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SOVIET WEAPONS DEVELOPMENT AND THE SCIENTIFIC COMMUNITY

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I. Introduction to Soviet Military R&D: The T-34 Tank

The incorporation of scientific findings and new technologies into weapons designs is accomplished by the movement of resources (including scientific knowledge and available technology) through processes that are conditioned by institutional structures, incentives and constraints, and R&D strategies. This process produces military outputs characterized by technical performance, mission capabilities, and — ultimately -- military value. The link between Soviet science and technology and Soviet weapons is the subject of this paper.

Most weapons development processes make use of a strategy that includes three main components:

1. New designs with extended periods of product improvements;
2. Parallel development of technologies and subsystems; and
3. Construction and test of experimental prototypes of integrated designs.

The emphases and mixes among these three components depends on factors such as the speed of technological change, the flexibility on the military-production sector, and the organization and incentives on the weapons development system. The Soviet Union's approach to weapons development has evolved over a 50-year period of adaptive change. We begin this story at the time of the creation of the Soviet military economy with Stalin's first Five Year Plan in the early 1930s and the development of the T-34 tank.

In the early 1930s, great uncertainty surrounded tank technology. The machines developed during World War I were becoming obsolete and new technologies in all areas of tank design were emerging, but visions of how new vehicles should look, what they should be able to do, and how they should be used were confounded by the multitudinous possibilities enticing designers and commanders. The Soviet Union solved the design dilemmas by taking one step at a time--sometimes on parallel paths, but always incrementally. The development of the T-34 illustrates some general rules about technology development in a state of open possibilities and great flux. Since it also set a pattern for Soviet military R&D that continues to the present, the story of the T-34 has double significance.

Development of the Soviet T-34 Tank. The Soviet Union was able to develop its armored technology from the relatively primitive state that existed at the end of the 1920s to a position of world leadership in tank design by the eve of World War II. This period was a time of major uncertainties and changes in technology, components, configurations, doctrine, tactics, and threat.

Soviet armor activity can be traced back to the Czarist regime of World War I. This experience was dissipated after the revolution and it was not until the mid-1920s that the first steps were taken to reestablish tank design cadres. Some modest design work, experimental construction, and limited production was undertaken, but no really acceptable vehicle emerged from that period. It was becoming clear by the late 1920s that there were many impediments to military technology and production.

The Party and Government then gave high priority to the building of military capability in general, and to tanks in particular. Education, research, and design institutions were established or enlarged. Manufacturing technology and enormous quantities of plant and equipment were imported in large volume from the West. Experimental armored brigades and staff colleges were established. Thus, by the early 1930s, institutions were in place that would put the Soviet Union at the forefront of armor technology and production by the time of the German invasion less than a decade away.

As part of this process, a commission visited the United Kingdom and the United States in 1930 to purchase tank designs, prototypes, and manufacturing licenses. One of the Soviet's foreign purchases was from an American designer -- J. Walter Christie. From out of Christie's M1931 tank came the T-34 — an evolutionary process that took only eight years.

The features that made the T-34 so effective were its low cost and producibility; well-shaped, heavy armor; an efficient diesel engine; well-protected and rugged independent suspension; low silhouette; and high-velocity 76 mm. gun. All of these features had been seen individually on other Soviet tanks. Their combined use on the T-34 was an example of design creativity that depended on the emerging experience gained from previous development and proof of components, subsystems, and alternative configurations.

Producibility was emphasized from the beginning. Christie's M1931 was redesigned for simplicity and was first produced as the BT-2 in 1932. Several variations followed and production rates were increased. Soviet tank production of all types during the 1930s averaged 3000 per year. During this period, production techniques for welding, riveting, and casting armor plate were learned. For example, electrically-welded plates, which greatly speeded production, appeared on a light tank — The T-26S — in 1938.

Sloping armor first appeared on an experimental outgrowth of the BT series in 1936 — the BT-IS. This armor, however, was only effective against low caliber bullets and fragments. Experiments with armor shapes showed that a conical turret had good antiballistic properties. The T-111 (T-46-5) -- an experimental prototype outgrowth of the BT-IS -- carried 60mm armor on both the turret and the hull, but its 45mm gun was too small for the heavily armored vehicle.

With the heavier armor, a more powerful tank engine was desirable. A government directive in 1932 had authorized development of a diesel tank engine.[1] This V-12 engine with an output of 500-600 horsepower became available for production installation in the BT-7M in 1938. The range of the diesel-powered tank compared to the gasoline-powered BT-7 increased from 275 miles to 400 miles, even though the weight also increased by a ton.

The increased mobility that was potentially available from the new engine forced reconsideration of the suspension system. All of the BT series tanks were designed for moving on either road wheels or tracks -- a feature inherited from the original Christie model. However, this system required complex suspension, steering, and drive mechanisms. The most important element of Christie's M1931 suspension, however, was its independent suspension and great vertical movement of the road wheels, which permitted high speed on both roads and cross-country. By 1939, eight suspension types had appeared in production tanks, and more had been tested on experimental vehicles. On the basis of this experience, a tank design group in 1938 suggested dropping the wheel-track system in favor of a pure track tank. On their own initiative, they began design of a new tank -- the T-32 -- closely patterned after a wheel-track experimental prototype -- the A-20 -- which they had just completed. The A-20 had incorporated the new diesel engine, and heavy, well-shaped armor, but only a 45mm gun. A sister tank, the A-30, carried a larger 76mm gun. Thus, several elements were converging by 1938 -- the armor shape and thickness, suspension, and engine. The gun though was still a problem.

With the heavier armor that was undergoing development, the acquisition of a long-range, high-velocity gun would allow Soviet tank forces to face either opposing tanks or antitank artillery with relative immunity. Some of the medium tanks and all of the heavy tanks had carried short-barrelled, low-velocity 76mm guns since 1932. The early BT series models carried an effective high-velocity 45mm antitank gun with a muzzle velocity of 2,350 feet per second, but by the late 1930s this caliber was ineffective. The length of the 76mm gun increased gradually from 16 calibers in 1932 to 24 calibers in 1938, but muzzle velocity was still less than 1,200 feet per second, which -- as demonstrated by the results coming from Russian fighting in Finland -- provided firepower of little effect.[2] A new requirement for a high-velocity gun was then issued and a 76mm design of 30.5 calibers in length and 2,200 feet per second muzzle velocity was the outcome. (In comparison, the 76mm gun on the German PzKw IV tank was only 1,240 feet per second at that time.) This is the gun that was mounted on the A-30 prototype in 1938, but the turret was too small to accommodate the longer weapon. The T-32 turret was specifically designed to carry this longer piece.

The low silhouette of the T-34 came about partly from the reduced height of the turret. Stalin's influence enters here as he continually urged a reduction in tank height through redesigning the turret. In 1938, he called in the two leading tank designers and emphasized the requirement for increased armor, new tracks, and a smaller turret. The results of these imperatives were seen in the squat turrets of the experimental prototypes of the late 1930s and in the subsequent T-32 and T-34. This was not achieved without cost, however, as it severely cramped the interior space of the turret and restricted the depression of the main gun to 3 degrees below the horizontal.

The T-32 was accepted for final development in 1939, and a refined version — the T-34 — appeared within a few months. Almost all subsystems and design features had appeared in previous tanks. The exception to this provides a telling argument for the utility of an evolutionary approach combined with independent subsystem development. When instructions were received to refine the T-32 design, the design bureau began work on a new transmission. The first production units were so unreliable that tanks were sent into combat with spare transmissions cabled to the rear deck. The transmission problems were not solved until late in the war.

More than 40,000 T-34 tanks were produced. Liddell-Hart characterized the T-34 in terms that can be used to describe Soviet weapons today:[3]

> The machines were rough inside and out . . . . Their design showed little regard for the comfort of the crew. They lacked the refinements and instruments that Western tank experts

considered necessary as aids to driving, shooting, and control . . . .

> On the other hand, they had good thickness and shape of armor, a powerful gun, high speed, and reliability -- the four essential elements . . . . Regard for comfort and the desire for more instrumental aids involve added weight and complications of manufacture. Such desires have repeatedly delayed the development and spoiled the performance of British and American tanks. So they did with the Germans, whose production suffered from the search for technical perfection.

General Heinz Guderian, the German armor theoretician and commander reported on his first meetings with the T-34: "Up to this point we had enjoyed tank superiority. But from now on the situation was reversed."[4]

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 teknike). 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 nondefense products, especially the Aviation, Shipbuilding, Radio, Electronics, and Communications Ministries.

The bulk of applied military research and development is performed in the research institutes and design bureau 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.[5] 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 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.

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 electronics components
Ministry of Machine Industry: Ammunition, ordinance
Ministry of Communications Equipment Industry: Radio, telephone, television, other communications equipment

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. The military production ministries operate, to a large extent, under the same system of incentives and constraints as the centrally planned civilian sector.

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 experienced 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 abreast 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 of 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 parent 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. One of the most powerful of these commissions 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 to the VPK specify participants, tasks, financing, and timetables for a project. When approved, the draft becomes a "VPK decision" -- 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.

The VPK is primarily an implementing organization rather than one that originates policy. 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 and monitor 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.[6]

The Committee has no direct authority over the ministries or the Academy of Sciences system; it attempts to shape events largely through 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 were said to be larger and more influence than its other departments.[7]

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.[8] 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 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 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; 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.[9] These procedures (the "formal" acquisition process) establish standardized projects steps from the statement of requirements to delivery of the product. Each project 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.

Over the past 50 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 US 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 US 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.[10] 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.

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 later 1960s, the T-64 appeared with almost all subsystems of new design, but only a few with advanced performance and technology. The tank carried a new engine and transmission, new suspension, and 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.

However, a parallel tank project — the T-72 — fell within traditional weapons acquisitions patterns. The T-72, apparently, was planned as a conservative back-up to the aggressively new T-64. As a major product improvement to the T-62, the T-72 shared many of T-64's components as well as some of the older T-62's —including the diesel engine that had been improved over the years from the T-34 engine of 1938. A product-improved model of the T-72 appears to be the tank bearing the T-80 designation. In the meantime, the T-64 had severe problems after initial development and was withdrawn for a period of time. Whether it becomes the progenitor of an improved line of vehicles (perhaps one incorporating a turbine engine)or is a dead-end -- victim of the risks facing all-new designs -- remains to be seen.

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 reportedly carry a laser rangefinder, 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 the 2,200 ft./sec. speed of the T-34 gun 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 former Minister of Defense and the Chief of the General Staff (Marshals Ustinov and Ogarkov), 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.

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

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. 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.[11] 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 noncontract funding from all other sources grew at less than half that rate.[12] In higher education institutes, contract research accounts for more than 80 percent of all R&D, although these institutions are 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.[13]

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 3,000 people, who are engaged in a wide variety of defense, industrial, and scientific tasks.[14]

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.

Not all of the incentives to do military contract research, though, 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.

It is 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 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.[15]

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. The late 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."[16] 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.[17]

Science Consultants. Consulting by civilian scientists ia 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 US practices.

Academy personnel are sometimes included on technical committees convened by a military-industry ministry to consider the preliminary 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 problems can often be described in a compartmentalized manner without a contextual framework. In some cases, results are simply sent to a postbox number so that even the institutional affiliation of the sponsor is hidden. In fact, is 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.

Commissions, panels, and other formally established boards are another means for bringing science information to bear on important questions. 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 "exact considerable influence over the course of research."[18] 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.[19]

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.[20] 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 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.[21] 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 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.

Administrative reforms in the early 1960s, however, removed from the Academy applied research institutes and those that were most 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 the vigorous growth of military R&D in civilian institutes, 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 3,000 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.[22]

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 development program.

The military science sector has been unable to meet all of its R&D requirements, particularly in highly advanced technologies. The technology requirements of new systems are likely to be 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. 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 development process.

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 used in the early phases of those programs has now become the norm for new special projects. "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.[23] It is not accidental that this description applied to weapon system development generally, and to the management of large, military-related, "big science" programs specifically.[24] It has 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.[25]

Such "big science" military research activities is the new "front end" to systems that have never been built before. The differences between these activities and the science contributions during the preweapons-acquisition phase lie in the scale of the undertakings and in the breadth of the technological development that a system — new in all its parts — will require if it is to prove feasible. It is one thing, for example, to work 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 Three Components of Soviet Military R&D

The Soviet union has developed a weapons acquisition system tied to the science and production sectors that, by fostering technical change while reducing risks, is well-tailored to the Soviet set of incentives and constraints. This approach to weapons development is based on three components: evolutionary improvements; technology development; and experimental prototypes.

Evolutionary improvements limit risks and constrain uncertainty. It is the Soviet designers' first choice for advancing performance in a large proportion of successful weapons. The development of new technologies and the transfer of science to application is accomplished in a broad-based effort by both the civilian and military science communities. The funding for the effort is largely independent of weapons programs; however, the closer a scientific project is to a specific weapon, the more likely that science financing is tied to the final system. The output of technology development and subsystem maturation feeds into the product-improvement development stream as well as into the construction of experimental or trial prototypes.

Both Soviet military planners and their weapons designers have used prototypes in many weapons types as a regular means of assessing new concepts, technologies, components, and wholly new configurations. It has been a tool for determining whether an older product is no longer worth improving and whether a new design yields the desired capability. In the development of the T-64 and T-80 tanks, numerous variants of new models were observed — obviously tests of alternative designs. Models have been reported with a turbine engine, missile launchers, and "kneeling" suspension. Some models have apparently been produced in numbers large enough for troop tests in large-scale maneuvers.

Where technology is changing rapidly, emphasis is on developing the technology; for more stable areas, product improvement is the chief means for enhancing performance. Programs that have been conducted outside this strategy have often failed or encountered great difficulty.

Over the past 50 years, the Soviet Union has established an approach to military R&D that fits the Soviet environment. Few forces can now be discerned that are likely to cause it to abandon such an effective style.

NOTES

1. This engine may have been a Soviet copy of a Hispano-Suiza aircraft engine. The Soviet Union was importing a great deal of Western technology at that time, and some features of the imported designs could be expected to turn up in almost any new Soviet equipment.

2. The length of a gun in calibers is defined as the barrel length divided by the diameter (caliber) of the bore. Longer barrel length is a means for attaining higher muzzle velocity of the round by allowing more complete combustion of the propellant within the barrel.

3. Liddell Hart, Basil H., The Red Army, Harcourt, Brace & Company, 1956, p. 181.

4. Guderian, H., Panzer Leader, Ballantine Books, New York, 1957, pp. 182-183.

5. 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.

6. 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.

7. Morris Bernstein, 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.

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

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

10. "U.S. Finds SA-6 to be Simple, Effective," Aviation Week and Space Technology, December 5, 1973, p. 22.

11. Cocks, op. cit., pp. 99-100.

12. 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.

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

14. 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.

15. Whetten, op. cit., p. 53.

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

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

18. Cocks, op. cit., p. 131.

19. 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.

20. These points are made by Weinert, op. cit., p. 231.

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

22. Whetten, op. cit., p. 46.

23. Cooper, op. cit., p. 42.

24. 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.

25. 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.