviet researchers are "good in theory," encompassing all of mathematics and physics, plus many other areas. Though the Soviet educational system certainly provides a good fundamental background in classical mathematics (in particular, applied analysis), and there have been outstanding Soviet research leaders in some areas of theory, the simplistic assessment is not universally true. The Soviet strength in "theory" is least in some of the areas requiring close interaction with experimental work, as illustrated by the minimal contributions of Soviet theoretical physicists in high energy physics, where the great experimental discoveries have all been made in the West (as have all the great theoretical insights, with the exception of Yukawa's hypothesis of the role of the meson in nuclear forces). The situation in computer science seems to follow that pattern. The Soviet lag in development of highly capable machines (including supercomputers) has meant that Soviet applied mathematicians and computer scientists are at a substantial disadvantage with respect to the West, and this has been mirrored in less substantial contributions to computer science at all levels. Moreover, it has been argued (see, for example, Steen, 1988) that the computer is the most powerful force changing modern mathematics, and in particular, computational methods pervade all aspects of applied mathematics. From this perspective, Soviet science workers, whatever their abilities and training, are handicapped in all areas of mathematics and its applications to science by their lesser access to computers than their Western peers.

It is undoubtedly true that the Soviet scientific literature has a higher proportion of papers presenting only analysis, without comparison to experimental data, than the US literature. However, many of these papers would not be considered worthy of publication in Western journals. Moreover, there is a much

stronger tendency of Soviet physical scientists and engineers to develop analytic solutions to physical problems than is true in the West. In many cases, such analytic solutions may be useful in conveying understanding, but in many other cases the analytic solution was obtained by gross simplification that imperils the validity of the resulting formal solution. In other cases, the "analytic solution" turns out to be an infinite series of transcendental functions, difficult to visualize, or even to compute.

As would be expected, Soviet work in theoretical computer science appears to be five to 10 years behind that of the West. There are selected areas in applied mathematics related to theoretical computer science in which the Soviet Union appears to be doing work comparable to that in the West. However, some Soviet attempts to apply their mathematical skill to computer science theory, such as Soviet theoretical work in modeling animal and artificial neural networks, appears weak in general.

B. THEORETICAL COMPUTER SCIENCE

In the early 1980s, the Soviet activity in theoretical computer science was judged to be comparable to that of the United States of eight to 10 years before (Hammer et al., 1984). This judgment seems to be applicable today. Many of the "hot" topics in the West are not even being examined in the Soviet Union. Within the important area of theoretical investigations of programming languages, this includes such topics as formal semantics, type theory, transformational programming, and logic programming (Wegner et al., 1989). In some areas where there is Soviet work, like automata theory, the work is similar to that of the West a decade earlier.

A potential exception to this bleak picture is the work in algebraic complexity theory. The Soviet background in this area goes back to work by Kolmogorov in the mid-1960s. Kolmogoroff has made contributions up until quite recently (Kolmogoroff and Uspenskiy, 1987). While the current effort is nowhere near as vigorous as back then, there may be a revival of effort underway.

C. RELATED AREAS OF APPLIED MATHEMATICS

The Soviet work in some areas (for example, dynamical systems) is first-rate, and perhaps even superior to that of the West. The now-popular area of chaotic systems has seen significant contributions over the years from Soviet scientists and mathematicians (beginning with Kolgomoroff, Arnol'd, and Anosov in the 1960s). While it can be asserted that the West is now in the lead in this area, there is still world-class activity in the Soviet Union (a semi-popular exposition of some of this work is contained in Chernikov et al., 1988).

In other areas (for example, various fundamental aspects of control theory) there is some good Soviet work, but it generally follows activities in the West. There is a strong tradition of Soviet interest in optimization (including optimal control) that has been justified as related to improving the Soviet centralized planning process.

An interesting aspect of the Soviet literature is the attention given to residue or modular arithmetic (Kleitman et al., 1983). This technique is matched to the use of computers with parallel channels for each digit, because carries are slow, which happens to be an undesirable attribute of digital optical computers as currently envisioned. Thus, this interest in residue arithmetic appears to have had some impetus from the Soviet initiative in optical computers (discussed in Chapter II). Residue arithmetic also appears to be a useful and efficient way to perform some tasks in signal processing, and its use for such tasks has been investigated seriously in the United States. However, residue arithmetic appears (to US computer scientists) to be inapplicable to general purpose computing. For multiplication or addition, it is straightforward to convert numbers (expressed as integers) to a representation in residues with respect to the primes used as bases, perform a series of multiplications and/or additions, and convert back to the conventional representation via a table look-up. However, it is impossible to perform divisions or comparisons (that is, test on greater than/less than) in the residue representation; thus, these common operations would require the (expensive in time) transformation into conventional representation. The applicability of residue arithmetic to signal processing can be illustrated by the example of the fast Fourier transform. Since this is a series of multiplications and additions, it can be done easily in residue representation.

D. NEURAL NETWORKS AND RELATED AREAS OF BIOPHYSICS

Soviet scientists have indicated their desire to participate in the present wave of international interest in artificial neural network research by holding an informal national conference to discuss the subject, but thus far have not been conspicuous contributors to the mainstream of this discipline. (This is not surprising, because many of the hottest areas of research require access to computational resources that are much more capable than those usually available to Soviet researchers, or are closely related to military applications.)

One Soviet research group (led by V. I. Kryukov of the Soviet Academy of Sciences' Pushchino Research Computer Center) has presented a paper at several international neural network research conferences. The paper describes formal mathematical analyses of a particular class of neural networks. This paper reflects the major thread in present Soviet research related to artificial neural networks: formulation of broad (but somewhat vague) models of human higher brain functions. Papers sketching these concepts appear regularly, but they generally do not contain specific analyses, simulations, or experiments that could contribute to a critical scientific evaluation of the ideas.

On the other hand, Soviet neuroscientists are doing good work that contributes to the world effort aimed at understanding information processing in the human nervous system. Their strongest contributions examine subtle aspects of chemical communication among synapses. Many Soviet publications describe unique nonlinear mathematical analyses of self-organizing nervous-system analogs, but this work has not been influential. (Western researchers, as well as other Soviet groups, are aware of this work but have not been inspired to use, continue, or extend it.)

In the late 1970s and the early 1980s, Soviet researchers participated actively in international research efforts aimed at understanding information processing in the retina and other parts of the vertebrate visual system. These research groups have published little or no new work in the mid- to late-1980s.

CHAPTER VI

SCIENTIFIC AND TECHNICAL APPLICATION AREAS

A. OVERVIEW OF TRENDS IN STATE OF THE ART

During the late 1980s, much-needed laboratory minicomputers (made in the Soviet Union and Eastern Europe) began to appear in significant numbers in Soviet scientific research laboratories with high priority and international visibility. Imported personal computers (with varying degrees of capability) have also become available in significant numbers in Soviet laboratories. Some of these have been microcomputers purchased by Soviet scientists traveling abroad. That there is still a shortage of PCs in the Soviet Union can be deduced from Soviet press reports, including the published stories about the opportunities for profit by resale of PCs imported by individuals.

As described elsewhere in this report, there has been a relaxation of the COCOM regulations governing the allowable capabilities of computers that are exported to the Soviet Union, so that, as of the summer of 1989, PCs up to the level of the IBM AT could legally be exported by COCOM countries to the Soviet Union. More capable mini- and microcomputers (as well as mainframes) are still not to be exported routinely to the Soviet Union by COCOM members, but many computer manufacturers appear to be applying for waivers or exceptions.

Upgrading of Soviet computer capabilities appears to be occurring, and this upgrading has already improved Soviet performance in some of the areas discussed below, but these improvements appear to be far from universal. A brief synopsis of current capabilities and trends is as follows:

- Soviet scientists appear to be developing the capability of computer control of experiments, at least for particle accelerators and magnetic fusion experiments, though at the level of the West a few years ago.
- Soviet work in modeling and simulation continues to lag that of the West. Although the Soviet Union attempts to use analytic solutions, clever problem formulation, and more efficient algorithms to compen-

sate for their less capable computers, it is unable to attack many classes of problems routinely addressed in the West.

- The Soviet Union is severely deficient in CAD/CAM capabilities.
- Soviet work in the areas of robotics, artificial intelligence, image processing, and pattern recognition is far behind that of the West and is severely impeded by the lack of computers.

B. COMPUTER-CONTROLLED EXPERIMENTS

Until recently, the chronic Soviet shortage of mini/microcomputers was apparent in the rarity of their use of control experiments (for example, Davidson et al., 1987). This is an area in which substantial change seems to be occurring as indigenously produced PDP-11 class minicomputers become more available, and relaxation of COCOM regulations continues. For example, adequate laboratory computers (PDP-11s or clones) are being installed at the T-15 tokamak at the Kurchatov Institute to help control the experiments and gather the data. (This was not the case for previous generations of Soviet tokamak experiments.)

Automation of diagnostic and measurement systems and automatic control of whole accelerator systems are extensively discussed in the Soviet accelerator literature. There are some outstanding concepts in their approach, which includes a strong multi-disciplinary blending of modern control theory with accelerator physics, going beyond the more fragmented approach often seen in the West. At the operating level, the amount of equipment and support available has not been very large, but actual application of automation has been underway since at least the early 1980s. Control problems attacked include orbit control in large circular machines, optimization of the multiple injection and capture parameters of proton synchrotrons, and miscellaneous linear accelerator control problems.

At the Eleventh All-Union Conference on Particle Accelerators held on 25-27 October 1988 in Dubna, the session on accelerator controls immediately followed the opening plenary session, possibly indicating a high level of visibility of computer control techniques in the Soviet accelerator community. Topics dis-

cussed in the session included closed orbit measurements, beam intensity measurements in fast-cycling synchrotrons, diagnostics for high current lithium lenses, semiconductor profile measurement devices, and a microprocessor system for measuring betatron oscillations. Automatic control systems were discussed for several accelerators, indicating implementation at some stage at all the major centers on a variety of applications. The current approach appears to be emphasizing PC-scale applications, but including multiprocessor linking. The system applications appear to be at a level prototypical of Western work of a few years ago.

As can be inferred from this specific illustration, continuation of the trend depends upon the Soviet ability to find hard currency to buy the types of equipment they need for their jobs.

C. MODELING AND SIMULATION

The severe limitations (in processing speed and size of fast memory) of the best computers available to Soviet researchers are most apparent in computer modeling and simulation. The severity of the impact of these limitations on the overall strength of the research effort varies from field to field. In combustion theory and computational fluid dynamics, some problems just are not attacked, even though these may be in areas with a history of strong Soviet contribution of both physical insight and analysis.

These limitations on computer modeling can have a direct effect on the approach to design of systems or structures. For example, the Soviet capability in finite element modeling of spacecraft structures seems to be at the level about 1,000 degrees of freedom, similar to what can be done on PCs in the United States, while it is not uncommon in the West to model more than 100,000 degrees of freedom (on a supercomputer) for spacecraft design. To overcome this liability, Soviet researchers must restrict themselves to simpler and more conservative (and thus heavier) spacecraft designs.

The Soviet Union is able to keep roughly abreast with the West in many areas requiring computer modeling by a combination of clever problem formulation and efficient algorithm development. Such seems to be the case, for exam-

ple, in accelerator design. Soviet researchers have obtained and run many of the design codes used in the West, and have also built some of their own. They have developed a program for computation of magnetic field configurations in three dimensions on a Bulgarian-developed ES-2706 array processor.

There are beginning to be examples of more capable computers available to Soviet researchers in some high-visibility research areas. Western magnetic fusion researchers have seen two US-made Convex minisupercomputers (presumably used for plasma and other simulations) at the Soviet nuclear weapons development laboratory in Troitsk. Researchers from the prestigious Kurchatov Atomic Energy Institute participating in the International Thermonuclear Engineering Reactor (ITER) design study claim to still use BESM-6s for their calculations at home. This would require very long runs for some of the calculations reported. They report that their colleagues at the Keldysh Applied Mathematics Institute use much more capable (unspecified) computers in their modeling calculations, but they (the Kurchatov modelers) have no access to Keldysh facilities. (The Keldysh modelers have provided input to the ITER effort in the form of calculations to answer Soviet "homework" questions.)

The lack of world-class computer facilities seriously affects the efficiency of Soviet research in molecular modeling, where the ability to display molecules plays an important role in advancing the state of the art in synthesis of drugs and in molecular modeling in general. The absence of graphics/display capability leaves one to physically build molecular models through blocks and sticks, a slow and painful process. In addition, one does not have the capability of quickly testing for isomorphisms, stereo-isomorphism, and other symmetries.

D. CAD/CAM/CAE

The Soviet deficiency in CAD/CAM/CAE is probably nowhere more significant than in the microelectronics industry. The megabit-plus dynamic random access memory (DRAM) chips, 32-bit microprocessors, and other advanced microcircuits now in production in the West were dependent in their design phase on the help of powerful computer-aided design (CAD) tools. Computer aided manufacturing (CAM) technology is a significant contributor to both low cost and high reliability in the output from Western microcircuit plants. Much

more powerful workstations and factory computers than those that have been available to Soviet engineers (and specialized software developed and delivered on those platforms) are necessary to use these important design and production tools. Though reliability has long been a serious problem for the Soviet micro-electronic manufacturers, they have not been able to develop the satisfactory automated controls for microelectronics processing equipment that could alleviate the problem. They also sorely miss automated test equipment for microprocessors, etc. (Sello and Kirkpatrick, 1988).

Soviet participants in the ITER design activity have asked for help in getting COCOM waivers to allow them to buy three microVAXs and a VAX-7700 to run the MEDUSA CAD software system in their design work. They claim they can get comparable equipment through the back door, but do not want to risk causing trouble to the design effort by doing so. They also want to buy authentic software so they can get the updates as they appear. The Soviet Union obviously wants to buy legally because they would get better, faster equipment at a cheaper cost. According to Professor Goodman, the Soviets often ask for the equipment (free), not just the waivers.

E. EMBEDDED COMPUTING

The Soviet published literature obviously does not contain discussions of the computing capabilities built into military weapons systems, or the data rates of military C³I systems. Some notion of the capabilities intended for advanced systems may be derived from the literature describing SAR processing for oceanography. In this case, the primary Soviet mode of data processing is by means of an optical bench processing film (Held et al., 1990), while the United States is now using supercomputers. The Caltech Jet Propulsion Laboratory uses a 6 Gflop/sec computer for SAR processing research, a capability unlikely to be available to Soviet researchers in the near future. US researchers are convinced that digital processing (at these high computing rates) is necessary, but Soviet researchers may not share that view (or may be forced to make do with optical analog computing).

F. ROBOTICS AND ARTIFICIAL INTELLIGENCE

Research in robotics has been given a high priority in the Soviet Union, and there are some related research areas in which the Soviet work is at least as good as that in the West (for example, control theory), but there appears to be a Soviet weakness in coupling their theoretical work to actual robotic systems.

Soviet research in artificial intelligence has a long history of vigor and competence in theoretical or analytical areas such as planning, improvement of planning strategies via learning from experience, design of control systems, process control, representations of physical processes, and higher level reasoning about computer programs (Despain et al., 1985). However, much of this seems to be pursued as essentially pure theoretical research.

Artificial intelligence research that would be important to robotics (specifically computer vision) seems to be much less advanced. The nature and degree of advancement of Soviet research in robotics and artificial intelligence probably reflects the limitations on artificial intelligence research and development tools as discussed in Section IV.C.7.

There is little evidence that the climate for artificial intelligence research is improving in the Soviet Union. Adequate hardware for research continues to be in short supply, as are satisfactory software environments to support experimentation. These factors, combined with the apparent isolated position of the typical Soviet artificial intelligence researcher, do not add up to a promising situation. Unless there is marked improvement on all fronts—hardware, software, and general research climate—substantial improvement in artificial intelligence research is unlikely.

G. IMAGE PROCESSING AND PATTERN RECOGNITION

The lack of computing hardware and software has a significant impact on research and development in a number of areas including computer vision, image processing, and pattern recognition. The Soviet Union is far behind, by 10 to 15 years, in these areas despite its strong research in theoretical aspects of statistical pattern recognition (Klinger et al., 1989). This is not to imply that Soviet

researchers are unaware of the research and development going on in the United States and other Western nations. In fact, it appears from the references cited in their papers that Soviet scientific workers are closely following Western research. It appears that Soviet scientists are aware of the potential of computer vision, image processing, and pattern recognition for societal and military purposes, but are unable to pursue research in these areas due to a lack of computing facilities.

These conclusions were substantially corroborated at the Sixth Scandinavian Conference on Image Analysis held in Oulu, Finland on 19-22 June 1989. At this conference, Soviet researchers presented three papers. The paper "Search of Anomalies in Texture Binary Images by Analysis of Quadtrees" (Fatyanov et al., 1989) discusses the search of imperfections in binary texture images using a procedure implemented on an IBM AT. This is certainly not state-of-the-art research in characterizing texture of imperfections in magnetic material through image analysis. The paper "The Descriptive Framework for an Image Recognition Problem" (Gurevich, 1989) delineates a theoretical framework for the analysis of images through synthesis. The broad framework is fine for theoretical studies, but its usefulness for any realistic problem is highly questionable. The paper "Comparative Study of Some Character Recognition Algorithms" (Verikas et al., 1989) compares eight structural-statistical character recognition algorithms. While the paper gives a fairly detailed description of algorithms, it does not give any information about the experimental set-up or the digitizing and computing facilities used in the investigation. These three papers are significantly better prepared and presented than the large number of papers translated from Russian-language journals. It is fairly clear from these papers that Soviet emphasis is still on binary images and more theoretical pursuits. This is a direct consequence of the lack of digitizing and computing facilities.

There are examples of excellent Soviet work in image manipulation as part of their space program (for example, pictures taken by an unmanned Venus lander and transmitted digitally back to earth). The processing was able to correct for the geometric distortion due to the camera "panning," to use multiple transmissions to correct for data dropouts, and also to enhance contrast. However, this sort of activity could be carried out over a span of weeks or months. Military image processing tasks (and even many routine civil tasks) are likely to be much more time-urgent, a requirement Soviet computers may not be able to meet.

Similar evidence of the Soviet lag was obtained from six papers submitted by Soviet researchers in response to an invitation to include papers in a book entitled *Advances in Computer Vision and Image Processing: Research in the USSR*, edited by Dr. T. S. Huang of the University of Illinois, at Urbana, to be published by JAI Press in 1991. These invited papers from premier Soviet contributors did not include any new or especially significant techniques.

Another source of information is the book *Pattern Recognition/Classification/Forecasting* (Moscow, Nauka, 1989), edited by Yu. I. Zhuravlev, a corresponding member of the Soviet Academy of Sciences. The book contains nine papers. The paper by I. B. Gurevich, "The Image Recognition Issues," appears to be identical to the one published at the Sixth Scandinavian Conference on Image Analysis at Oulu, Finland, in June 1989. The emphasis of the other papers appears to be theoretical pattern recognition and image processing. Given (1) that the Soviet Union is still short of computing, digitizing, and display equipment, (2) the earlier FASAC panel assessment, and (3) the recent three corroborating pieces of evidence, it is fair to estimate that the Soviet Union is still far behind the West in computer vision, pattern recognition, and image processing.

The relaxation of controls on shipping IBM/PC-AT type machines will certainly improve the Soviet pattern recognition research capability in the long term, if the machines become available to workers in this field. However, this change is likely to be gradual. The effect of shipping high-performance workstations such as the SUN Sparcstation I or SUN 4/260 with a TAAC-1 graphics card would be more dramatic, although even such changes might not be apparent for a few years. It may be added that the Soviet Union is obviously aware of the capability of these workstations since they were displayed and demonstrated at the June 1989 Sixth Scandinavian Conference on Image Analysis.

CHAPTER VII

THE CHANGING SOVIET RESEARCH ENVIRONMENT: PROSPECTS AND CHALLENGES

A. INTRODUCTION

The *glasnost*'-induced public discussions of problems in Soviet science and society have been startling to Westerners who have been accustomed to observing the repression of freedom in the Soviet Union and have taken this repression for granted. Presumably, Gorbachev and the other Soviet leaders initially looked to *glasnost*' as a "safety valve" for airing discontent, as well as a mechanism for developing support for reforms needed to improve Soviet society. The Soviet public's fervor in self-expression appears to be much greater than the leadership had expected and has been much more difficult to channel.

Any discussion of the future in the Soviet Union is handicapped by two opposing effects. On the one hand, a dramatic new development may occur, as many have since Gorbachev came to power. On the other hand, the huge Soviet bureaucracy can be very effective in delaying and perhaps even nullifying an intended substantial reform. The tension between the two opposing effects is illustrated in the continuing on-again/off-again attempts at a transition to a market economy.

It is also important to note that the changes are likely to have negative as well as positive effects. There are losers as well as winners, and many Soviet citizens (as elsewhere) are just fearful of change. On the other hand, many of the initial, perhaps half-hearted approaches to reform have dampened popular enthusiasm and cost good will. Many people, including many scientists, who believed in Gorbachev's efforts in the first few years have begun to lose their enthusiasm for change and their belief that things could improve. In assessing the changes that are underway, we must also pay attention to the difficulties that the reform efforts can generate.

This chapter is not intended to provide a synopsis of all the changes that have occurred in Soviet society since Gorbachev's rise. Rather, it is an attempt to

focus on the significance of the changing environment for science and technology development in the Soviet Union.

B. GLASNOST'

The first thing to state about *glasnost'*, whether it is translated as greater openness or greater frankness, is that it is always preceded by "greater." It means less control over information, less censorship, and fewer restrictions. It does not, at least not yet, mean freedom of speech or freedom of the press in the sense those terms are understood in the United States.

1. Increased Freedom of Information

The *glasnost'* development must be viewed as a positive influence on Soviet science and technology in general. Progress in technical areas is best made by building on the contributions of many clever minds, and openness is the best antidote to unwise development projects, just as it is to pseudo-science. The increased openness within Soviet society should have the effect of increasing the efficiency of information transfer among scientists, between scientists and technology developers, and so forth.

Similarly, greater openness to the West should have a positive effect on Soviet science and technology, increasing the rate of migration of ideas and technology from Western Europe, the United States, and the Far East to the Soviet Union. The Soviet Union has invested much intellectual capital in a bureaucracy aimed at keeping track of foreign technology developments for possible Soviet use; however, this system lacked the efficiency of direct information transfer from Western information developers to Soviet users. There should also be some benefits to Western science and technology from greater openness of Soviet science, though they probably will not be as great as the benefits to the Soviet Union, primarily because the breadth and depth of Soviet science and technology is nowhere near that of the West. Still, there are bound to be "new" ideas available from the Soviet Union in some specific niches ignored in the West.

Contacts of Soviet scientists with Western colleagues (in the Soviet Union, at international meetings, or during long- or short-term visits by Soviet scientists to laboratories abroad) have become progressively less nervous over the last few years. More exchanged time is spent in frank, open collegial (professional-to-professional) dialog, less in avoiding unpleasant or forbidden subjects, in "sizing one another up," or in defending one's "system." Interaction with foreigners is "allowed" and sometimes encouraged.

Although the onerous Soviet security regulations governing publication of technical papers have been relaxed somewhat, not everyone understands what the rules actually are. Clearance of manuscripts is still controlled by the institutes (in a long process with much opportunity for technical, political, or national security censorship).

2. International Communication and Travel

The increase in the number of Soviet scientists traveling abroad has been nothing short of phenomenal. In 1988, some 1,500 Academy scientists went abroad. In 1989, that number increased to 20,000. In 1990, some 14,000 visited the United States alone.

Though travel abroad is still not routine, Soviet scientists can now often come abroad if they have advance invitations from Western research institutions, especially if the proposed host is willing to pay. These invitations are highly prized. Travel is still controlled by a scientist's institute, and availability of foreign currency is a continuing problem. Self-financed travel, like good equipment, has always been, and remains, the prerogative of "rich" institutes.

There are many specific examples of this increased frequency of foreign travel by Soviet scientists, particularly to meetings in Western Europe. Soviet participation in the Sixth Scandinavian Conference on Image Analysis (held in Finland in June, 1989) was the first in this series; three Soviets attended and presented three papers. At the Rome International Conference on Pattern Recognition held in November 1988, the Soviet Union was elected as a member of the International Association of Pattern Recognition (IAPR), an international organization of 23 national pattern recognition societies, including the United King-

dom, Japan, and the United States. Soviet attendance at meetings in the United States has also increased dramatically in the past few years. For example, over 20 Soviet scientists attended the SPIE meeting in Los Angeles in January, 1991.

3. Freer Emigration and the Brain Drain

In parallel with the greater freedom of travel enjoyed by scientists, there has been an easing and resulting increase in emigration. This includes but is not limited to Jews. Perversely, the trend toward "democracy" in the Soviet Union is likely to increase the open expression of intergroup hostility and prejudice, as is only too clear in the open fighting between Azerbaijanis and Armenians. Virulent anti-semitism is being espoused by such groups as the National Patriotic Front *Pamyat* and The Union of Writers of the Russian Federation (Goldanskiy, 1990); and the central government is finally beginning to cope with the problem (a leader of *Pamyat* has been sentenced by a Soviet court for his disruptive anti-Semitic activities), but the threat of discriminatory actions persists. This unpleasantness will add to the generally miserable prospects of life in the Soviet Union, creating greater pressure for emigration. A substantial fraction of the emigrés can be expected to be highly educated and highly motivated people, including scientists and engineers.

Academic scientists have open to them a modified form of emigration. They can find short-term activities abroad (temporary research posts or post-doctoral appointments in their specialty), and decide later whether to return to the Soviet Union.

A new Soviet law permitting foreign employment was originally scheduled to be in effect on 1 September 1990, but passage has been delayed. Nevertheless, large numbers of Soviet scientists and engineers have arranged for foreign employment. Many leading Soviet scientists, particularly mathematicians and physicists, have been hired by US universities. The most visible such "migrant worker" is R. V. Sagdeyev, former director of the Space Research Institute, currently a member of the Congress of Peoples' Deputies, and now a visiting professor at the University of Maryland. G. I. Marchuk, President of the Soviet Academy of Sciences, stated that 534 researchers from the Academy left the Soviet Union in 1990 for planned periods of six months to five years.

The down side of increased travel and contact is growing concern about the brain drain. During President Gorbachev's meeting with President Bush, a group of Soviet academicians visited the US National Academy of Sciences. Yuriy Osipyan, a physicist and a member of the new Soviet Presidential Council, cited the brain drain as the most pressing problem facing Soviet science. Numerous articles have appeared in the Soviet press calling attention to this danger. However, some Western observers have questioned just how serious the problem is likely to be. The Western market for emigré scientists may well reach the saturation point very quickly. The top-level people, of course, will always be welcomed, but they are usually the ones with the least incentive to leave. The opportunities are likely to vary dramatically between fields. Mathematicians and theoretical physicists are most likely to have developed reputations by publications, and can move most easily. On the other hand, many areas of Soviet experimental physics are so beset by problems with equipment and supplies that capable individuals have no opportunity to demonstrate their competence in the field. They may also need new equipment in their new locations.

The Soviet Union is likely to encourage study in the West by young scientists. Soviet scientists now regularly note that all the Russian and Soviet winners of Nobel prizes in science worked in foreign laboratories during their early training. They welcome the idea of Soviet graduate students spending time in laboratories abroad, including laboratories run by Soviet emigrés.

C. ECONOMIC CHANGES

Soviet restructuring (*perestroyka*) involves economic as well as organizational changes. As this report was being completed, the talk about introducing a free market economy was increasing in intensity, but the prognosis was still uncertain.

1. New Mechanisms of Financing Research

There are other powerful forces for change in the Soviet research establishment. Much is being said about the "self-financing" of Soviet research institutes.

This is not, of course, an abrupt change from the past. Research institutes supported by industrial ministries are already "self-financed" in the sense that they have an external "customer" who cares (at least in principle) about their product. Many Academy of Sciences institutes have had relatively long-term support from military customers (for example, the oceanography institutes have received significant funding from the Soviet Navy). An estimated 15 percent of the Academy institutes' research budget comes in the form of contract work from industrial sponsors, primarily military (Thomas, 1988). Nevertheless, finding support will be a new experience for many, and has led to discussions in the popular press about how the monetary value of research should be calculated! It is almost inevitable that the first-order result of the move to self-financing will be to disrupt the current patterns of research. It is all too likely that this will eliminate some promising research (along with some not-so-promising research). It may not remove the influence of those academicians who have been able to sit on powerful All-Union committees and send themselves money to run an institute.

The move toward project financing is in the abstract a positive one, except that there will have to be some judgments made to cushion the blows to prevent untimely cancellation of good long-term research with no influential sponsor. Many US scientists believe that it is important to have a diversity of potential sources of sponsorship, so that research funding need not depend upon the judgment of a single individual. In the past, the research agenda within a typical Soviet institute has been strongly dominated by the director. The effect of project funding should be to loosen the grip of the institute director, even in the case where he is double-hatted and also sits on the committee awarding funds in a specific area. Opening up institute funding to project-by-project review is bound to provide the opportunity for more review by the director's peers (and rivals for funds). In an environment of true competition for funds on a project basis, an institute director should also be anxious to solicit new ideas from his staff to develop new projects, as well as to expand old ones. However, it will be interesting to see how the Soviet system develops.

Current efforts are aimed at making the system "leaner and meaner" by forcing researchers to compete for project funding. However, it is proving very difficult to make the decisions that would deprive employees of their jobs. Eliminat-

ing positions goes against the grain of any bureaucracy, and the Soviet Union is a bureaucracy writ large. Furthermore, Soviet society has evolved a very strong ethos of social welfare protection. There is supposed to be a safety net of housing, income, and employment for all. To admit that the system has produced material deprivation and then say that it can only be cured by eliminating social protections is a very difficult political message to sell.

Most often, laboratories and institutes have carried out reviews of their staff, tried to set priorities, but then made reallocations at the margins rather than seriously cutting anyone's funding. The pressure to make serious cuts is likely to continue, but Soviet bureaucrats are skilled maneuverers. Soviet officials recently visited the National Science Foundation to attend a week-long briefing on US science policy, at which they specifically asked for assistance and information on grant funding. However, many of them seemed more interested in learning how to apply for grants from Western sources than in figuring out how to establish similar institutions in the Soviet Union.

2. Cooperatives

An important unknown in assessing the future of Soviet technological development is the potential role of cooperatives. These organizations have sprung up in all sectors of the Soviet economy since the rules governing their operation were liberalized in May 1988. There are now tens of thousands of these ventures in almost all areas of Soviet society. A small fraction of these cooperatives are involved in research and development. Many of these are trying to develop joint ventures with foreign entities.

There are two types of cooperatives: those that are created by governmental entities, and those that are strictly private. The co-ops are generally small and impecunious, and the members may be able to make use of the facilities where they normally work. The members have no tradition of entrepreneurial behavior to fall back on, and lack the simplest parts of the infrastructure a small business in the United States takes for granted (how can you "let your fingers do the walking" when there are no phone books, much less yellow pages). Some of the interest that the cooperatives have in trading with the West may be motivated by the thought that it may be easier logistically to work with foreigners than with

fellow Soviets in another province (though the foreign currency is clearly the major attraction).

There is much controversy over the role of private cooperatives in Soviet society. The 70 years of communist "education" have taught the "evils" of private ownership, and it has been reported that the Supreme Soviet would have outlawed cooperatives involved in foreign trade but for Gorbachev's intervention (Kalb and Kalb, 1989). This negative sentiment is likely to limit the size of cooperatives (or to impel them to seek cover in the currently more popular modality of a joint venture).

Cooperatives may provide opportunities for some industrious technically-trained people to find niches where they can market their personal labor for a profit. The first technical area in which this is likely to happen is software development, but there may be others. It should be noted that the availability of these new non-conventional forms of employment may, in the long run, decrease the attractiveness of a conventional science career: some of the brightest and most venturesome will be attracted to establishing their own co-ops, which may or may not be technology oriented.

3. Joint Ventures

Considerable Soviet enthusiasm has developed for joint ventures (JVs) between Soviet entities and foreign companies as a means of upgrading products available for the Soviet internal market (notably, for the purposes of this report, including PCs and other computer hardware and software, and telephones and communications hardware). The central theme is usually knowledge or technology transfer from the foreign company to a factory set up under joint ownership in the Soviet Union. These ventures can be attractive to the foreign partners only if there is a real possibility of removing their profits from the Soviet Union, at least in the long run. At present, it is most likely that hard currency can be obtained for the JV by complex commodity barter transactions, since it is not likely that Soviet factory products will be competitive outside the Soviet Union. Not every Western firm is likely to be willing to consider such an arrangement (it is said that IBM, for example, just is not interested), and even those willing to negotiate will be cautious about what they transfer. The

announced JVs with Siemens and Phoenix Group (see Section III.C) are prototypical. In the case of the Phoenix Group JV, the Laenderbank of Vienna (Austria) will act as an intermediary in finding buyers with convertible currencies for Soviet chemicals, oil, steel, or other commodities and collect these funds to pay Phoenix for its shipments to the Soviet Union (and hopefully its share of the venture's profits). Whatever the limitations of JVs, they do have the advantage of bypassing the bureaucracy of the Soviet centralized trading organizations, and thus shortening the chain in negotiations. Joint ventures can be attractive to the Soviet partners simply because of the opportunities for foreign travel and the possibilities of relative freedom from the stifling Soviet planning bureaucracy.

Joint ventures between Soviet entities and foreign companies were first authorized by the Supreme Soviet in January 1987, and their numbers have grown dramatically since then (about 1,200 registered by January 1990, and 2,500 by the end of the year). Most of these have faltered: *Business Week* (19 March 1990) estimated that 18 percent of registered joint ventures were operating. For most JVs, the difficulty of expatriating profits from a nation that does not have a convertible currency remains insurmountable. Reforms proposed by Gorbachev in October 1990 are intended to address the problem of currency conversion, but the mode of implementation is still uncertain.

Production and sale of computer hardware (especially PCs or components thereof), software, and processing services is one of the four major areas of US-Soviet joint ventures formed through late 1989 (Nigh et al., 1991). In addition to those intending to produce for the Soviet market, some JVs are planning to produce software or other labor-intensive information products for export. For example, a database joint venture is being undertaken by Maxwell Communications of the United Kingdom and the Soviet All-Union Scientific and Technical Information Institute (VINITI). The venture, called Scitechinform, will be based in Moscow and will provide chemical information. It will be staffed primarily with VINITI chemical abstractors (*Information World*, Oxford, 1 May 1989). This type of JV appears to be more attractive and should be easier to implement than those requiring complex barter arrangements.

4. Foreign Sources of Funding

Soviet scholars are increasingly turning to Western foundations and educational institutions as sources of research support. Any US funding source willing to make grants to foreign nationals is likely to be receiving applications from Soviet researchers. The National Science Foundation and the National Institutes of Health are high on their list. There has also been a growing number of Soviet scientists visiting Western universities and laboratories for extended stays. Some of these individuals will become part of the brain drain, but many are likely to become better integrated into the world community while continuing to work in the Soviet Union.

The new "freedom" of the Soviet Academy of Sciences institutes to solicit funds from abroad has led to serious attempts by some institutes to make connections with foreigners for JVs and other forms of funding. For example, the Troitsk Kurchatov Research Institute had several of its senior scientists attend and present papers about their works and products at a "Soviet-American Symposium on Research, Technology and Trade" in March 1991 in San Francisco. To date, not much has come of such solicitations.

D. STRUCTURAL AND ADMINISTRATIVE CHANGES

Considerable restructuring of the Soviet institutions involved in research and development has occurred. This has been a gradual process, likely to evolve further (particularly if real economic changes are made).

1. New Leadership in a Changing Structure

The reshuffling of the personnel and, to a lesser extent, the structure of the Soviet central government has been the work of a superb politician. Gorbachev has managed to keep himself in control, even as he has opened the political process. Elections to the Congress of Peoples' Deputies have involved real contests, and the Supreme Soviet is no longer a rubber stamp for the bureaucracy. The process of setting up the legislature as a counter force to the massive bureaucracy is a clear example of Gorbachev's political genius. Nevertheless, there still is a Communist Party, with its huge bureaucracy.

There are also the conflicting interests and political establishments of the several republics (including, most notably, the Russian Republic), most of which are striving for both political and economic autonomy. In such a fluid situation, there are pluses and minuses for the scientific and technical community. On the one hand, the politicians want to use any tool possible to improve the living standards of the people, and they believe that science and technology can provide important tools. On the other hand, it is hard to get (or keep) stable funding for long-range research while there is such an urgent need for help "right now."

Because of the long-term Soviet drive toward technological development as a key to both military power and economic progress, prominent scientists have long had access to the top levels of the Soviet government, both through the Academy and independently. Gorbachev has continued this tradition, and has named Yuriy A. Osipyan, a vice president of the Academy of Sciences, as a member of his Presidential Council.

The history of *perestroyka* has been one of continuing experimentation with institutional change. The gradualism in economic reform has been frustrating to many of Gorbachev's early admirers. He apparently felt slow change was required to bring along the conservatives who occupied the infrastructure in the Communist Party and the ministries. (Gorbachev is a politician, not an economist, so his receptivity to economic change is molded more by events than by theoretical concepts.) The resistance to change is gradually being overcome, but there is a widespread perception of the need for a detailed plan (for example, in defense industry conversion). Prior Soviet history has accustomed people to working within a structure of elaborate plans, so that the lack of such a plan leaves many dissatisfied and at a loss as to how to proceed. It can be argued that part of the "Gorbachev solution" is to accustom the Soviet people to greater individual initiative and less devotion to plans. Whether designed or driven by events, the Soviet political and economic systems are most likely to continue to evolve gradually (barring a violent upheaval).

2. Changes in the Academy of Sciences

A striking institutional change that is likely to have profound influence on the course of development of Soviet science during the next few years is the recent change of leadership at a very large number of Soviet Academy of Sciences institutes, as well as the replacement of several academician secretaries. Institute directors over 70 years of age were required to resign *en masse*, to resume research under the administrative leadership of newly-chosen younger successors.

The enforced retirement of geriatric leaders of the Soviet Academy of Sciences is obviously another positive step for Soviet science (and technological development as well). Changing the leadership is bound to result in the infusion of support for new ideas as well as a critical review of "sacred cows" that had been protected by the old leadership. The net result cannot help but be an improvement in the Soviet Academy's research agenda. However, the new establishment figures are themselves not youngsters, so that this move by itself is unlikely to have a dramatic immediate effect. Still, the new leaders can have a significant effect if they open the Academy and its institutes to more democratic decision making. Such moves seem to be taking place.

The progress in democratization of the Academy has not been smooth, as illustrated by the initial unwillingness of the Academy bureaucracy to nominate Sakharov and Sagdeyev to the Congress of People's deputies. However, there are notable steps toward greater autonomy within institutes. For example, the individual laboratories at the Lebedev Physics Institute have much greater freedom of action under their new director than was the case when academician N. G. Basov was in charge. The institute has been reorganized as a federation of six scientific departments sharing common administrative services (Isakov, 1990). Academician L. V. Keldysh was elected director of the institute for a five-year term; he was elected by members of the two departments of the Academy to which the institute's departments report.

3. Improvements in VUZ Science

The Soviet system in which the best scientific research is done in Academy of Sciences institutes that are separate from institutions of higher education (VUZy) appears peculiar from the US vantage point. The US system of higher education (particularly but not exclusively at the graduate school level) is structured on the notion that teaching and research go hand in hand. In some instances, the gap in the Soviet system is bridged by prominent scientists who have dual affiliations with universities and research institutes, but this appears to be more the exception than the rule. There is also the anomalous case of Moscow State University, where there are groups of outstanding research scientists.

There are changes underway or being discussed to increase the interaction between the VUZy and research institutes, and otherwise involve the VUZy in research. There is even talk of creating "scientific and technical parks" centered around VUZy (Laverov, 1990).

4. Other Organizational Innovations

Soviet attempts at solving difficult problems have long involved creation of new bureaucratic institutions or reorganization of existing ones in an attempt to break down barriers between institutions. Of particular interest in relation to science and technology are Scientific-Production Associations (NPOs), Interbranch Scientific-Technical Complexes (MNTKs), State Interbranch Associations (GMOs), and Temporary Collectives.

The NPOs combine research institutes, design bureaus, pilot plants, and production facilities in one organizational umbrella. However, the key decisions are generally controlled by the ministry that oversees the separate entities, so that the result may be only the creation of an added layer of bureaucracy, and creation of an additional means to punish overly independent plant managers (Balzer, 1989).

The NPO mechanism has existed for many years, but the MNTKs were created in the late 1980s. The attempt is to broaden the NPO mechanism to cross ministry barriers, thus making it possible to include scientific and technical

experts from the VUZy and the Academy of Sciences, as well as from other ministries. There are 24 MNTKs, almost all in high technology (Kassel, 1989). Eight are headed by Academy of Sciences institutions. The MNTKs are already being criticized as ineffective, although a few appear to be working successfully. The MNTKs have limited resources, and the ministries in particular are unwilling to relinquish control of their best groups.

The MNTK "Personal Computers" was set up in 1986 under the Soviet Academy of Sciences, and was first directed by B. N. Naumov, who was also director of the Problems in Information Science Institute. Before his unexpected death in 1988, Naumov complained vigorously of his inability to obtain resources or cooperation from the Soviet ministries, and proposed joint ventures with Western companies as the best solution for obtaining PC design and production facilities for the MNTK (Snell, 1990).

The GMO is another attempt to breakdown ministerial barriers; it also appears not to be succeeding. The temporary collectives appear to be more than competitive with ordinary scientific research institutes (NIIs) in research and product development, but almost by definition are unable to carry products through to the pilot plant and production stages.

It is almost inevitable that there will be further attempts at reshuffling relationships between the various elements in the education, science, technology, and production complexes. Success in overcoming the barrier between research and production will require a different approach that incentivizes the production managers to alter their past practices.

E. DEFENSE INDUSTRY CONVERSION

The Soviet defense industry has long had the highest priority, with the civil sector obliged to be content with the residuals. What should be more natural, then, than to call upon the defense industry to try to help in the production of consumer products? This is not, in fact, a new idea. The defense industry has always produced some civilian products, and expansion of this output first blossomed in the late 1960s, and the civilian share of products manufactured by the defense industry has been estimated to have grown from about 20 percent in 1965

to 40 percent in 1985 (Alexander, 1990, and references therein). Calling upon the defense industry to cut back military production and substitute production of civilian products thus appears to be a logical extension of previous practice.

In the earlier part of the Gorbachev era, an attempt was made to revitalize the civilian economy by transferring defense industry managers to the civil production sector, and setting up civil analogs of the Military Industrial Commission (VPK) for machine building and for agriculture and food products. These experiments did not work, and their failures may have led the Soviet leaders back to the notion of conversion of defense industry capacity to civilian purposes.

The current Soviet notions of conversion are substantially more aggressive than those of the Brezhnev era. An actual reduction in military procurement was begun late in 1988. However, almost immediately there were complaints about the lack of a plan for the utilization of the excess personnel, facilities, and materials.

The course of defense industry conversion is still an uncertain one, and the overall strategy was being debated throughout 1989 and 1990, even as conversion was in fact taking place (Leskov, 1990). There are still proponents for transferring enterprises out of the military-industrial complex to the civilian sector, rather than investing more money in the defense ministries for civil production facilities.

At one stage, there was talk that "conversion" included the concept of expanded arms sales abroad to obtain foreign currency that could be used to buy consumer products abroad. This notion fails economically because most customers for Soviet arms do not have the required currency, and because it is counter to the recent Soviet initiatives at limiting the international traffic in arms. A related notion is an attempt to expand the Soviet share of the highly competitive international market in civil aviation. There has also been an attempt to provide space launch services to other countries, without significant success.

The moves made by Gorbachev to implement defense industry conversion and cut armed forces are likely to result in less total assets applied to science in support of the military. Conversely, there is a counter-argument that the Soviet fear of superior Western technology in military systems will keep their research base well funded, even while the armed forces shrink. However, consistent implementation of such a policy by military authorities would require a remarkable streak of self-denial. It is possible that Soviet military R&D will not shrink proportionately as much as military production and the armed forces, but some shrinkage would appear inevitable, to demonstrate a "commitment" to peace as well as to placate defense production workers and military officers who would feel that others should share their sacrifices.

Moreover, if the Soviet military are to have less support, they would be likely to be less willing to devote operational resources to obtaining field data for scientists and engineers, or to look at high-technology solutions to operational problems, unless it would result in increased funding for them. There should be some interest in high-quality equipment to compensate for lower force size.

There is no obvious substitute sponsor to pick up funding of science to compensate for the loss of military support. The open arguments in the Soviet scientific establishment and press about the value of manned space exploration indicate that the availability of new money for space-oriented science is unlikely. In fact, there appears to be considerable public resentment about the cost of the Soviet space program (*Trud*, 12 April 1989), and defenders of the program have been impelled to make public statements through the Soviet press stressing the "savings" and "spin-offs" attributable to various space programs.

It is conceivable that the Soviet Union could launch a technology initiative analogous to those undertaken by the European Community, such as EUREKA and ESPRIT, to make use of the efforts of scientists and engineers no longer needed for military and space programs, but there is no such effort yet afoot. (Interestingly, Yugoslav and Hungarian firms are now participating in EUREKA.)

CHAPTER VIII

PROJECTIONS FOR THE FUTURE

A. INTRODUCTION

We write as great changes are taking place in Soviet society. The changes are fundamental and more far-reaching than anything since Stalin established the course of Soviet society at the end of the 1920s. Many changes appear improvised in response to circumstances, and the full spectrum of changes has not yet appeared. There is always the possibility of some reversals of course, though it can be argued that a return to the brutal repression of previous times is highly unlikely. If attempted, it would entail tremendous costs, especially in science and technology. Nevertheless, a transition to some form of market economy, though under discussion for a few years, is still not assured, and the present social ferment in the Soviet Union could lead to unpleasant times.

The widespread availability in the Soviet Union of correct information about the West (and the Soviet Union itself) via external broadcasts has had its effect on reinforcing the momentum for change, and it would be well-nigh impossible for a future Soviet regime to cut off this information flow, if it were to try. The important point for this paper is that the great majority of Soviet citizens have become aware that their misery is not necessary, and that people in some other countries have much greater personal comforts (as well as more personal freedom). Discontent appears to be pervasive throughout Soviet society, except, presumably, among those privileged individuals who fear that their relative advantages are likely to disappear. One of the ways in which this discontent can now be expressed is to emigrate, and highly skilled scientists are among those exercising that option.

In this report, we assume the continuation of the course represented by *glasnost* and *perestroika*, including a decrease in the relative priority given to the Soviet military establishment. We will try to project the future development of Soviet information sciences within that context, as discussed in Chapter VII. Within these broad constraints, substantial uncertainty remains. The modest tinkering to date with the Soviet economic system is clearly insufficient to foster an entrepreneurial environment of the sort familiar to the US computer and

communications industries, just as it is unlikely to provide the needed incentives in other areas of the Soviet economic system.

B. LIKELY SOVIET PROGRESS IN THE INFORMATION SCIENCES

It is clear that the current restructuring moves in the Soviet Union generally will have positive effects on the progress of the information sciences, at least in the longer run. It is unlikely that the improvements will be rapid or dramatic. The surest way for the Soviet Union to obtain modern, reliable equipment is to import it from the developed world, and this is still limited primarily by the Soviet lack of hard currencies. The opening of the East European countries to the West may actually decrease their need to trade with the Soviet Union, so that, as a significant example, East German technical products now sent to the Soviet Union may be sold in Western markets instead. Setting up joint-venture factories will take time and, even though highly educated, the Soviet work force has a built-in tradition of lethargy. The long years of guaranteed jobs (except for political malcontents or minorities) and brainwashing about the abuses of "profiteering" have accustomed most Soviet workers to doing little work for little reward. A computer scientist who traveled to the Soviet Union to discuss computer-related joint ventures (Dyson, 1989) estimated that the typical Soviet government worker operates at 10 percent of capacity, while co-op workers operate at 20 percent. This bears little resemblance to the motivation of the workforce in Silicon Valley.

The Soviet ambitions for developing foreign exchange in the information industry are unmatched by capabilities. The principal Soviet asset is a cadre of bright, educated people. However, the people lack experience in developing and marketing commercial products in a competitive environment, and are hindered by the primitive Soviet infrastructure for supplies and communications.

The most likely high-technology export successes for the Soviet Union should be in computer software, since this is an area in which the primary input by far is intellectual labor. It is unlikely that the Soviet Union can compete in building very large or complex programs, but they might be competitive in programs for micro- and minicomputers. There is already a computer game, Tetris, on the world market that was developed by two Soviet computer programmers,

though the Soviet programmers have not profited significantly from the introduction because of their lack of business experience (*Wall Street Journal*, 8 June 1990). JV Dialog is a US/Soviet computer software and hardware joint venture involving an American trading company (Management Partners International), and several Soviet partners, including KamAz (a truck manufacturer) and Moscow State University (*BLOC*, December 1989/January 1990). In addition to representing Microsoft in the Soviet Union, Dialog has agreed to provide software to Hewlett-Packard.

A related area of possible Soviet achievement would be cooperation in the development of technical databases. For example, there is an opportunity in automating the traditionally excellent Soviet system for abstracting and interpreting scientific literature. The Soviet Union has large numbers of scientific workers, many of whom have had excellent and extensive training in their respective disciplines. Prominent Soviet scientists traditionally have been synthesizers of important areas of science (through textbooks and review articles). In addition to tradition, this may reflect the fact that review and synthesis require less external resources than laboratory research. Reviews of foreign developments and other continuing educational activities also have been crucial to maintaining capability in the relatively isolated Soviet scientific community, most of whose members have had to operate outside the mainstream of international science. Whatever the reasons, the Soviet abstract publication *Referativnyi Zhurnal* (which is still produced with wide voluntary participation by working scientists) and the Soviet review journals in the *Uspekhiy* series have excellent reputations in the international scientific community.

There is an excellent potential fit here between the unique Soviet ability and willingness to provide large amounts of highly skilled intellectual labor, on the one hand, and the Western ability (and, given the return, probable willingness) to provide the tools needed to automate entry of and access to this vast resource and to integrate it (physically and economically) with other international technical information systems. The first serious attempt at implementing this concept is the JV Scitechinform mentioned in Section VII.C.3.

The Soviet Union will continue to experience problems in manufacturing equipment supportive of the information sciences. It should eventually achieve

(most likely by construction of a foreign-designed plant through a joint venture) the long-awaited goal of volume production of PCs, possibly within the next three to five years; for example, JV Dialog hopes to be producing 500,000 PCs per year in a plant in Kishinev, Moldavia by 1995 (Snell, 1990). However, by then those PCs will be several years behind the leading edge of the world state of the art.

The Soviet manufacture of larger machines will continue to lag, until a more realistic link is forged between design and production responsibilities. Interestingly, Velikhov (1989), in a long report to the Soviet Academy on computer accomplishments in 1988, admits that production in industry of machines developed by the Academy "is being held up." This appears to indicate a continuation of the long-standing situation, wherein the industrial ministries are unable or unwilling to produce the computers designed by the Academy (Wolcott and Goodman, 1988; Snell, 1990).

C. IMPACT OF PROGRESS ON OTHER AREAS OF SCIENCE

The access of Soviet scientists and engineers to computers is improving slowly. The impact of this improved access will vary from one technical field to another. It is likely that the access (in needed quantities) to machines of the IBM AT class will make a significant difference in a number of areas such as process control in industry (including microelectronic chip manufacturing), automatic control of accelerators and other complex experimental devices, data reduction from scientific experiments, and relatively simple (by US standards) computer modeling and simulation. This computer capability should improve the Soviet standing in many scientific and technical fields. It is unlikely, however, that the Soviet Union will be able to gain on the West in those areas that require the most complex and sophisticated computer processing capabilities such as activities in image processing, pattern recognition, other areas in artificial intelligence, and large three-dimensional simulations (such as climatology and weather prediction).

The net effect on the course of Soviet science and technology from the many factors discussed in Chapter VII should be positive in the long run, though much is dependent on the continuation of *perestroyka*. The history of Soviet society is

filled with examples of attempted reforms (though of smaller magnitude) that did not have a significant effect. The current set of reforms is so comprehensive that the initial effect may be to slow progress in many areas while the various interests try to cope with the new arrangements.

In particular, the liberalization of information transfer both within the Soviet Union and with other countries inevitably will increase the intellectual vitality of Soviet science and technology. The liberalization of travel should have the same effect, but carries with it the danger of a "brain drain" in the short term.

The process of "conversion" of the Soviet defense industry plus the moves toward self-financing of research institutes are likely both to create temporary disarray and to decrease the total funding available to Soviet science.

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APPENDIX A

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APPENDIX B
FASAC REPORT TITLES

(* asterisk before title indicates report is classified)

(completed)

- FY-82/83** * Soviet High-Pressure Physics Research
Soviet High-Strength Structural Materials Research
Soviet Applied Discrete Mathematics Research
* Soviet Fast-Reaction Chemistry Research
- FY-84** Soviet Physical Oceanography Research
Soviet Computer Science Research
Soviet Applied Mathematics Research: Mathematical Theory of Systems, Control, and Statistical Signal Processing
Selected Soviet Microelectronics Research Topics
* Soviet Macroelectronics (Pulsed Power) Research
- FY-85** FASAC Integration Report: Selected Aspects of Soviet Applied Science
Soviet Research on Robotics and Related Research on Artificial Intelligence
Soviet Applied Mathematics Research: Electromagnetic Scattering
* Soviet Low-Energy (Tunable) Lasers Research
Soviet Heterogeneous Catalysis Research
Soviet Science and Technology Education
Soviet Space Science Research
FASAC Special Report: Effects of Soviet Education Reform on the Military
Soviet Tribology Research
Japanese Applied Mathematics Research: Electromagnetic Scattering
Soviet Spacecraft Engineering Research
Soviet Exoatmospheric Neutral Particle Beam Research
Soviet Combustion Research
Soviet Remote Sensing Research and Technology
Soviet Dynamic Fracture Mechanics Research
- FY-86/89** Soviet Magnetic Confinement Fusion Research
Recent Soviet Microelectronics Research on III-V Compound Semiconductors
Soviet Ionospheric Modification Research
Soviet High-Power Radio Frequency Research
Free-World Microelectronic Manufacturing Equipment

(completed/cont.)

FY-86/89 FASAC Integration Report II: Soviet Science as Viewed by Western Scientists
Chinese Microelectronics
Japanese Structural Ceramics Research and Development
System Software for Soviet Computers
Soviet Image Pattern Recognition Research
West European Magnetic Confinement Fusion Research
Japanese Magnetic Confinement Fusion Research
* Soviet Research in Low-Observable Materials
FASAC Special Study: Comparative Assessment of World Research Efforts on
Magnetic Confinement Fusion
FASAC Special Study: Defense Dependence on Foreign High Technology
Soviet and East European Research Related to Molecular Electronics
Soviet Atmospheric Acoustics Research
Soviet Phase-Conjugation Research
FASAC Special Study: Soviet Low Observable/Counter Low Observable Efforts:
People and Places
Soviet Oceanographic Synthetic Aperture Radar Research
Soviet Optical Processing Research
FASAC Integration Report III: The Soviet Applied Information Sciences in a Time of
Change

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FY-86/89 Precision Timekeeping Research in the Soviet Union
Soviet Satellite Communications Science and Technology
West European Nuclear Power Generation Research and Development
* Radiation Cone Research
FASAC Special Study: Non-US Artificial Neural Network Research

FY-90/91 Soviet Chemical Propellant Research and Development
Soviet Optoelectronics Research
Soviet Parallel Processing Research
Soviet Nonlinear Dynamics Research
Foreign Research Relevant to Countering Stealth Vehicles
Soviet Research in Penetration Mechanics
Soviet and Free World Bandpass Radome Research and Development
FASAC Special Study of Non-US Artificial Neural Network Research
Soviet Macroelectronics (Pulsed Power) Research

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