Soviet Science and Weapons Acquisition

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Soviet Science and Weapons Acquisition

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PREFACE

This report was sponsored by the National Academy of Sciences to aid its Panel on Scientific Communication and National Security. The intent of the report is to inform the Panel's deliberations by an independent assessment of one facet of a complex policy issue: the relationship between Soviet weapons development and the scientific community. Rand does not purport to develop here a complete policy framework for dealing with the issue of scientific information transfer. Because of the time constraints imposed by the Panel's schedule, we have not had the opportunity to perform new research, but rather have refocused and synthesized past research to fit the Panel's interests.

SUMMARY

The principal actors in Soviet science and weapons acquisition include the nine military-production ministries; the Ministry of Defense; the military and civilian science sectors; and two coordinating agencies--the powerful Military-Industrial Commission (VPK), and the State Committee for Science and Technology (GKNT). The "military science" sector is defined as comprising the research institutes of the military-production ministries, and institutes directly subordinated to the Defense Ministry and the military services. The "civilian science" sector consists of the USSR Academy of Sciences, its Siberian Division, and the regional academies of sciences; the research component of the higher educational institutions; and the research establishments of the civilian production ministries. Soviet science organizations are marked by their separation--by administration, stage of R&D, and scientific field.

Soviet weapons acquisition is shaped by formal procedures, the planned economy, a powerful and demanding customer, and bureacratic conservatism. Designers therefore face strong disincentives to use advanced technology or to look toward science for solutions to design problems. Incentives promote the art of design, whereby weapons developers make as much use as possible of available components and materials. The VPK and the Party overcome some of the impediments to R&D arising from the unresponsive economy and other sources through their intervention and coordination.

The general tendency in Soviet weapons is for relatively simple designs; designs that make much use of common subsystems, components, parts, and materials; that are evolutionary in their improvements; and that are comparatively limited in performance. Important exceptions to the tendency exist, however, and weapons are becoming more complex, calling on more diverse technologies than in the past.

Where once a Soviet production ministry could be close to self-sufficient with its own stable of institutes and design bureaus, today an array of talents is necessary that crosses organizational and sectoral boundaries. This is true for production and testing, as well as for component development. Therefore, despite the conservatism of the process, the changing character of the systems is placing greater demands on science.

Increasingly, the political leadership has emphasized the importance of science, and has promoted the use of contract research in science establishments. Civilian science has had increased incentives to perform military research. Individual scientists also participate in military affairs as consultants and as members of panels and commissions. Key individuals (usually institute directors) act as science entrepreneurs and promote the ideas of scientists before decisionmakers.

There has been a severalfold increase in civilian science support for the military since the 1960s. Its contributions mainly precede the formal weapons acquisition process. It appears to be directed toward developing the science and technology base and maturing the technologies that will later flow into the risk-avoiding weapons R&D process.

Civilian science has also made major contributions to military "big science" programs such as high-energy lasers and, most likely, high-energy-beam weapons research.

The lines are blurring in the Soviet Union between pure and applied research, military and civilian science, Academy and industry. For many years in the 1960s, and historically, the Academy system was truly "academic," but policies intended to promote greater science involvement in the affairs of the nation have had some effect. Scientists and institutions, especially those at the forefront of their fields, are more likely to be involved in military science--through a variety of mechanisms--than twenty years ago. Consequently, the likelihood that Soviet science contacts with the West will prove useful to the Soviet military has also increased.

It may be advisable to impose restrictions on transfers of scientific information to a potential enemy if the information is controllable; if it generates significant positive resource-enhancing effects or is likely to lead to particularly undesirable capabilities (from the U.S. viewpoint); if these capabilities have important effects on U.S. military efforts; and if the gains from avoiding these effects through controls are not outweighed by the direct and indirect costs that the controls impose on domestic science and research.

Four categories of scientific information illustrate key issues for analysis: (1) scientific theory; (2) knowledge of activities in specific areas; (3) know-how; and (4) instrumentation and equipment. The Soviet Union does much better with theory than with laboratory hardware. The transfer of know-how and equipment is more amenable to control than theory and knowledge of a field.

Most arguments for the control of scientific information transfer break down into three elements: (1) resource-enhancement effects; (2) effects on particular capabilities; and (3) influence on the recipient's world view. The primary task of the analysis of science transfer should be to elucidate the degree to which and the way in which a transfer could aid the military effort of a potential enemy.

ACKNOWLEDGMENTS

The main lines of this report grew out of discussions with Robert Perry and Thane Gustafson of Rand. An earlier draft benefited from the detailed comments of Rand colleagues Emmett Keeler and Nancy Nimitz, and those of David Holloway of the University of Edinburgh. The sections on science ties to the military (Sections V-VII) were derived from Rand research conducted with Abraham Becker.

CONTENTS

I. INTRODUCTION

The relationship between science and the Soviet military has been intensifying over the past two decades. The forging of tighter and more numerous links is the net result of opposing sets of forces: those that act to preserve the technological and organizational status quo; and those that encourage the adoption of new technologies and mature the scientific base. An enduring set of forces acts to limit change and the use of new technology and science in the Soviet Union, including the manner in which Soviet weapons acquisition is organized and managed; the procedures--both formal regulations and customary modes of behavior--that govern the process; and the motivations and constraints that shape actions. But, acting in the other direction, the evolving nature of perceived military needs, the movement of science and technology itself, and policies intended to alter connections between science producers and science users have generated forces for change. The resulting alteration in the relationship between science and the military affects the process of science information transfer both within the Soviet Union and between the Soviet Union and other countries.

This report describes Soviet weapons acquisition and its ties to Soviet science; it then discusses the logic of restricting the transfer of scientific information, which is categorized into several classes. Our knowledge of Soviet weapons acquisition and its ties to the science community is based on a great deal of past research. Although most of that research has been directed toward purposes other than the question of scientific communications and national security, I have attempted to refocus the literature to illuminate this question.[1]

Before proceeding, however, we must realize that not much is known about the way in which science is transformed into useful products in any country, and that even less is known about what affects the transformation. When we turn to Soviet affairs, especially those dealing with the military, our information is even more incomplete. With these warnings, we can proceed.

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[1] Previous studies by the author form the basis for the present report: R&D in Soviet Aviation, The Rand Corporation, R-589-PR, 1970; Armor Development in the Soviet Union and the United States, The Rand Corporation, R-1860-NA, 1976; The Process of Soviet Weapons Design, The Rand Corporation, P-6137, 1978; Modeling Soviet Defense Decisionmaking, The Rand Corporation, P-6560, 1980; "Weapons Acquisition in the Soviet Union, United States, and France," in Frank B. Horton III, et al. (eds.), Comparative Defense Policy, Johns Hopkins University, Baltimore, 1974; Decisionmaking in Soviet Weapons Procurement, Adelphi Papers 147-148, International Institute for Strategic Studies, London, Winter 1978-79. Other relevant studies are cited in the text.

II. ORGANIZATIONS IN SOVIET WEAPONS R&D AND SCIENCE

The principal actors in Soviet science and weapons acquisition include: the producers--the nine military-production ministries; the buyers and users of the products--the Ministry of Defense; the military and civilian science sectors; and two coordinating agencies--the powerful Military-Industrial Commission (VPK: *Voenno-promyshlennaia kommissiia*), and the State Committee for Science and Technology (GKNT: *Gosudarstvennyi komitet po nauke i tekhnike*). In this report, the "military science" sector is defined as comprising the research institutes of the military-production ministries, as well as institutes directly subordinated to the Ministry of Defense and the military services. "Civilian science" consists of the USSR Academy of Sciences, its Siberian Division, and the regional academies of sciences; the research component of the higher educational institutes; and the research establishments of the civilian production ministries.

DEFENSE INDUSTRY

Each of the nine military-production ministries is responsible for the research, design, development, and production of weapons or their components. (See Table 1.) Some civilian production ministries also contribute to military R&D in a minor way; and several of the military-production ministries make substantial contributions to non-defense products, especially the Aviation, Shipbuilding, Radio, Electronics, and Communications Ministries.

Table 1

MILITARY-PRODUCTION MINISTRIES AND REPRESENTATIVE PRODUCTS

Ministry of Aviation Industry: Aircraft, aerodynamic missiles

Ministry of General Machine Building: Ballistic missiles, space-launch vehicles, spacecraft

Ministry of Defense Industry: Conventional ground forces weapons, small arms, antitank guided missiles

Ministry of Shipbuilding Industry: Naval vessels, submarines, merchant vessels

Ministry of Medium Machine Building: Nuclear weapons

Ministry of Radio Industry: Computers, avionics, guidance equipment

Ministry of Electronics Industry: Integrated circuits, electronics components

Ministry of Machine Industry: Ammunition, ordnance

Ministry of Communications Equipment Industry: Radio, telephone, television, other communications equipment

The bulk of applied military research and development is performed in the research institutes and design bureaus of the military-production sector. More than 90 percent of applied R&D in the Soviet Union is performed in the industrial sector, including the military-production ministries. But the industrial sector also performs a significant share of basic research, varying over the years roughly from 8 to 23 percent of the national total.[1] However, because of the far-ranging scope of scientific and industrial activity engaged in by defense industry, it is often necessary for them to go beyond their organizational boundaries for scientific support, particularly in basic research. They require

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[1] Louvan E. Nolting, *The Financing of Research, Development, and Innovation in the U.S.S.R., By Type of Performer*, U.S. Department of Commerce, Foreign Economic Reports FER-No. 9, April 1976, p. 45.

some aid in weapons development itself, but generally their own research institutes adequately support the design bureaus that develop the systems and the plants that produce them. The highly directed nature of the industrial ministries' tasks renders them less able to conduct the required research on new technologies or on systems based on new or unfamiliar principles. It is in these areas that civilian science makes its greatest contribution to the military and provides flexibility to the tightly organized system.

An important feature of Soviet industrial structure is the organizational separation of functions and of products. Research is performed in research institutes to support their ministries' product lines; design and development takes place in design bureaus; and production in factories. Ordinarily, each type of organization is administratively separate from the others and operates under different procedures and incentives. The ministries, too, are highly independent of one another; Russians often say that dealings between ministries are more difficult than negotiations between hostile countries. Since the military production ministries operate, to a large extent, under the same system of incentives and constraints as the centrally planned civilian sector, several mechanisms have been adopted to ameliorate its more deleterious effects on military-related efforts. The Military-Industrial Commission (discussed below) performs some of these buffering functions.

MINISTRY OF DEFENSE

Each of the military services has one or more directorates charged with managing its weapon developments. To support this function, these armament directorates maintain research institutes to provide technical expertise to the buyer and to manage contracts. Central agencies of the Defense Ministry also have their own institutes. Staffed with capable civilian and military personnel, these institutes often act as the link between the military requirement and the weapon developer. They maintain close contacts with the industrial institutes and design bureaus, keeping aware of technical advances and possibilities as they develop. These military institutes may perform preliminary design studies and engage in research on special military needs, such as reliability or maintainability problems, but they do not appear to do detail design work or basic research.

CIVILIAN SCIENCE

The premier establishments for fundamental research are the 200 research institutes associated with the USSR Academy of Sciences. The Siberian Division (a mini-academy of 50 institutes that is largely independent of the Soviet Academy) is strongly oriented toward cooperation with industry in the transfer of science and technology from laboratory to application. The regional academies, especially the Ukrainian Academy of Sciences (with its pilot production facilities and joint industrial laboratories), also tend to be better organized for industrial support and to pay greater attention to the application of research than the main division of the USSR Academy.

The universities and other institutes of higher education (*VUZy*) comprise the second part of what is defined here as civilian science. Research performed in this sector appears to be less coordinated and more fragmented than that performed in the academy system. One reason is that the great bulk of *VUZy* research is financed by contracts rather than by the State budget, leading to a diverse set of relationships and patterns of scientific involvement with an array of clients. Many of the researchers in the higher education sector participate on a part-time basis. Much of this research is concentrated in a few eminent universities and polytechnical institutes, with the rest scattered in small projects across the universe of educational institutes. Since the late 1950s, the Soviet leadership has taken several steps to bring the VUZy closer to both the Academy institutes and to industrial R&D, particularly through the incentives of contract research.

The research establishments of the civilian production ministries comprise the third component of civilian science. Organized in similar fashion to the military production sector, these institutes participate in military R&D to the extent that their ministries contribute to military systems.

COORDINATING AGENCIES

The Council of Ministers has created several specialist commissions concerned with important sectors of the economy. The most powerful of these is the VPK, with representation from the military-production ministries, the Ministry of Defense, the State Planning Commission (Gosplan), and probably the Central Committee Secretariat.

As monitor and coordinator of military R&D and production throughout the economy, the VPK reviews proposals for new weapons with respect to their technical feasibility and production requirements. Draft decrees submitted by lead design organizations specify participants, tasks, financing, and timetables for a project. When approved, the draft becomes a "VPK decision," which is legally binding on all parties concerned.

The VPK is instrumental in planning and supervising major technological programs with military uses, such as the development of integrated electronic circuit design and production. It also appears to be involved in the planning and coordination of military-related activities in the Academy of Sciences.

Despite the overall involvement of the VPK in most aspects of weapons acquisition, it is primarily an implementing organization rather than one that originates policy. It is the job of the VPK to police military priorities throughout the economy and to see that decisions are actually carried out. Nevertheless, because the VPK originates information, sponsors technical analyses, screens recommendations, approves them, and monitors results, it has a more than marginal influence on science, technology, and weapons.

The State Committee for Science and Technology (GKNT), another agency of the Council of Ministers, was established in 1965 (as a successor to a series of earlier agencies) to plan, oversee, and regulate scientific research and development, and to recommend the introduction of technological innovations throughout the economy. Evidence on the importance of the GKNT in military affairs is mixed; it has formal authority over all scientific organizations "regardless of jurisdiction," but (according to one expert) probably not over the defense sector.[2]

The Committee has no direct authority over the ministries or the Academy of Sciences system; it attempts to shape events largely through

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[2] Louvan E. Nolting, The Structure and Functions of the USSR State Committee for Science and Technology, Foreign Economic Report, No. 16, U.S. Department of Commerce, 1976, p. 2.

moral suasion (working through a network of subcommittees and scientific councils) or through leverage applied through its influence over foreign contracts, technology, and cooperation. Indeed, the GKNT departments dealing with foreign activities, such as those just mentioned, were said to be larger and more influential than its other departments.[3]

The GKNT may have some effect on military science through its formulation of the "basic scientific and technical problems" of the country and its working out of some 200 programs to deal with these problems; this is the section of the science and technology plan on which the GKNT concentrates. In particular, for the so-called "inter-branch problems," the GKNT controls an important share of the financing and tries to settle disputes among participating organizations.[4] Although we have no evidence on this point, it seems likely that the military would want to participate in the identification and inclusion of such problems in the science plan so as to better influence the course of the nation's scientific effort.

SEPARATION OF SCIENCE PERFORMERS

The institutional and individual performers of science in the Soviet Union are marked by their separation--by administrative subordination, stage of R&D, and scientific field. As a project progresses along the successive phases of R&D, it is relayed from one institution under one system of authority to another institution in another organizational structure. Thus, a new technology may begin in a

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[3] Morris Bornstein et al., The Planning and Management of Industrial Research and Development in the U.S.S.R., Science Policy Working Group, Joint US-USSR Science and Technology Exchange Program, SRI International, June 1980, p. 47.

[4] Paul M. Cocks, Science Policy: USA/USSR: Vol. II, Science Policy in the USSR, National Science Foundation, 1980, p. 40.

research institute of the Academy of Sciences, transfer to a research institute of an industrial ministry, enter into detailed design and development in a design bureau of the ministry, and finally be produced in one or more ministry factories.

In a complex project, since each of these organizations tends to specialize according to scientific field or class of products, several institutes, ministries, and *VUZy* could become involved; management and oversight would be the responsibility of a research institute or other agency in an armaments directorate of the military service customer. The VPK, through its project decrees and supra-ministerial status, exercises a necessary coordination over this organization-hopping activity.

Despite organizational separation and field specialization, there is considerable functional overlap among the various R&D performers; that is, some Academy institutes may develop and produce products, whereas a number of ministry institutes are leaders in basic research. Moreover, this overlap is growing as several policies (discussed below) act to break down the barriers originating in organizational separation and make the institutions on each side of the boundaries more alike.

III. SOVIET WEAPONS ACQUISITION PROCESS

Soviet weapons acquisition is highly constrained in a number of ways. One of its salient characteristics is the control and minimization of risk. An important technique used to control risk is the formal process outlining the steps to be taken in any development project.[1]

These procedures establish standardized project steps from the statement of requirements to delivery of the product. (This sequence will be referred to here as the "formal" acquisition process.) Each project, therefore, progresses according to a stipulated sequence that specifies the tasks to be carried out in each phase, the review procedures by the user, and acceptance routines. With each succeeding step, the technical possibilities become less uncertain, less research-oriented, and more narrow and applied. Science input, therefore, if it is to occur at all in the formal process, is most likely to enter at the very early stages.

The general inflexibility of the centrally planned economy is an additional constraint on weapons R&D. Because of unreliability of supply and inability to rely on contracts or plans to guarantee deliveries, designers are reluctant to ask for new products from suppliers they have not dealt with in the past. They face strong incentives to use off-the-shelf components that can be counted on to perform to acceptable (though perhaps not optimal) standards.

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[1] These steps have been standardized throughout civilian and military industry and are known as the "Unified System of Design Documentation" (YeSKD).

Over the past fifty years, since the present economic system was put into place by Stalin, military R&D managers have taken many steps to cope with the system. Design handbooks closely control the choice of technologies, components, and manufacturing techniques. Standards organizations at the national level, in the military-production ministries, and in plants and design bureaus ensure that standardized parts and techniques are used to the greatest possible extent. But perhaps most important in the Soviet environment, the buyer (i.e., the Ministry of Defense) has real authority over the product. The military can demand that an agreed-upon product be delivered as promised. Although vigorous negotiations may precede a design bureau's acceptance of a project, the responsible organization is expected to deliver, once the project is defined and accepted.

For all of these reasons, especially the last, designers are reluctant to venture into new realms. They face powerful disincentives to use advanced technology or to look toward science for solutions to their problems. Given these constraints, the art of design is promoted where the designer works with available materials--often creatively, sometimes with genius.

The number of conservative forces acting on the system, together with the necessity of coordinating complex development projects across many organizational boundaries--military, civil, ministerial, Academy--would normally hinder military R&D, as it hinders the civilian sector. However, the Communist Party and the government have given military R&D the highest priority over materials, manpower, and production capacity. These priorities are enforced by the VPK, which also coordinates activities that cross organizational lines. The VPK and Party can intervene to ease bottlenecks or loosen bureaucratic snags. But they are still acting within the Russian system. With the increasing complexity of modern weapon systems that incorporate a broader range of technologies and inputs than in the past, the military is likely to become increasingly dependent on the rest of the economy and could find it more difficult in the future to avoid the consequences of the civilian sector's patterns of behavior.

IV. CHARACTERISTICS OF SOVIET WEAPON DESIGN

CONSTRAINED USE OF TECHNOLOGY

Given the bounds on technical exuberance imposed by the process described above, it should not be surprising that the general tendency in Soviet weapons is for relatively simple designs that make much use of common subsystems, components, parts, and materials; that are evolutionary in their improvements; and that are comparatively limited in performance. Of course, exceptions to this pattern exist. The evidence is best viewed as a statistical distribution, especially revealing when compared with another country's experience. The bulk of the evidence suggests that the central tendencies in the distribution of characteristics of Soviet and U.S. weapons are distinctly separate, although there is considerable overlap between them.

One concrete example illustrates the general tendencies described above. The Soviet SA-6 surface-to-air missile was analyzed by U.S. defense industry specialists, who took note of its solid-fuel, integral rocket/ramjet engine. The design, considered "unbelievably simple but effective," permitted such simplifications as the elimination of a fuel control system, sensors, and pumps to control fuel flow.[1] However, because the system cannot be modulated for maximum performance as a function of speed and altitude, it suffers performance degradation off its design point when it loses oxidative efficiency. The analysts also found that the SA-6 employed identical components to those found in several other Soviet surface-to-air and air-to-air missiles whose deployment dates spanned more than a 10-year period.

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[1] "U.S. finds SA-6 to be Simple, Effective," _Aviation Week and Space Technology_, December 5, 1973, p. 22.

An exception to this pattern--an outlier in the distribution--is the T-64 tank. For 35 years, Soviet tank deployment was the epitome of the standard design pattern. But in the late 1960s, the T-64 appeared with almost all subsystems of new design, and some with advanced performance and technology. The tank carried a new engine and transmission, new suspension, a completely new and modern fire-control system, advanced armor, and a larger gun scaled up from its predecessor, the T-62; for the first time, a deployed tank had an automatic loader, which reduced crew size from 4 to 3, and permitted the T-64 to be even smaller than the compact T-62.

GROWING COMPLEXITY

The T-64 example illustrates an important point. Although strong conservative forces act on the design process, there is some movement. Science and technology advance, as do military requirements. Weapons performance is constantly enhanced; missions grow more complex, difficult, and numerous. Some T-64 tanks carry a laser range finder, digital fire-control computer, electro-optical tracking system with image processors, and armor arrays of several materials.

Not only do weapon systems perform more things, but each thing also calls on more technology and science than in the past. A gun barrel firing a projectile at 6,000 ft/sec instead of 3000 ft/sec requires more advanced metallurgical understanding, materials, and production, measurement, and test techniques than the older guns. Today's tanks call for a greater diversity and a broader source of scientific and technical expertise in their subsystem technologies, materials, and components. And tanks are among the more mature and technically stable systems in modern armories.

Where once a Soviet production ministry could be close to self-sufficient with its own stable of institutes and design bureaus, today an array of talents is necessary that crosses organizational and sectoral boundaries. This is true for production and testing, as well as for component development. Therefore, despite the conservatism of the process, the changing character of the systems is placing greater demands on science.

V. SCIENCE TIES TO THE SOVIET MILITARY

Increasingly complex systems are only one of the forces bringing science and the Soviet military closer together. The military leadership now is more experienced in technical and scientific affairs than in the past, when operational experience rather than technical expertise was the key to the top posts. The careers of the present Minister of Defense, Chief of the General Staff, and several deputy defense ministers have included stints as weapon developers and scientific managers of advanced technology programs. Brezhnev himself spent several years as a Party Secretary with responsibility for coordination of military industry and especially ICBM development. Former Defense Minister Marshal Grechko wrote explicitly of the need for a "unified military-technical policy"; one of the objectives of such a policy, he said, was to direct R&D, including fundamental research, to problems of military interest.[1]

The political leadership has stated a belief in the importance of science to national economic growth and productivity. In recent Five-Year Plans, Brezhnev has proclaimed a shift in emphasis from the Stalinist focus on quantitative goals to quality and efficiency--a shift that he figures could take at least a generation to accomplish. Though such proclamations are often only rhetoric, several concrete policies have been adopted that are intended to bring science closer to application.

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[1] Vooruzhennye Sily Sovetskogo Gosudarstva, 2d ed., 1975, pp. 193-195.

One of the more important of these policies has been the emphasis, since the late 1960s, on contract research on a cost-accounting (*khozraschet*) basis between science performers and clients. This has been part of a broader development in which new ties are being formed between civilian science and industry; the Academies of Sciences see themselves now as having an important role to play in innovation. Because of officially promoted contracting policy, combined with stable or reduced financing of science enterprises from the State budget, research institutes have actively sought potential customers. The military, with its seemingly limitless budgets, has become a choice target.

Civilian science contract work for the defense sector could be a significant proportion of all (defense and civilian) contract research. In 1975, about 12 percent of the total work of the USSR Academy of Sciences was financed by contracts; for the Siberian Division and the Ukrainian Academy, contract research was a considerably larger proportion of the total at roughly 20 percent and 38 percent, respectively.[2] Individual academic institutes report up to 80 percent contract financing. From 1962 to 1975, contract funding in the Ukrainian Academy increased at a rate of 18.5 percent per year, whereas non-contract funding from all other sources grew at less than half that rate.[3] In higher education institutes, contract research accounts for more than 80 percent of all R&D, although these institutions are

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[2] Cocks, op, cit., pp. 99-100.

[3] Thane Gustafson, *Selling the Russians the Rope? Soviet Technology Policy and U.S. Export Controls*, The Rand Corporation, R-2649-ARPA, 1981, pp. 61, 65.

responsible for only a small share (about 5 to 6 percent) of the national R&D effort. Although information is scarce on military R&D in the VUZy, it should be noted that an increasingly important role is being played by production ministry laboratories created within the educational institutes, at the expense of the client ministry.[4]

The Institute of Nuclear Physics at Moscow State University is an interesting example of the growth of contract research. According to a former staff member, the Institute is formally attached to and managed by the Physics Department, which supports some 500 faculty from the State budget. The self-supporting institute, however, employs more than 3000 people, who are engaged in a wide variety of defense, industrial, and scientific tasks.[5]

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[4] Julian Cooper, Innovation for Innovation in Soviet Industry, Center for Russian and East European Studies, University of Birmingham, England, 1979, p. 36.

[5] Lawrence L. Whetten, Management of Soviet Scientific Research and Technological Development--Some Military Aspects, School of International Relations, Graduate Program in Germany, University of Southern California, 1979, p. 46.

VI. TYPES OF LINKAGES BETWEEN SCIENCE AND THE MILITARY

CONTRACTS

Scientists participate in military affairs through a variety of mechanisms. Contracting is one of the most important. Not only did the directives encouraging contract research legitimize the activities of those research managers and institute directors with a desire to do more applied work, but it also provided the incentives to do so for the scientific entrepreneur as well as for the ordinary scientist who was simply responding to opportunities.

The chief incentive has been the provision of laboratory facilities, instrumentation, expensive equipment, experimental designs and models, and capital construction that flows from contract research generally, and from military research in particular. With the priorities of military sponsorship, a laboratory can obtain scarce materials and supplies, and develop new areas of research.

Because of these benefits, grantsmanship has become a rewarded talent; one technique involves the writing of proposals and institute plans to fit key phrases in Party programs; another, described to the author, requires frequent visits of researchers to government agencies in Moscow to keep abreast of plans and new developments. Some of this research, then, is not very different from what it would have been under other funding arrangements, whereas in other cases, responsiveness to potential contractors has helped to redirect institute interests to fit the needs of clients. It is not possible, though, to estimate the relative proportions in the two different categories.

Not all of the incentives to do military contract research are positive. On a personal level, several disadvantages accrue to military research, especially if it is classified, and most especially if it takes place in closed, secret laboratories. Apart from the rigidity of security controls, the most frequently mentioned disadvantages are the constraints on foreign travel and on open publication of research findings. Foreign travel, always problematic for Soviet scientists, is made almost impossible by close ties to military research. This policy was underlined by a designer from the Yakovlev aircraft design bureau who remarked to the author at the Paris Air Show that only people working on civilian projects could travel to Paris; the military side of the design bureau was treated almost like a separate organization, and no one from it was allowed to travel.

Control over publication is not quite so strict as control over travel, but it is still difficult to clear for publication a paper that originated in military-sponsored research. Sometimes a scientist can disguise the source of the research funding, or perhaps submit his papers to a journal unfamiliar with the technical publishing rules in his specialized field; but in general, military secrecy imposes a major barrier to publication, and hence affects the reputation and career of a scientist. Some Soviet scientists suggest, in fact, that it is easier to hide inferior work and less capable people under a military umbrella because the research is less likely to come under critical scrutiny. The better scientists therefore find a lower quality of work among their colleagues in military research, and are consequently deterred from participating in such work. If first-rate scientists are put off by the quality and environment of military research, second-raters perhaps find this a useful channel for career advancement. Although the lower quality of military scientists has not been universally accepted or described by all sources, the evidence contains enough instances to indicate that it is a serious issue that cannot be disregarded.

Another disincentive to working on military research is that cost and schedule overruns, which are tolerated on civilian projects, are considered serious infractions in some high-priority military contracts. Although the military client might accept fuzzy excuses for failure to reach objectives in basic research, his insistence on contract provisions increases as the work moves closer to production.[1]

The positive incentives to perform military research act primarily on the institution, whereas the negative incentives are felt mainly by the individual; for that reason, tension between the two often occurs. Civilian laboratories and individual scientists may be expected to do military work occasionally in order to build up their equipment and facilities, which they can then use to advantage in their main line of civilian research. Refusal to do military research could possibly hinder one's career possibilities.

In summary, the political leadership's goal of bringing science closer to application, and subsequent policies emphasizing contract research, have significantly strengthened the civilian science sector's ties to application in both the military and civil spheres. Indeed, several prominent proponents of the policy are now viewing the results with alarm, fearing that the moves may have gone too far. Concern about such tendencies has been expressed by many science leaders. The late

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[1] Whetten, op. cit., p. 53.

M. Keldysh, then President of the Academy of Sciences and a famous leader of applied military research in the aviation industry, declared in 1976 that an excessive orientation to production and involvement in the innovation process could impair the country's fundamental research potential. He observed that "an obvious tendency has emerged by Academy institutes not to cooperate with industry, but themselves to take the matter to its conclusion. In my view, this tendency is very dangerous".[2] Even B. Ye. Paton, President of the Ukrainian Academy and a vigorous proponent of science-industry cooperation, thought that an "inordinate enthusiasm" for short-term problems would act to the detriment of fundamental research.[3]

Although individual scientists often see disadvantages in military-sponsored research, strong enough positive incentives today make it difficult to escape from performing such work. Still, some tension will continue to exist and could be a problem in specific cases, although it does not seem to be a major hindrance to government policy.

SCIENCE CONSULTANTS

Consulting by civilian scientists is a frequent, but small-scale, phenomenon. It seems to be largely a personal matter involving the noninstitutional effort of a scientific expert. The activity does not seem much different from U.S. practices.

Academy personnel are sometimes included on technical committees convened by a military-industry ministry to consider the preliminary

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[2] Vestnik Akademii nauk SSSR, 1976, No. 9, p. 41; J. Cooper, op. cit., p. 37.

[3] Nauka i zhizn, 1977, No. 4, p. 19; quoted in Cooper, op. cit., p. 35.

requirement for a new system. Such committees review the feasibility of the requirement and may suggest research prior to further decisions in order to address technical problems and uncertainties.

It is not always necessary for a civilian scientist to have security clearances to consult on military projects. The problem can often be described in a compartmentalized manner without a contextual framework. In some cases, results are simply delivered to a postbox number so that even the institutional affiliation of the sponsor is hidden. In fact, it is through such signs that scientists often recognize a military connection to sponsored work.

Because of the absence of specific project, facility, or client identification in some of this work, it is often difficult for both participants and outside analysts to be clear about ultimate uses and users. It is perhaps for this reason that many Soviet scientists refer in a vague fashion to military research carried on in the civilian sector, without being able to delineate more clearly just what the work is about or who the ultimate client might be.

SCIENCE BOARDS, PANELS, AND COMMISSIONS

Commissions, panels, and other formally established boards are another means for bringing science information to bear on important questions. The issue of planning and directing science centrally has been approached through the formation of scores of problem councils and consultative bodies. The problems inherent in directing science were acknowledged by General Secretary Brezhnev in his address to the Academy of Sciences on its 250th birthday. "We have no intention of dictating to you the details of research topics--that is a matter for the scientists themselves. But the basic directions of the development of science, the main tasks that life poses, will be determined jointly."[4]

Some of the tasks of the various consultative groups include the selection of basic science directions. Such councils exist in the academy system, in the industrial ministries, and in joint groups that bring together individuals from different organizations. Assessing the importance of these groups, though, is difficult. The scientific problem councils of the Academy are consultative and have no formal administrative authority, yet they are said to "exert considerable influence over the course of research."[5] They suggest topics for inclusion among the "basic directions" and recommend assignments among institutes. Furthermore, inclusion of a subject on the lists of basic problems or basic directions provides a set of highly visible priorities that can influence the choice among alternatives when research managers must make decisions between programs. Other views, however, give the Academy of Sciences councils less weight. Their powers are undefined and their administrative support is often inadequate. Moreover, some of the participants in the council activities dismiss them as of no observable value. Even the chief academic secretary of the USSR Academy complained of the bureaucratic nature of the councils and of their inability to influence the choice of research projects.[6]

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[4] Pravda, October 8, 1975.

[5] Cocks, op. cit., p. 131.

[6] V. M. Sisakyan, quoted by Helgard Weinert, "The Organization and Planning of Research in the Academy System," in E. Zaleski et al., Science Policy in the USSR, OECD, Paris, 1969, p. 230.

Coordinating groups in industry seem to fare little better. When, for example, a leading Soviet computer scientist was questioned by the author about the results to be expected from a newly appointed top-level, high-status committee, formed to iron out problems in the computer industry, he dismissed the committee with a shrug and a laugh, indicating that it met once a year, had no formal authority, and was too large and unwieldy to come up with a coherent set of recommendations.

On the basis of this evidence, it is not possible to ignore such committees, commissions, and councils, nor is it appropriate to regard them in the same light as they may be described in their charters. At the least, these bodies serve as indicators of the direction of government policy, of the research trends that are favored, and of the institutions that have been given the leading roles. They also draw scientists into contact with decisionmakers as well as allow them to communicate among themselves.[7] Moreover, members of the Academy from military institutes may find that their involvement in Academy proceedings provides them with a good view of what is going on in the broader scientific world. Beyond this, especially in military affairs, the various committees and commissions may at times actually recommend, coordinate, and direct the course of scientific research in an effective way.

SCIENCE ENTREPRENEURS

Key actors in the links between science and the military (and in the larger science transfer process) are the science-promoters. This handful of individuals participates in numerous committees and are

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[7] These points are made by Weinert, op. cit., p. 231.

always in demand as consultants. They help break the bonds of rigidity, allowing the system to act more effectively. They usually head their own institutes, possess solid reputations as producers or managers of science, and sit on academic and government boards. Their institutes work on both military and civilian research; they chair problem councils and coordinating committees. Although their committees may not achieve all that is expected of them, these entrepreneurs of science have the opportunities to promote their own ideas and those of their colleagues before decisionmaking bodies and political leaders. Therefore, even if no formal ties exist, leading scientists may be connected to the military in a variety of ways.

VII. NATURE OF SCIENTIFIC SUPPORT

RAPID GROWTH

Many Russian emigre scientists have described periods of rapid growth of civilian scientific support of the military, especially since the late 1960s. Some estimates have suggested that the aggregate effort has grown by many times in the past 20 years. According to counts based on the first-hand evidence of former Soviet scientists, almost half of the research institutes in the Academy seem to have participated in military research.

The resurgence of Academy support of the military in the past 20 years is not a totally new phenomenon in Soviet military-science relationships. Before war broke out in 1941, Academy institutes were working on about 200 research topics ordered by the Defense and Navy commisariats (the predecessors to today's ministries). Some leading institutes--for example, the Ioffe Physico-Technical Institute in Leningrad--were heavily engaged in military research.[1] This work may have been prompted by new statutes introduced in 1935 that stressed the promotion of timely and efficient application of scientific achievements; for several years before this, the Party had pushed the admission of engineers into the administration of the Academy.

Within days of the German attack on the USSR, institutes of the Academy of Sciences were ordered to review their research programs and to redirect their efforts to defense-related work. Coordinated by a

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[1] G. D. Komkov, B. V. Levshin, and L. K. Semenov, *Akademiia nauk SSSR: kratkii istoricheskii ocherk* (The USSR Academy of Sciences: Short Historical Essay), Vol. II, 1917-1976, 2d ed., Moscow, 1977, p. 166.

science plenipotentiary of the State Defense Committee, scientists performed a great deal of valuable applied research during the war.

Following the war, civilian science made important contributions to nuclear weapons developments, ballistic missiles, radar, and jet propulsion. Many of the fields stimulated by wartime science contributions matured and stabilized sufficiently to form industrial ministries around the new technologies and products; electronics, missiles, and nuclear weapons gained ministerial status in the 1960s.

Several administrative reforms in the early 1960s removed from the Academy applied research institutes and those that were more oriented toward engineering. The remaining organizations were directed to concentrate on basic research. The more recent trend appears to be an attempt to find a balance between basic and applied research in the leading institutes of Soviet science.

Despite this vigorous growth, R&D contributions by the military production ministries and the Defense Ministry dominate civilian efforts by an order of magnitude. Civilian science is not a central actor in the formal weapons acquisition process. Such efforts as occur seem to be ad hoc, short-term, and associated with specific problems arising during development. The further a weapon proceeds in the development process, the more likely that civilian science support will be limited to solving unexpected and narrowly delineated problems that arise in design, test, production, or use. At the Institute of Nuclear Physics associated with Moscow State University, with 3000 employees, the ad hoc nature of much of the type of work is demonstrated by the fact that few military contracts are for more than 12 months, and most are for around 6 months.[2] In such cases, the problems are usually given to the

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[2] Whetten, op. cit., p. 46.

civilian institutes in abstract form and not presented as connected to a specific weapon development. Often, it is only through indirect means that a researcher might fathom the ultimate purpose of his efforts.

MAIN CONTRIBUTIONS OCCUR BEFORE FORMAL WEAPONS ACQUISITION

The military seems to sponsor research in the civilian science community for several reasons: to ascertain the feasibility of a requirement; to investigate potentially useful concepts and technologies; or to reduce the risks inherent in new things by research and experimentation. This kind of research appears to precede the actual incorporation of a new concept, technology, or device in a weapon design, although some of this work could be associated with a development program, particularly at an early stage.

In general, it appears that the military science sector has been unable to meet all of its R&D requirements to support the pre-weapons acquisition phases, particularly in highly advanced technologies. Much of the civilian science effort appears to be directed toward developing and maturing the science base and the technologies that will later flow into the risk-avoiding weapons R&D process. The broader range of weapons technologies must be brought to maturity before their incorporation in weapons designs. The technology requirements of new systems are likely to go beyond the capabilities of the military-science sector, especially in the short run when they have not yet adapted to the new demands. A lagged response of the military scientific base, therefore, requires more extensive support from civilian science.

Civilian science's main contribution to the military is to what can be described as an enlarged "front end" of the standard acquisition process. Despite this greater attention to science and technology in the early phases, we have no evidence that the style of design has changed. Designers and military customers alike still seem to shun risky solutions, untried technologies, and immature components. It is the new task of the science community to reduce the risk through research and experiment, to prove the technologies, and to demonstrate the technical feasibility of new kinds of components--before they enter into weapons development.

"BIG SCIENCE" AND THE MILITARY

In recent years, many Soviet science leaders have advocated program planning for large science projects. The program approach emphasizes the achievement of specific goals and the drawing up of a comprehensive set of measures for that purpose. In the postwar period, this approach has been customary for priority projects in the economic, social, and military spheres. In the development of both nuclear weapons and ballistic missiles, special systems of management were headed by councils subordinated to the highest levels of government and Party to assure the adequacy of priority and resources, backed by political authority. Nuclear weapons and ballistic missiles were later institutionalized within the standard ministerial structure, but the management pattern of those successful programs has now become the norm. "For the most important problems, a lead ministry or lead organization will be designated and granted certain rights in relation to other participants and the allocation of resources," with a government decision fully specifying schedules, resources, and executors.[3] It is

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[3] Cooper, op. cit., p. 42.

not accidental that this description applies to weapon system development generally, and to the management of large, military-related, "big science" programs specifically.[4] It has been the chief means by which the Soviet leadership has attempted to achieve major advances in science and technology. In some instances, as in the development of nuclear weaponry, it has been highly successful. In other areas--the supersonic transport Tu-144 being a conspicuous example--special management techniques, abundant resources, priority, and political backing have not overcome recalcitrant technologies and an economy that is generally inhospitable to innovation.

Current examples of the project-planning technique may include the work on high-energy devices, including so-called "particle beam weapons" and high-energy lasers. Of the 20 to 30 research organizations participating in these efforts in a major way, approximately half are members of the Academy of Sciences (national and regional), one-quarter are higher education institutions, and the remaining quarter are affiliated with the military-production ministries.[5]

The enlargement of those military research activities we have called "big science" is a new "front end" to systems that have never been built before. The differences between these activities and the science contributions during the pre-weapons-acquisition phase lie in the scale of the undertakings and in the breadth of the technological

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[4] By "big science," is meant coordinated research activity involving many participants, large volumes of resources, and expensive facilities investigating and applying science at the frontiers of knowledge.

[5] Examples of institute participation are presented in Simon Kassel and Charles D. Hendricks, High Current Particle Beams, I: The Western USSR Research Groups, The Rand Corporation, R-1552-ARPA, 1975.

development that a system--new in all its parts--will require if it is to prove feasible. It is one thing to work, for example, on holographic signal processing for a conventional radar system. It is substantially more complex to devise a high-energy laser defense for ballistic missiles. All of the subsystems and components in the latter case must be researched, demonstrated, and integrated into a system. No existing organization has the capabilities to carry out the whole task for such systems. Specially designated lead institutes and loose, informal coordination seem to define the chosen approach. Once again, though, these activities appear not to have affected the standard approach to weapons acquisition. The big-science efforts are clearly distinct from weapons development, although many of the same defense industry organizations may participate in big-science projects as in conventional developments.

VIII. THE LOGIC OF CONTROLLING SCIENTIFIC INFORMATION TRANSFER

THE LOGIC OF CONTROL

Consideration of the control of scientific information requires setting out a simple logic or framework in order to establish a context for specific points. The first prerequisite in this logic is feasibility. Control is more feasible when there are few sources of the information and when they are in the controller's own country. Magnetic fusion research, for example, from its beginnings in wartime, was highly classified in the United States and was confined to research sponsored by the Atomic Energy Commission. This control lasted until 1958, when scientists from India, Great Britain, and the USSR revealed their own research competence and results in the field. At that point, the feasibility of control dwindled and the benefits of collaboration grew apace, whereupon the U.S. declassified its fusion research.

To justify control, the information should be valuable to potential enemies. Scientific information can be valuable if it enhances overall efficiency, or if it permits and encourages undesirable enemy military capabilities. (These points will be discussed in greater detail below.) It is thus necessary to estimate the size of the resource-enhancement effects, the probable military uses of the science, and the potential damage to the U.S. of permitting a transfer. That damage should then be weighed against the costs generated by control processes or by the forgone profits or other benefits from sale and exchange. A case can be made for control, therefore, if the information is controllable, if it generates significant positive resource effects or is likely to lead to particularly undesirable capabilities, if these capabilities have important effects on U.S. military efforts, and if the benefits of avoiding these effects through controls are not outweighed by the direct and indirect costs that the controls impose on domestic science and research.

Ultimately, most arguments for controlling (or encouraging) transfers to a potential enemy can be decomposed into three elements: (1) general resource-enhancement effects, (2) effects on particular capabilities, and (3) influence on the other side's world view.[1] Any transaction will generally have all three effects. Most important for the analysis of science transfer is the second effect: the way and degree that a particular science transfer could aid the military effort of a potential enemy.

Resource-enhancement effects act to increase the resource base or national income of a country by directly adding to resource availability: by direct credit and resource transfers; by supplying a product more cheaply than it can be produced domestically; or by increasing efficiency and productivity. This, in effect, is equivalent to an overall shift in the income or budget of the recipient; the increase can be allocated in a general way throughout the economy. But, in addition, the accompanying effects of a transaction will usually make some particular set of goals relatively cheaper to obtain than other goals, and thus encourage expenditures in specific directions.[2]

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[1] The first two effects are what economists call the income and price effects.

[2] In standard economic analysis, these income and price effects are not independent. They jointly depend on supply and demand elasticities, and prices.

The changing-world-view argument is based on the notion that a potential enemy will become more (or less) benign as transfers to it are encouraged (or denied). A control policy could be undone, therefore, if the potential enemy's reaction were to view the world as more dangerous, and therefore increase its military expenditures. The other argument is also heard: Reducing science-transfer controls will ease tensions and lead to a less dangerous world. The validity of the arguments, however, has not been demonstrated in either the benign or malevolent guises.[3]

By decomposing the effects of a transaction into its general and particular components, the considerations for control can be made more explicit. Income enhancement effects from the transfer of grain, electronics technology, or bombs can be analyzed by the same metric. However, the particular effects of such very different transfers are likely to lead to quite different behavior. The primary task for analysts of science transfer should be to elucidate the particular effects: that is, how and to what degree a particular transfer could aid the military effort.

CATEGORIES OF SCIENTIFIC INFORMATION

The transfer of scientific information can occur in many ways. Four information categories illustrate key issues for the analysis of the effects of transfer on Soviet weapons development: (1) scientific theory; (2) knowledge of activities and progress in specific areas; (3) experimentation and procedural know-how; and (4) instrumentation and equipment.

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[3] For a skeptical view on the positive effects of trade on Soviet sensibilities, see Nathan Leites, *The New Economic Togetherness: American and Soviet Reactions*, The Rand Corporation, R-1369-ARPA, 1973.

Soviet science is strong in theory, but weakens as one moves down through the categories to hardware, where it suffers in comparison with the West. Soviet theory often equals that of the West, especially when it does not depend on empirical foundations that require a great deal of modern equipment.[4] The USSR has had notable difficulty in producing laboratory equipment. Institutes are often forced to spend considerable time and resources building their own one-of-a-kind devices. It is noteworthy that Russian emigre scientists mention that a laboratory outfitted with Western equipment is a mark of high-priority, military research. Indeed, obtaining access to such equipment is one of the incentives for engaging in military work.

Knowledge of what is going on in a field, of who is doing what, of the main directions and the false steps, is of great benefit in planning one's own research efforts. It is especially useful to followers rather than leaders. It is a category of science-information transfer whose value rises when the user is in second place or cannot afford risky ventures.

Know-how is often the most important, and most often the missing element in the transfer process. Its absence can prohibit or delay transforming an idea or device into something useful. Examples abound of Soviet attempts to duplicate American devices and processes--from Tupolev's copy of the B-29 bomber to recent efforts to reverse-engineer integrated circuits. In many cases, institutes or design bureaus are presented with a device and ordered to imitate and produce it--by a

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[4] Thane Gustafson, "Why Doesn't Soviet Science Do Better Than It Does?" in Linda Lubrano and Susan G. Solomon (eds.), *The Social Context of Soviet Science*, Westview Press, Boulder, Colorado, 1980, p. 32.

minister or political leader. In most instances, this takes years, it is very difficult, and according to those involved, sets back indigenous Soviet science by almost as many years as it takes to master the foreign example.[5] The assertion of being retarded is widespread over time and technologies; it was made by Tupolev, who was forced by Stalin to produce the Tu-4, and more recently by those involved in similar activities in electronics. The important point here is that know-how is what does not get into the journals. It requires personal contact and, frequently, dedicated effort by both parties. This applies to the transfer not only of know-how concerning a device or process, but also to purely theoretical information. Soviet analysts of science often point with envy to the "invisible colleges" of their colleagues in the West, where scientists working in the same field can make easy contact by telephone, letters, or visits. The Soviet penchant for secrecy and compartmentalization, together with the high institutional barriers between organizations and sectors, strongly impedes the internal flow of information as well as international flows.

One influence of international scientific information transfer that is associated with knowledge of the field lies more in the psychological and cultural realm than in the world of imitation and reverse engineering. In reviewing statements by Soviet scientists about the conduct of research, one is struck by the number of times that American or other Western experience is cited to justify, rationalize, or legitimize their own initiatives. An example of this, as related to the author by an American physicist, concerned the Soviet physicist Leonid

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[5] It should be mentioned that this claim could be a self-serving complaint by people who see themselves invidiously compared with their American counterparts.

I. Rudakov of the Kurchatov Institute. He had been mentioned by name in the first major article in the U.S. on beam weapons.[6] This came to the attention of high Soviet government officials, an event which, Rudakov claimed, assured him full funding for his beam fusion program, despite a good deal of earlier doubt and hesitation by the authorities. He noted that, "I no longer have to make neutrons to survive." This looking to the West is not new. It goes back to Peter the Great and the founding of the St. Petersburg Academy of Science in 1724, when Western science was the norm as well as the goal. Apparently, it still is.

Considerations of the control of science information transfer must account for the different characteristics of the various categories mentioned above. Theory is transmitted through journals, articles, papers, preprints, presentations at meetings, seminars, and other processes. Control is difficult unless the research is performed predominantly under closed, secret conditions. Even when the bulk of the research in a field is performed in secure facilities, parallel activities in open institutions can lead to some loss of control, as recent activities in cryptology demonstrate. Furthermore, it is not sufficient to control only the formal publication process. Communications take place prior to publication through the "invisible colleges" mentioned above.

Knowledge of what is going on in a field is just as difficult to control as theoretical information. Published results of research are important, of course; but so is information on the kind of work that is being pursued, which is usually available from a wider variety of sources than are the actual research results.

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[6] Clarence A. Robinson, Jr., "Soviets Push for Beam Weapon," <u>Aviation Week and Space Technology</u>, May 2, 1977, p. 16.

Because transfer of know-how often involves the energetic participation of the possessor of the information, its transference is more readily identifiable and controllable than theory or general knowledge. It generally goes beyond the mere description of research results or of product attributes; it involves the myriad details of technique. Attempts to acquire know-how are more obvious than the acquisition of more general knowledge, precisely because of the extensive efforts that may be required. Because know-how is often associated with applications, the use to be made of the information may also be discerned, thus informing the application of controls.

When one considers laboratory instrumentation, equipment, and supplies, however, the situation is different. When used directly (that is, when its acquisition is not for imitation but for actual use), the scientific information is embodied in the hardware. Since such equipment is designed to be used and documentation is usually available to facilitate its use, control of transfer requires controlling the physical shipment of the equipment. In some cases, the equipment is so highly specialized that its end use is fairly obvious. This is not always the case, though; much of the Soviet deficiency in this area is in general purpose laboratory hardware as well as in special purpose, low-production-quantity devices. However, since military uses have highest priorities on foreign purchases, acquisition (legal and illegal) of foreign equipment is more likely to be for military-related research than for other uses.

IX. CONCLUDING REMARKS

The lines are blurring in the Soviet Union between pure and applied research, military and civilian science, Academy and industry. For many years in the 1960s, and historically, the Academy system was truly "academic," but policies intended to promote greater science involvement in the affairs of the nation have had some effect. Scientists and institutions, especially those at the forefront of their fields, are more likely to be involved in military science--through a variety of mechanisms--than twenty years ago. Consequently, the likelihood that Soviet science contacts with the West will prove useful to the Soviet military has also increased.

It has not been the aim of this report to delve deeply into the logic of control, but rather to describe the ties of Soviet weapons acquisition to science and the transfer implications arising from those ties. Three main points flow from that analysis: (1) The Soviet weapons design process faces many incentives that orient it away from the use of advanced science and technology. (2) However, the increased complexity of modern weapons makes greater demands on science and technology. (3) As a net result of these two forces, contributions of Soviet civilian science to the military have been on the increase since the late 1960s; these efforts tend to precede the routine weapons-acquisition process; and civilian science contributions are vital to nonroutine "big science" military efforts.

Of course, many general questions on the transfer of scientific information remain, answers to which would better inform future policy:

(1) How should the value of the flow of scientific information and technology be measured?[1] (2) How can "defense-relevant" scientific information and technology be identified? (3) How can the contribution of science to the military be quantified? (4) What are the direct and indirect costs of control to the controller? Progress in answering these questions would permit a more rational and appropriate application of the logic of control than is possible today.

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[1] For example, should information be valued at the original cost to the sender, the savings to the receiver, the total value to the receiver (consumer's surplus), or at a market price established by actual or proxy transactions?

RAND/R-2942-NAS