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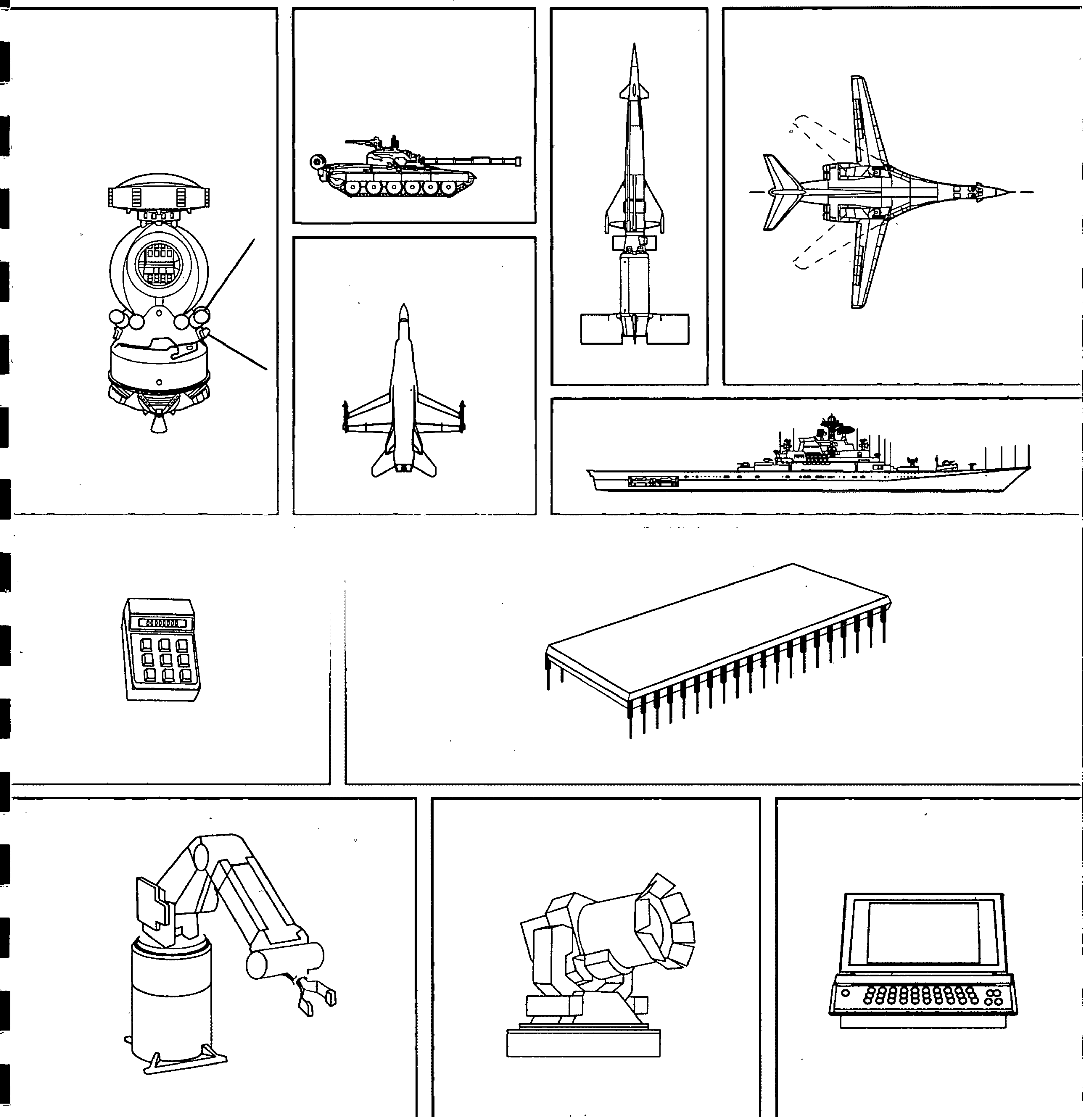
Soviet Requirements For Western Technology: A Forecasting Methodology



SOVIET REQUIREMENTS FOR WESTERN TECHNOLOGY: A FORECASTING METHODOLOGY

INTRODUCTION

The following paper presents a proof-of-concept for a methodology which demonstrates how the Soviets use Western technology in future military systems, and forecasts Soviet requirements for Western technology.

Although the methodology is only a proof-of-concept, our aim is to demonstrate its value on a larger scale to the U.S. export control community for forecasting future Soviet technology acquisition targets. The paper provides a brief overview of the Soviet process for identifying Western technologies required for development and production of future weapon systems. The methodology, which simulates this process, is presented with a detailed case study of its application in the area of microelectronics.

BACKGROUND

Intelligence has played and will continue to play an active role in defining export control priorities. However, its impact is often obscured by the host of other interests that result in our current control list. We believe it is important to identify the list of technologies and equipment which are expressly critical to development and production of future Soviet military systems.

We have searched for a means to systematically identify future Soviet acquisition targets. Previous studies on Soviet acquisition of Western technology have outlined the Soviet collection process and the way in which they go about identifying their targets of interests. These studies were based on a large volume of historical evidence. While we assume Soviet collection tactics will likely remain the same, future acquisition targets for military applications will largely be based on requirements for future Soviet military programs. Past deficiencies resulted in the collection efforts we observe today; today's deficiencies will be the object of future collection efforts.

We believe that intelligence assessments of future Soviet military systems, combined with estimates of Soviet technological capabilities, can offer a means to predict a large share of their future collection targets. This proof-of-concept provides an assessment of Western technology requirements for these future systems. We believe that emerging technologies--those not yet ready for application to military systems--and technologies acquired to study U.S. capabilities constitute a smaller percentage of overall technology acquisition requirements.

SOVIET PRIORITIES FOR WESTERN TECHNOLOGY ACQUISITION

As described in the White Paper* on Soviet technology acquisition, Soviet acquisition efforts can be divided into two separate but overlapping programs: an espionage program, and an illegal trade program. The former is managed by the Soviet Military Industrial Commission (VPK), and carried out primarily through the Soviet and East European intelligence services; the latter is managed by the Ministry of Foreign Trade and carried out primarily by Western traders under contract to the Soviets. A more detailed discussion of these two programs may be found in appendix I.

In the VPK program, requests for Western technology are generated by individual engineers and scientists working at design bureaus and institutes which are tasked with design and development of military systems. These requests are forwarded to the VPK, where they are ranked both in terms of their critical need to a specific development program and in terms of their broad application to several development efforts. The membership of the VPK includes senior representatives of the defense industries. The VPK, in coordination with the Ministry of Defense and others, compiles and prioritizes the list of Western technologies and equipment for acquisition (see figure 1).

In the illegal trade diversion program, requests for Western technology are generated by organizations within the various defense industrial ministries

* "Soviet Acquisition of Militarily Significant Western Technology: An Update," September 1985.

Figure 1
Soviet Bureaucracy for Weapons Acquisition

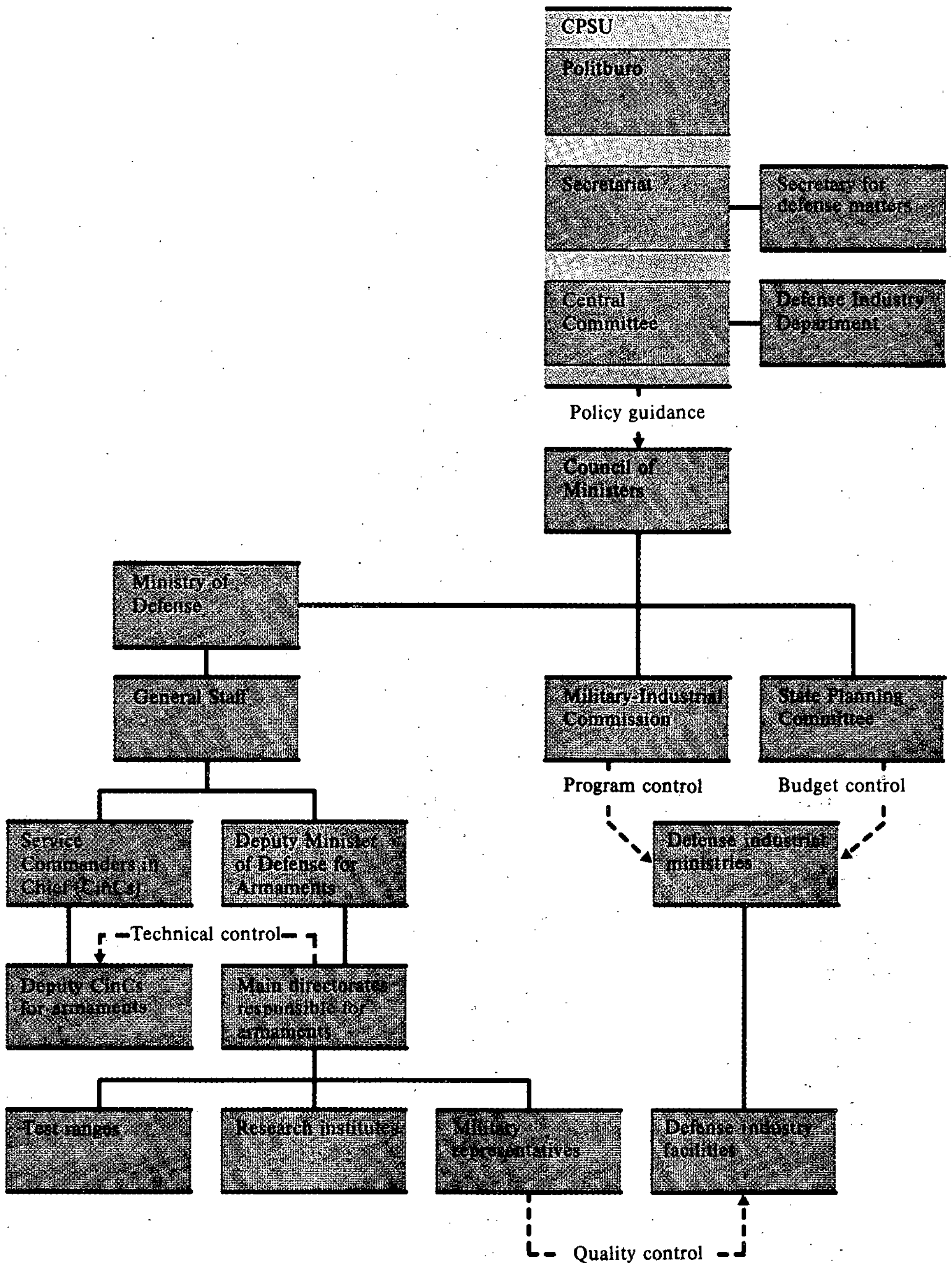


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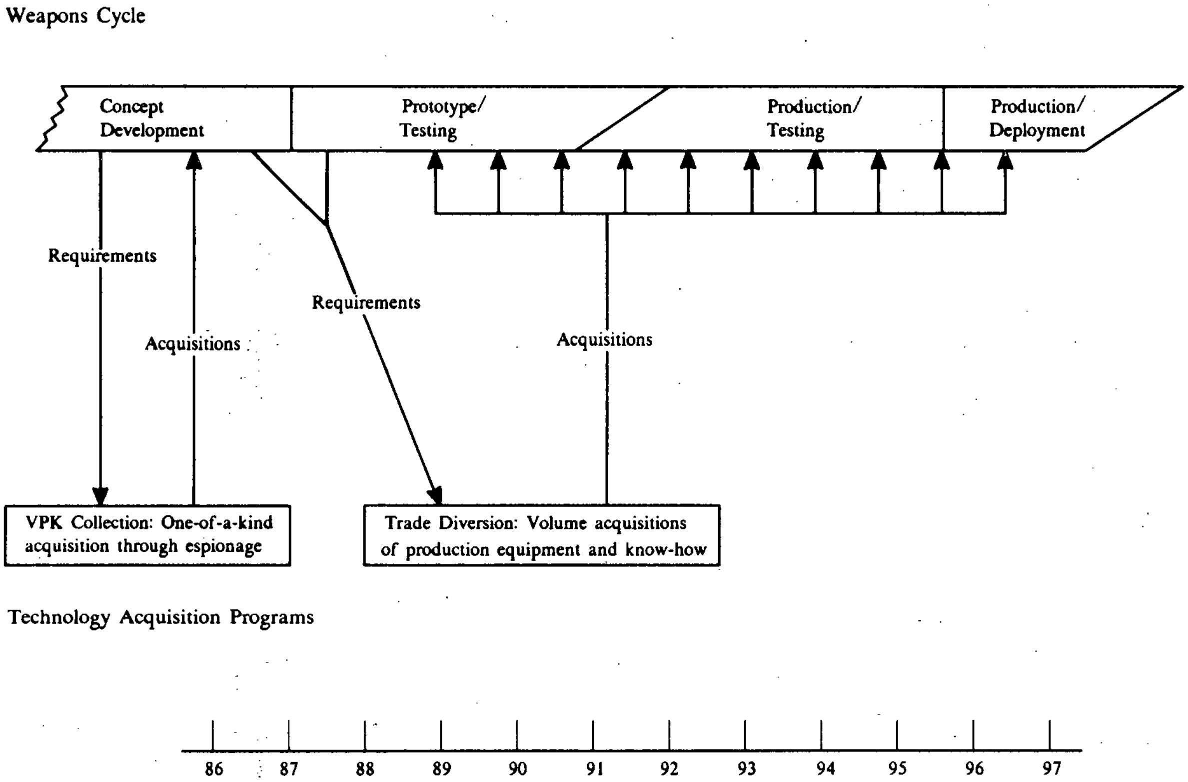
Figure 2
Soviet Weapons Development Cycle: Application of Western Technology



responsible for production of military systems. These requests are forwarded to the Ministry of Foreign Trade, which directs large volume acquisition of the required equipment. The illegal trade diversion program probably has a much larger budget than the VPK program, with each defense industry allocated a portion of the acquisition budget for its specific needs.

The Soviet decision maker uses two measures to determine which Western technologies should be targeted for acquisition: how important a given technology is to perhaps only one military system, but a system which is essential to Soviet military planning; and how pervasive a given technology is across the spectrum of military systems, and would therefore benefit many systems. The methodology developed here simulates Soviet decisions in searching for those technologies and equipment improvements which are required for development and production of future Soviet military systems.

USING SOVIET MILITARY DEVELOPMENTS TO FORECAST TECHNOLOGY REQUIREMENTS

The Soviet approach to military systems development and the associated identification and application of new technologies is highly structured. Figure 2 generally depicts the lead times required for acquisition of technologies to be incorporated in new military systems. For example, Soviet weapon systems which have transitioned from the concept development phase to the prototype/testing phase in the last few years will benefit from current Soviet large volume technology acquisition efforts. Future Soviet large volume acquisition efforts are associated with those Soviet military systems which have yet to enter the prototype/testing phase.

Systems which are more than three years from prototype/testing, however, will benefit from acquisitions of one-of-a-kind technology to feed concept studies for these future military systems. One-of-a-kind technology requirements are satisfied largely through the VPK-directed collection efforts of Soviet intelligence services and export controls have little or no impact. Systems which will soon enter the prototype/testing phase will benefit from future acquisitions of large volumes of the required production equipment and technology. These volume acquisitions will be satisfied largely through the illegal trade diversion program and export controls will have an impact on their acquisition. In order to be useful, the methodology must alert the policy-maker to equipment and technologies which will be sought in large volume by the Soviets during the next several years. Thus, we selected Soviet military systems entering prototype/testing during the period 1987-1990 for our study--systems whose production cycle will benefit from large volume acquisitions of equipment and technology far enough in the future to allow effective reaction, but soon enough to be relevant to export control decisions.

METHODOLOGY

The Concept

The methodology was conceived as a tool to identify future Soviet collection requirements for Western technology and equipment based on analysis of Soviet military system development programs. These programs, which contain systems entering the prototype/testing phase between 1987 and 1990, represent military systems expected to enter operational status usually between 1995 and 2003. Those programs which will result in operational systems beyond 2003 are beyond the scope of this level of intelligence analysis. Indeed, these programs are largely in the very early stages of concept development and likely have not resulted in requirements for volume acquisition of Western technology, but rather in requirements for classified or proprietary documents to be acquired through espionage. The methodology is a dynamic process which requires the most recent intelligence assessments in each mission area in order to remain current.

In concept, each system is examined to determine the perceived performance improvements or innovations required to achieve the specific mission requirements. The performance gains are then characterized by the subsystem improvements or innovations required to attain them. Each subsystem is assessed in order to determine the critical components required. The components are characterized in terms of the technologies required to implement them.

In addition to identifying specific technology requirements, the methodology results in two key estimates: an estimate of the critical need (i.e.,"criticality") to a specific military system, and an estimate of span of application (i.e., "profusion") of a technology both within a specific weapon system and to Soviet military systems in general.

In this proof of concept, we have taken those microelectronic technologies requirements and further expanded them to specific materials, production and process technologies and test equipment requirements. A full-scale version of this methodology would similarly link equipment and processes to each technology requirement category.

The Procedure

Military systems to be surveyed were selected by dividing Soviet systems into three major categories: Strategic Systems, Tactical Systems, and Space Systems. We subdivided strategic systems into Offensive, Defensive, and C^3I*. We subdivided tactical systems into C^3I, Land, Air, and Naval. We subdivided space systems into Military and Civil. The various tactical systems were then further subdivided into detailed categories, depending upon their mission. Within each subdivision we listed the specific types of Soviet systems which meet that mission requirement. A listing of the system types surveyed is contained in appendix II.

* Command, Control, Communications, Intelligence.

For this study we interviewed the analyst in CIA's Office of Scientific and Weapons Research responsible for each listed system type. Interviews generally lasted from one to two hours, during which the analysts were asked to identify the particular Soviet systems, if any, which will enter the prototype/testing phase between 1987 and 1990. For each particular system identified, the analysts were then asked to list the system's predicted critical performance requirements based on their experience in Soviet design practices for that category of weapon system. For each performance requirement the key subsystems were listed, for each subsystem the key components, and for each component the key technologies. The different levels are interlinked, with a clearly defined path from each military system through its performance requirements, subsystems, components, and down to its specific required technologies.

The Results

To measure the criticality of each technology to system performance requirements, the analysts were further asked to provide an assessment for each component of the importance (high/medium/low) of improvements in that component to meeting performance goals (a "high" ranking signifying that without significant improvements the performance goal could not be met, a "medium" ranking signifying that improvements in that component play a major role in meeting the performance requirement, and a "low" signifying that improvements in that component are not required for that performance improvement but rather would only incrementally enhance an already satisfactory capability). Similarly, analysts were asked to provide an assessment for each technology of the importance (high/medium/low) of that technology in meeting component performance requirements. We then generated a measure of the criticality of each technology to meeting system performance goals by combining these two rankings. Using classified sources we could then compare the needs with the indigenous technology base levels to determine whether technology transfer requirements would be levied. Soviet technology base shortfalls would become prime candidates for collection requirements.

To determine the absolute criticality of any given technology to a particular system level of performance, even though that technology might appear several times under different components, we consider the path having the maximum criticality as the absolute criticality. To measure a technology's span of application within a given military system we developed a numerical "profusion" score (see appendix III for a mathematical discussion of this score). The profusion score takes into account a technology's maximum criticality, and then adds a diminishing increment to its score for each additional entry within that system. A profusion score spanning all systems was generated in a similar fashion.

RESULTS SUMMARY

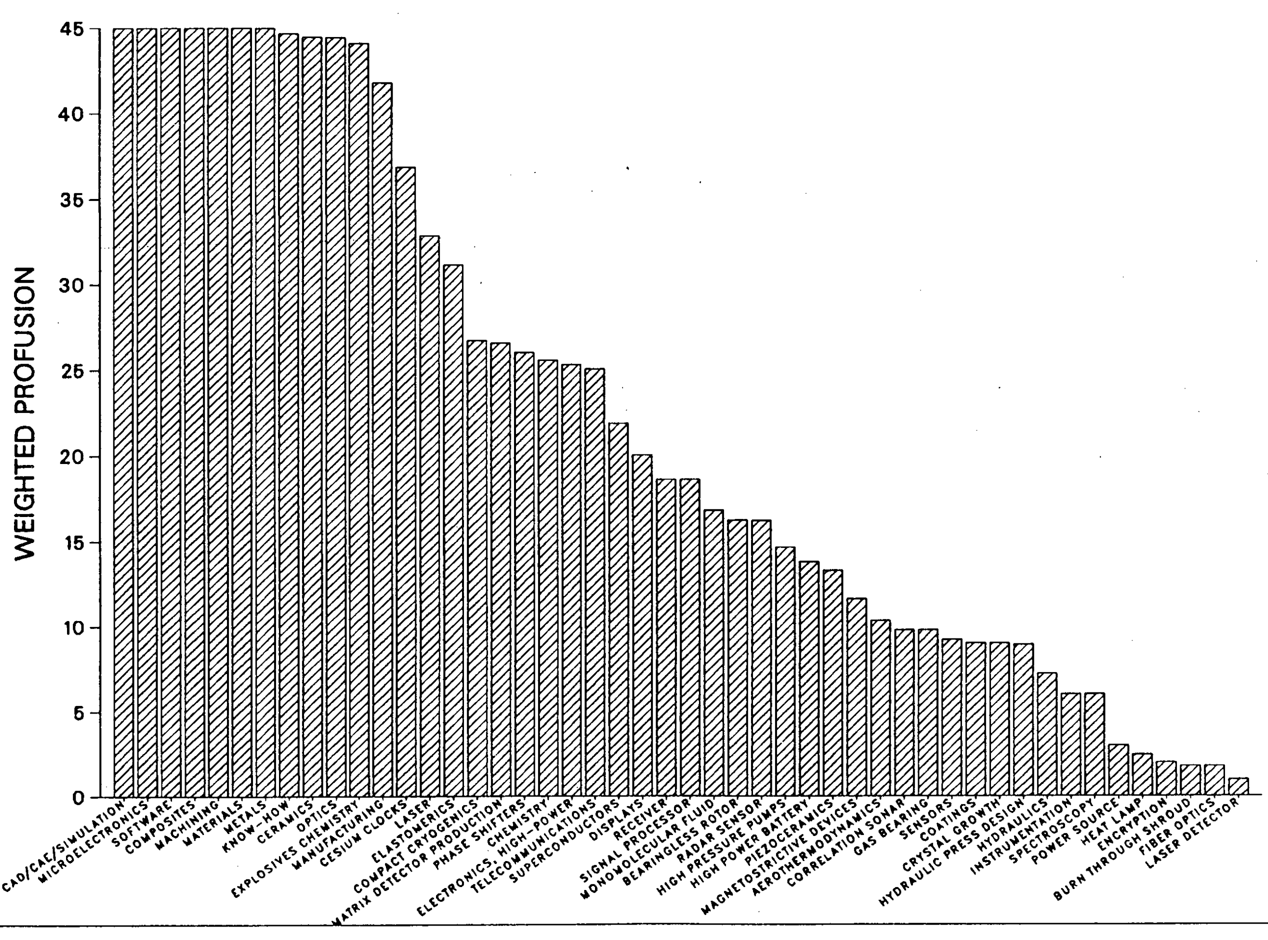
We believe this proof-of-concept adequately simulates the Soviet decision-making process. The analysts we interviewed play the role of the Soviet military systems designers, choosing technologies for use in specific development programs. The analysts' assessments of the criticality of a given technology for their particular system can be used by U.S. policymakers and experts on Soviet military strategy, jointly playing the role of Soviet decision-makers, in evaluating the need for that technology in light of the place of that system in Soviet military planning. Our profusion score aids the U.S. policymaker in understanding the Soviet resource allocation decision-making process, in which highly profuse technologies are acquired to aid a wide variety of military systems.

Overview Matrix

An overview of the results from this proof-of-concept is presented in the fold-out (figure 3, found at the back of this report). This overview matrix relates all technologies to all military systems which will begin prototype/testing between 1987 and 1990. Based upon analyst input, we have assigned three criticalities to each entry: helpful, important, and essential. Using the profusion score, described in detail in the appendix, we generated an overall "importance" score. This score is presented in figure 4. Because of the nature of this exponentially diminishing calculation, values between 40 and the maximum 45 signify that the technology in question has critical applications in a wide variety of components in most, if not all, military systems. On the other hand, values below 9 signify that the technology in question is not rated with the maximum criticality in any system. Values between 9 and 40 signify that the technology is likely critical to at least one system, with higher values signifying

FIGURE 4

TECHNOLOGY PROFUSION ACROSS ALL SOVIET WEAPONS



ever-increasing application across a variety of systems. Several technologies stand out as especially important--CAD-CAE-simulation, microelectronics, software, composites, machining, materials, metals, ceramics, optics, and explosives chemistry. Know-how also stands out from the remaining important technologies, even though it is not, strictly speaking, a technology. These stand-out technologies, and know-how, are discussed below. Most, but not all, of these technology needs will result in Soviet attempts to acquire Western technology and equipment. Some technology needs--those technologies for which the Soviets lead the West--will be satisfied through indigenous development of the requisite capability. Data for all systems studied and technologies identified are presented in appendix IV, Volume II.

Discussion of Technologies

Computer aided design, engineering, and simulation have perhaps the broadest impact on the military systems surveyed. CAD-CAE-simulation was mentioned in almost 80 percent of the systems surveyed, and was essential to almost 50 percent of all systems. The Soviets are weak in this area, due to their overall lag in computer technology. We expect that equipment and know-how related to CAD-CAE-simulation, together with advanced application software, will continue to be a major technology acquisition target for the Soviets.

Microelectronics was virtually tied with CAD-CAE-simulation in our study. It was mentioned in 85 percent of the systems surveyed, and was essential to over 60 percent of all systems. We have chosen microelectronics for our case study, demonstrating how particular microelectronics technologies impact on Soviet military systems development.

In addition to the application software described above, the Soviets will need software improvements for direct use in programming the computers and signal processors used in their weapons systems. Software was mentioned in over 55 percent of the systems surveyed, and was essential to almost 30 percent of all systems. For many applications, however, we believe that indigenous Soviet software capabilities will be sufficient. We expect that software know-how for direct applications to military systems will not emphasized for acquisition to nearly the same extent as, for example, microelectronics.

Composites, both organic and metal-matrix, were mentioned in almost 50 percent of the systems surveyed, and were essential to 30 percent of all systems. The Soviets lag the West in this area, and we expect that composites technology will continue to be an acquisition target.

Machining, especially multi-axis high-precision automated machining, was mentioned in over 60 percent of the systems surveyed, and was essential to over 30 percent of all systems. The Soviets are weak in this area, and we expect that machining equipment and technology will continue to be a priority acquisition target.

Materials, especially semiconductor infrared & electro-optical detector, coating, and radar window materials, were mentioned in almost 65 percent of the systems surveyed, and were essential to almost 30 percent of all systems. For many applications we believe that Soviet capabilities lag the West, and we expect materials technology will continue to be a priority acquisition target for the Soviets.

Metals and metallurgy were mentioned in over 40 percent of the systems surveyed, and were essential to over 20 percent of all systems. For many applications, however, we believe that indigenous Soviet capabilities will be sufficient. We expect that metals and metallurgy will not be emphasized for acquisition to nearly the same extent as, for example, CAD-CAE-simulation.

Know-how, although not a technology, was mentioned in 40 percent of the systems surveyed, and was essential to 15 percent of all systems. Some know-how requirements were directly related to specific military applications, such as air-to-air refueling or carrier-based flight operations, and can not be affected through export controls. Other requirements, such as production or quality-control know-how, can be affected through current technical data regulations or through enhanced monitoring of co-production agreements overseas.

Ceramics were mentioned in 30 percent of the systems surveyed, and were essential to 10 percent of all systems. The Soviets lag the West in some areas of ceramics research and application, and lead in others. We expect that specific ceramics technologies will be an acquisition target in the West.

Optics were mentioned in over 10 percent of the systems surveyed, and was essential to 8 percent of all systems. The Soviet Union benefits from East German capabilities in optics, which are adequate for most military applications. We expect that optics technology will be a target for acquisition, but not to the same extent as, for example, materials.

Explosives chemistry, especially related to propellants and warhead explosive charges, was mentioned in almost 40 percent of the systems surveyed, and was essential to over 10 percent of all systems. Soviet capabilities in propellants lag the West somewhat, and we expect that technology acquisitions in this area will continue. In warhead explosives, however, the Soviets hold a clear and substantial lead over the West, and we do not expect that technology acquisitions in this area will occur, except for military planning to counteract U.S. capabilities.

Although we have chosen to discuss the above technologies in detail, many other technologies--such as chemistry, manufacturing, or laser--were mentioned as important or essential to a variety of systems. These and many other technologies would deserve full treatment in a larger, more detailed study.

Discussion of Systems

Our discussion of technologies above is based on a variety of analyst interviews in which technologies are mentioned by many analysts. Individual experience levels or preferences, therefore, are averaged out. However, because the starting point for our methodology is a specific Soviet military system and each specific system was discussed by only one analyst, a discussion of system-by-system results would be necessarily suspect. There is no justifiable method to segregate systems which truly require a wide variety of technologies from systems which list a wide variety of technologies because of one analyst's opinions. Within each system, however, comparisons of relative importance or profusion between technologies are valid. A larger, more detailed study would circumvent this statistical problem by interviewing a variety of analysts from different organizations for each system, and applying a consensus approach to the results.

Some overall results are apparent from our discussions with a variety of analysts covering similar systems. The Soviets appear to be most dependant on Western technology acquisitions for new aircraft and missile. This results from the high impact in performance that microelectronics, CAD-CAE-simulation, and composite materials can make on these system designs. These technologies would be targeted for acquisition in the West because the USSR has limited capabilities in these technologies. On the other hand, for land warfare weapon systems such as tanks, armored personnel carriers, or artillery, the Soviets have devoted considerable resources to their indigenous technical capabilities, and are highly capable. The Soviets would therefore look to the West only for limited technology acquisitions to further refine their capabilities in a few specific areas such as fire control computers or night vision equipment where their weak technology base would affect performance.

Case Study: Microelectronics

The results presented above identify key technology categories, but are not specific enough in themselves to be used to generate a specific export control list. To demonstrate the practical application of the methodology down to the specific (and controllable) equipment level, we performed a case study. Because of high and continued intelligence and policy interest in Soviet microelectronics, as well as the broad application of microelectronics across numerous military systems, we selected microelectronics technology as a case study to demonstrate the specific application of the methodology down to the equipment level. Based on analyst input for each system, we have identified specific microelectronics capabilities which are key to meeting component performance requirements, and through these components, key to meeting system performance requirements. By comparing the microelectronics capabilities required for system improvements to current Soviet microelectronics capabilities and weaknesses, we can identify the specific materials, production, and process technologies which currently limit Soviet ability to develop the military systems to required performance levels.

Category Selection and Target Determination

We selected four categories of digital microelectronics for study. These broad categories--high-speed LSI, first generation VLSI, second generation VLSI, and VHSIC--span almost all requirements listed by the analysts interviewed. Less capable microelectronics are already clearly within Soviet capabilities, and are thus not likely targets for technology acquisitions driven by future military systems. Wherever component performance requirements could be completely satisfied by less capable microelectronics already fully developed by the Soviets, we have not listed any technologies targeted for acquisition.

To determine which particular materials, production, and processing technologies are targets for acquisition within each category selected, current Soviet capabilities have been compared to the capabilities required for each category. Any technology which is a bottleneck to full volume production of ICs within these categories is assumed to be a critical acquisition target. We have not listed equipment which would be helpful rather than critical, as control of "helpful" technologies represent a different policy decision from control of "critical" technologies. Because the Soviets lag far behind the U.S. in microelectronics, equipment bottlenecks in Soviet production capabilities can be solved by acquisition and assimilation of relevant U.S. technology. If the Soviets were as advanced in microelectronics as they are in explosives and armor, many critical needs for the Soviets might not be available from the West, and would therefore not be acquisition targets.

Priority Technology and Equipment Targets

The Soviets have achieved LSI integrated circuit technology in full volume production. Production of both 16K DRAMs and copies of the Intel 8080A reached full volume in 1981. Device yields are still relatively low and device operating speeds must be improved for high-speed applications. To improve production yields the Soviets require improvements in their clean room design and practices which currently are unacceptable by Western standards. To circumvent problems with worker discipline the Soviets will need to acquire automated production equipment in all areas. In this way they hope to minimize defect density. To better monitor their production lines the Soviets will acquire process control equipment, particularly parametric testers and materials characterization equipment. To increase device operating speed the Soviets require higher-quality substrates and epitaxial layers, optimized layout know-how to minimize path lengths between devices, and device design know-how to minimize gate propagation delay. In summary, for high-speed LSI circuits, critical bottleneck technologies targeted for acquisition in the West are:

Clean Room Design and Filters
Automated Production
Parametric Testers
Materials Characterization
High-Purity Polysilicon
Czochralski Crystal Pullers
Epitaxial Growth (VPE, MBE)
Optimized Layout Know-How
High-Speed Gate Know-How

The Soviets have achieved first generation VLSI integrated circuit technology in limited volume to full volume production. Production of 64K DRAMs reached full volume in 1984, while production of copies of the Intel 8086 will probably reach full volume next year. Device yields are extremely low, well under 10 percent, and reliability has been a problem. The Soviets will tighten their design rules to shrink die area, improving yields. Operating speed must be approximately doubled, and circuit complexity must be increased. To improve production yield and reliability the Soviets require (in addition to the areas listed under LSI), improvements to non-epitaxial layer quality, ion implanters, wire bonders, wafer probe testers, and VLSI circuit testers. To tighten their design rules the Soviets require improvements to projection aligners, electron-beam mask making systems, chemical plasma etchers, reactive ion etchers, and ion milling systems. To increase operating speed and circuit complexity the Soviets require improvements to their CAD capabilities in addition to the areas listed under LSI. In summary, for first generation VLSI circuits, critical bottleneck technologies targeted for acquisition in the West are:

(Technologies for High-Speed LSI), plus
Low-Pressure CVD
Ion Implanters
Wire Bonders
Wafer Probe Testers
VLSI Circuit Testers
Scanning and Stepping Projection Aligners
E-Beam Mask Makers
Chemical Plasma Etchers
Reactive Ion Etchers
Ion Millers
CAD Equipment

The Soviets have achieved second generation VLSI integrated circuit technology only in pilot production to limited volume production. Production of 256K DRAMs reached initial series production when the first production wafer was started in 1985; production of copies of the Intel 8086 probably also reached initial series production in 1985, and production of copies of the Motorola 68000 will probably reach initial series production only this year. The Soviets will probably not achieve even pilot production of 1 megabit DRAMs or Motorola 68020 copies until 1989-90. Device yields remain extremely low, lower even than first generation VLSI. To develop acceptable second generation VLSI the Soviets will require all technology required for first generation VLSI, plus improved metalization for multi-level interconnections and advanced packaging techniques for 100-plus-pin packages which dissipate several watts of power. In summary, for first generation VLSI circuits, critical bottleneck technologies targeted for acquisition in the West are:

(Technologies for 1st Gen VLSI), plus
Magnetically-Enhanced Sputtering
100-Plus-Pin Packaging Know-How
High-Power Packaging Know-How

The Soviets have not achieved VHSIC technology even in pilot production, and are unlikely to do so until the early 1990s without extensive technology acquisitions from the West. To achieve VHSIC goals the Soviets will require:

(Technology for 2nd Gen VLSI), plus
Design Know-How to Optimize Speed in Military Applications

Results Summary

An overview of our results is presented in the fold-out (figure 5, found at the back of this report). This overview matrix relates all required microelectronics technologies and equipment to all expected military systems. Because all the technologies and equipment are critical to meeting the specific microelectronics capabilities listed for each system, we have assigned every technology or equipment the maximum criticality of its microelectronics category within particular systems. This causes the same criticality to be generally assigned to each technology or equipment type under a particular system.

IMPLICATIONS

Despite its limited scope, we believe this proof-of-concept has succeeded in demonstrating its potential utility to both the intelligence and export control communities. Its results confirm the conventional wisdom in most cases (i.e. that microelectronics, machining, etc. are essential). The significant difference is that these conclusions are linked directly to Soviet need, rather than mirror-imaged perceptions based on past and current U.S. requirements. In our case study, the results reflect the Soviet lag in technology development and their level of need. These results do not confirm the conventional wisdom in every instance and offer a chance to improve our control strategy.

We believe that large-scale development of this methodology would result in similar opportunities to validate or adjust our export control strategy across the spectrum of critical technologies to reflect forecasts of Soviet need. This larger scale effort will require a commitment of resources and, more importantly, a long term commitment to the process of collecting and collating the necessary expert information. We believe the result would be a more focused control strategy and a more defendable control regime.

APPENDIX I: VPK AND TRADE DIVERSION PROGRAMS

The VPK Program

The VPK program is intended to raise the technical levels of weapons and other military systems or equipment as well as to improve the technical levels of manufacturing processes. This program is managed by the most powerful government organization in defense production--the Military Industrial Commission (VPK) of the Presidium of the Council of Ministers. Mainly, although not exclusively, through intelligence channels, the VPK seeks one-of-a-kind military and dual-use hardware, blueprints, product samples, and test equipment to improve the technical levels and performance of Soviet weapons, other military systems, and defense manufacturing equipment and to reduce any dependency on advanced Western products. This is done in large part by exploiting and adapting design concepts embodied in acquired equipment and associated documents.

Requestors

Most technology acquisition requirements are issued by the design bureaus of the Soviet defense and defense-related industries. These are the Ministries of the Aviation Industry, Machine Building (projectiles and explosives), Defense Industry (armor and electro-optics), General Machine Building (strategic missiles and space), Communications Equipment Industry, Radio Industry (radars and large-scale computers), Medium Machine Building (nuclear weapons and high-energy lasers), Shipbuilding Industry, Electronics Industry, Chemical Industry, Electrical Equipment Industry, and Petroleum Refining and Petrochemical Industry.

These design bureaus are responsible for developing the military systems and sub-systems required by their chief customer, the Ministry of Defense. Once the Ministry of Defense, working with the various uniformed services, develops performance requirements for a new or modified military system, the defense manufacturing ministries begin concept development for a system which meets those requirements. Whenever possible, off-the-shelf sub-systems and technologies are used at this stage. When off-the-shelf technology is insufficient to meet the required performance characteristics, however, the ministries must either develop the necessary technology indigenously, acquire the technology from the West, or both. It is generally at this stage--concept development--when the design bureaus of the defense ministries request Western hardware and blueprints and the VPK translates those requests into lists of collection requirements, assigns a category and priority to each requirement, and issues these requirements to a technology collection organization.

Collectors

The VPK tasks a variety of organizations to collect Western technology. The principle collectors are the Soviet Committee for State Security (KGB), the Chief Intelligence Directorate of the Soviet General Staff (GRU), the various East European intelligence services, the Soviet State Committees for Science and Technology and Foreign Economic Relations (GKNT and GKES) and Academy of Sciences, and the Ministry of Foreign Trade (MFT).

These collectors use a variety of techniques to acquire Western technology, principally collection of open source materials, classic espionage, trade diversion, accessing unclassified data bases, attending scientific conferences, and academic exchanges. Depending on the specific nature of the technology required--proprietary blueprints, production equipment, technical data, etc.--the VPK would assign the collection organization best suited to acquire that technology. For example, the KGB and/or GRU would likely be assigned to collect proprietary blueprints by espionage means, the MFT would likely be assigned to collect dual-use equipment by trade diversion, and the GKNT or Academy of Sciences would likely be assigned to collect militarily significant technical data from trade shows or from Western academic colleagues.

Successes

The VPK program is a Soviet success story. Over 3,500 specific collection requirements for hardware and documents were satisfied for the 12 industrial ministries for just the 10th Five-Year Plan (1976-

1980). About 50 percent of more than 30,000 pieces of Western one-of-a-kind military and dual-use hardware and about 20 percent of over 400,000 technical documents collected worldwide in response to these requirements were used to improve the technical performance of very large numbers of Soviet military equipment and weapon systems.

According to the Soviets, about one-third of the VPK requirements are totally or partially fulfilled annually, strongly suggesting that Western industrial security, counterintelligence, export controls, and other efforts do have an effect. But each year the number of VPK requirements grows by about 15 percent. This is a strong indication that the expanding Soviet military industrial program continues to rely on Western technical solutions and advances. It also indicates increased collection success and defense-industrial user expectation.

The four industries receiving the most Western military technology and dual-use products during the 10th Five-Year Plan were electronics (over 6,000 pieces of equipment, largely microelectronics-related), chemical (almost 4,000 pieces), petroleum-petrochemicals (over 1,500), and communications (over 1,500). The top four industries saving the most manpower and other resources in research project development were the armor and electro-optic industry, the aviation industry, the communications industry, and the electronics industry. In some areas, such as armor, the Soviets are using Western technology not to catch up, but to enhance a capability that already is at least equal to, and probably better than, that of the West.

Trade Diversion

The trade diversion program overlaps the VPK program but is administratively separate. It appears to be administered by the Ministry of Foreign Trade's (MFT's) Main Engineering and Technical Administration (GITU), staffed and managed largely by intelligence officers. The trade diversion program is comparable to the VPK program in scope, but is characterized not by requirements for one-of-a-kind military technology, documents, or equipment, but by illegal and legal acquisitions of relatively large numbers of dual-use products for Soviet military programs. These products are requested by the defense industries for direct use in manufacturing lines to increase the throughput or output of plants or for designing future equipment. Often manufacturing cells, complete production lines, or even entire plants are sought from the West. Much of this equipment and technology falls into the areas of computers, microelectronics, numerically controlled machine tools, robotics, material fabrication, and testing equipment.

Requestors

Requests for Western technology collected via trade diversion are generally issued from one of the 12 key defense and defense-related industries. These requests may be motivated either by requirements for particular military systems or by requirements for general industrial modernization. In the former case the methodology presented in this study identifies the critical technologies and equipment targeted for diversion. In the latter case studies of industrial modernization requirements will identify the critical technologies and equipment.

Those volume trade diversion requests which are prompted by requirements for particular military systems may occur as early as the system's concept development phase. Requests for trade diversion continue through the early prototype/testing phase, by which time the Soviets know which technologies will or will not be incorporated in the military system when it is deployed.

Collectors

The Soviet intelligence services and the Ministry of Foreign Trade (MFT) are involved in various ways with most of these trade diversions, some of which are conducted through ostensibly normal trade channels. The MFT and industrial ministries operate a large network of foreign trade organizations, commercial offices, joint companies, and foreign procurement offices whose staffs know the hardware markets and act as ready contacts for technology traders and diverters who may volunteer their services to the Soviets. They are also quite adept at spotting opportunities for diversions and obtaining controlled Western products. These functions are performed by legitimate Soviet trade officials, intelligence officers under trade cover, and trade officials working directly for intelligence officers.

Mechanisms

One of the most effective and secure trade diversion methods used by the Soviets is the contract or broker diverter. Contractor diverters work for set or negotiated fees; broker diverters receive a commission, usually a percentage of the equipment purchase price. Both are individual traders or businessmen with some affiliation to high-technology manufacturing or trade circles. They are very knowledgeable of high-technology markets and product availability and either volunteer their services to the Soviets or are spotted by Soviet assets in the West or in the USSR.

All diverters use similar techniques to ship equipment to the Warsaw Pact. Common practices include: purchasing equipment from the original equipment manufacturer or from an authorized distributor and subsequently "selling" the equipment through several dummy companies until the paper trail is lost and the equipment may be shipped to the East Bloc; purchasing the equipment from the manufacturer or distributor and, while the equipment transits a "free trade zone" in one of several countries, switching the destination of the equipment from a legitimate Western company to an East Bloc foreign trade organization; and setting up or cooperating with a company in a non-CoCom country to purchase equipment from a CoCom country which does not attempt to control items after the original sale, and shipping the equipment directly on to the Warsaw Pact.

Other diversion methods include making small Western firms dependent on Soviet legal orders over a period of years, causing the occasional Soviet request for illegal purchase or a support role in a larger illegal trade operation to appear difficult if not impossible to refuse. The Soviet also acquire technology through so-called acceptance engineers, who are assigned as quality inspectors on a long-term basis to Western firms engaged in manufacturing items for Soviet end users. They use this opportunity to spot agents for immediate or future exploitation.

Successes

In direct monetary value, volume acquisitions through illegal trade probably far exceed those of the VPK-directed effort. The Soviet have diverted thousands of different items of high technology in the past two decades, totaling billions of dollars in hardware value alone. In the microelectronics area alone we know the Soviets acquired at least 2,500 pieces of major manufacturing equipment between the early 1970s and the early 1980s, spread across the entire integrated circuit production process. Using trade diversion as a foundation, the Soviets have developed their microelectronics industry at a much more rapid pace than would otherwise have been possible. Industries such as computers, machine tools, and materials were built up in a similar fashion.

APPENDIX II: SOVIET MILITARY SYSTEMS SURVEYED

STRATEGIC: OFFENSIVE

Light, Road Mobile ICBM
Medium, Mobile ICBM
IRBM
Heavy ICBM
Solid SLBM
Liquid SLBM
SSBN
Small Strategic SLCM
Large Strategic SLCM
Small Strategic ALCM
Large Strategic ALCM
Small Strategic GLCM
Large Strategic GLCM
Strategic Bomber
SRAM

STRATEGIC: DEFENSIVE

Exoatmospheric ABM
Endoatmospheric ABM
BM Radars
Ground-based Air Defense Radar
Long-range SAM
Medium-range SAM
Ground-based Air Defense Laser
Fighter/Interceptor
AWACS
Tanker
ASAT Weapon System
Laser/NPB Space-based Weapon
RF Weapon

STRATEGIC: C^3I

Recon and Intel Collection
Nuclear Weapons Control
Nuclear Weapons Targeting
Reconstitution
Radioelectronic Combat
Mobile Communications and Command Posts

TACTICAL: C^3I

Tactical Air Warfare C^3I
Tactical Land Warfare C^3I
Tactical Naval Warfare C^3I

TACTICAL NUCLEAR:

900 Km SRBM
500 Km SRBM
100 Km SRBM

TACTICAL LAND: ASSAULT VEHICLES/HELICOPTERS

Attack Helicopter
Tilt-rotor Aircraft
Tank
Light Combat Vehicle

TACTICAL LAND: FIREPOWER SUPPORT

Artillery
Multiple Rocket Launchers
Tank-launched ATGM
Helicopter-launched ATGM
Hand-held ATGM
Artillery Ammunition
BW/CW Munitions and Protection
Anti-personnel Weapon

TACTICAL LAND: AIR DEFENSE

Antisensor Laser
Short-range SAM
Medium-range SAM
Long-range SAM
Hand-held SAM
Antiaircraft Gun

TACTICAL LAND: ENGINEER SUPPORT

Force Mobility
Flank Defense/Countermobility
Survivability

TACTICAL AIR: COUNTERAIR/ATTACK

Air-to-surface Missile
Air-to-air Missile
Precision Guided Munitions
Aircraft Gun
Aircraft Bombs
Aircraft Rockets

TACTICAL AIR: RECONNAISSANCE

High-altitude Long-range Aircraft
Tactical EW Aircraft
Battlefield Reconnaissance Drone

TACTICAL AIR: TRANSPORTS AND TRANSPORT HELICOPTERS

Strategic Transport
Strategic/Tactical Transport
Tactical/Assault Transport
Heavy-lift Helicopter

TACTICAL AIR: FIGHTER AIRCRAFT

Counterair Fighter
Air Superiority Fighter
Ground Attack Fighter

TACTICAL NAVAL: NAVAL PLATFORMS

Torpedo Attack Submarine
Cruise Missile Attack Submarine
Large CTOL Aircraft Carrier
V/STOL Aircraft Carrier
Surface Combatant
SLBM Tender
Space Event Support Ship
Oceanographic Research Ship
Mine Warfare
Amphibious Assault
High Performance Platforms

TACTICAL NAVAL: WEAPON SYSTEMS

Sea-launched Anti-ship Cruise Missile
Air-launched Anti-ship Cruise Missile
Coastal Defense Anti-ship Cruise Missile
Ship-to-Air Missile
Shipborne Laser Weapon
Shipborne Phased-array Radar
Naval Gun
Naval Mine
Torpedo
Remote ASW
Acoustic ASW
ASW Missile

TACTICAL NAVAL: AIRCRAFT

High-performance V/STOL Fighter
CTOL Naval Fighter
Naval AWACS/AEW Aircraft
Naval Helicopter

SPACE: MILITARY

Space Station
Space Tug
Space Shuttle
Heavy-lift Booster
Medium-lift Booster
Imaging Satellite
Navigation Satellite
Launch Detection Satellite
Data Relay Satellite
Strategic Communications Satellite
SIGINT Satellite
Meteorological Satellite
Ocean Reconnaissance Satellite
Orbital SAR Reconnaissance
Soviet Aerospace Plane

SPACE: CIVIL

Mars Manned Spacecraft
Venus Asteroid Mission
Astronomical Satellite

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APPENDIX III: PROFUSION SCORE CALCULATION

To determine the span of application--the "profusion"--of a technology, we developed a weighted scoring system which takes into account not only a technology's maximum criticality for a given system, but also the number of times it appears. Our intent is to provide an overall "importance" score, which heavily weights the maximum criticality figure and assigns an exponentially diminishing increment to the score for each additional entry:

$$\text{PROFUSION} = (\text{1st CRITICALITY}) + (4/5)*(\text{2nd CRITICALITY}) + (4/5)^2*(\text{3rd CRITICALITY}) + (4/5)^3*(\text{4th CRITICALITY})\ldots$$

This calculation is a summation with a maximum value of 45, achieved for an infinite number of criticality scores of "9" (the maximum possible). For example, a technology with two criticality scores of "9", two scores of "6", and one of "1" would have profusion score:

$$9 + (4/5)*9 + (16/25)*6 + (64/125)*6 + (256/625)*1 = 23.5$$

Within a given system, this profusion score can be used to compare the importance of different technologies. Because the criticality scores assigned by the analysts are subjective, however, it would not be correct to compare scores derived from one analyst with those derived from another. Since one analyst usually covers only one system in this proof-of-concept study, system-to-system comparisons are not valid. Taken in the aggregate, however, these subjective variations cancel out in the over 80 interviews conducted. We have therefore also applied the profusion concept across all systems surveyed. This score can be interpreted as the importance of a given technology to the Soviet military as a whole.

Because of the nature of this exponentially diminishing calculation, values between 40 and the maximum 45 signify that the technology in question has critical applications in a wide variety of components in most, if not all, military systems. On the other hand, values below 9 signify that the technology in question is not rated with the maximum criticality in any system. Values between 9 and 40 signify that the technology is likely critical to at least one system, with higher values signifying ever-increasing application across a variety of military systems.

FUTURE SOVIET WEAPONS SYSTEMS: Technologies Required

Figure 3

Technology	A-A Missile	Acoustic ASW Sensors	Acoustic Sensing System	Air Superiority Fighter	Air-launched Anti-ship Cruise Missile	Air-to-surface Missile	Aircraft Bombs	AN-12 Class Tactical Transport	AN-124 Class Strategic Transport	Anti-personnel Weapon	Antiaircraft Gun	Antisensor Laser	Artillery Ammunition	Artillery	ASAT	Astronomy Satellite	ASW Missile	Attack Helicopter	Ballistic Missile Radars	Bomber
Aerothermodynamics															●					
Bearingless Rotor																		●		
Burn Through Shroud																				
CAD/CAE/Simulation	★		●	★	●	★		★	★	●	★	●			★	★		★		★
Ceramics				★	●			★	●									★		★
Cesium Clocks																				
Chemistry					●															
Coatings																				
Compact Cryogenics	●																			
Composites	★			★	○			★	●							●		★		★
Correlation Sonar																				
Crystal Growth																				
Displays																				
Elastomerics																		★		
Electronics, High-power																				
Encryption	○																			
Explosives Chemistry	●					○	●							●				★		
Fiber Optics																				
Gas Bearing																				
Heat Lamp																				
High Power Battery	★																			
High Pressure Pumps																				
Hydraulic Press Design																		○		
Hydraulics																				
Instrumentation			●																	
Know-how	★	●	●	★		★									●			●	★	●
Laser Detector		●				●											●	●		
Laser																				
Machining	●	●	●	●	★			★	★		★			●	★			★		
Magnetostrictive Devices			●																	
Manufacturing				●				★	★			★						●		
Materials	★		○	★		★		★	★			★	★		●	●		★		★
Matrix Detector Prod	★																			
Metals				★	○			★	●		★			●	●			★		★
Microelectronics	★	★	★	★	★	★					★		●		★	●	●	★	★	★
Monomolecular Fluid																				
Optics	○			★		★						★						●		
Phase Shifters															●					
Piezoceramics			●																	
Power Source																				
Radar Sensor																				
Receiver																				
Sensors																				
Signal Processor																				
Software	★		●	●		★									★		●	★	★	
Spectroscopy																				
Superconductors										●										
Telecommunications																				

Technology	BW/CW Munitions and Protection	Carrier Based CTOL Fighter	Counterair Fighter	Cruise Missile Attack Submarine	Endoatmospheric ABM	Exoatmospheric ABM	Ground Attack Fighter	Ground Based AD Radar	Handheld ATGM	Handheld SAM	Heavy ICBM	Helicopter Launched ATGM	High Performance Platform	IL-76 Class Strategic/Tactical Transport	Imaging Satellite Systems	Interceptor	Large ALCM	Large CTOL Aircraft Carrier	Large GLCM	Large SLCM
Aerothermodynamics																				
Bearingless Rotor																				
Burn Through Shroud																				
CAD/CAE/Simulation		●	★	★	★	●	★	●	★	○	★	★	★	★		●		●		
Ceramics		●	★				★						★	●		●				
Cesium Clocks																				★
Chemistry																				
Coatings																				
Compact Cryogenics						★						●			●					
Composites		●	★	★	★		★				★		★	●		●	★		★	★
Correlation Sonar																				
Crystal Growth																				
Displays																		★		
Elastomerics																				
Electronics, High-power				●																
Encryption																				
Explosives Chemistry					●				★	○	★	★				●				
Fiber Optics																				
Gas Bearing																				
Heat Lamp																				
High Power Battery																				
High Pressure Pumps											●									
Hydraulic Press Design									○			○								
Hydraulics		●																		
Instrumentation																				
Know-how	★	○	★	●	●		★	●								●		●		
Laser Detector																				
Laser																				
Machining		●	●	★			●	★	★		●	★	★	★	●	●		○		
Magnetostrictive Devices																				
Manufacturing		●	●				●				●		★	★	●	●				
Materials	●	●	★	★		○	★			●		●	★	★	●	●		●		
Matrix Detector Prod																				
Metals		●	★	★			★		★			★	★	●		●				
Microelectronics	★	★	★	★	★	●	★	★		★	●	★	★		●	★	★	★	★	★
Monomolecular Fluid																				
Optics							●													
Phase Shifters								●										●		
Piezoceramics																				
Power Source																				
Radar Sensor																				
Receiver																	●		●	●
Sensors																●				
Signal Processor																	●		●	●
Software			●		●		●	★		●			●		○	●		★		●
Spectroscopy	●																			
Superconductors				●																
Telecommunications																		★		

Technology	Launch Detection Satellite	Light Combat Vehicle	Liquid SLBM	Long-range SAM	Med-range SAM	Mobile Comms and Command Posts	Multiple Rocket Launcher	Naval AWACS	Naval Gun	Navigation Satellite	Non-acoustic ASW	Nuclear Weapons Control System	Nuclear Weapons Targeting System	Precision Guided Munition	Radioelectronic Combat	Reconnaissance and Intel Collection	Reconstitution	Sea-launched Anti-ship Cruise Missile	Ship-to-air Missile
Aerothermodynamics																			
Bearingless Rotor																			
Burn Through Shroud				○															○
CAD/CAE/Simulation		★	★	○	●	●	●	○		★		●	●		●	★	●		
Ceramics		○		○	★													●	○
Cesium Clocks			★																
Chemistry																		●	
Coatings																			
Compact Cryogenics	○															●			
Composites			★	○	●											★		●	○
Correlation Sonar			●										●						
Crystal Growth																			
Displays																			
Elastomerics																			
Electronics, High-power															●	○			
Encryption																			
Explosives Chemistry		★	★	○	●		●		●										○
Fiber Optics						○													
Gas Bearing			●										●						
Heat Lamp		○																	
High Power Battery																			
High Pressure Pumps			●																
Hydraulic Press Design		○																	
Hydraulics																			
Instrumentation																			
Know-how	★		★			○		★				★		★			○		
Laser Detector			●								★	○	★	●			●		
Laser																			
Machining	●	★	★					★	●	★	★		●			●		★	
Magnetostrictive Devices																			
Manufacturing			●										●			●		●	
Materials	○	○	★	●	★						★	○		★		●	●	●	●
Matrix Detector Prod																			
Metals		★			●				●									●	
Microelectronics	★	●	★	★	★	●		★		●	★	★	★	★	●	★	★	★	★
Monomolecular Fluid			●										●						
Optics											★			★					
Phase Shifters								○											
Piezoceramics																			
Power Source																			
Radar Sensor			★																
Receiver																			
Sensors																			
Signal Processor																			
Software	★		★	★	★	●		★			★	●	●	★	●	★	●		★
Spectroscopy																			
Superconductors																			
Telecommunications				●											●		●		

Technology	Shipborne Laser Weapon	Shipborne Phased Array Radar	Short Range Attack Missile	Short-range SAM	Sigint Satellite	Small ALCM	Small GLCM	Small SLCM	Solid SLBM	Space Event Support Ship	Space Station	Space Tug	SSBN	Surface Combatant	Tank-launched ATGM	Tank	Tilt-rotor Aircraft	Torpedo Attack Submarine
Aerothermodynamics																		
Bearingless Rotor																		
Burn Through Shroud																		
CAD/CAE/Simulation	●	●	★		★	★	★	★	★	★	★	●	★	★	★	★	★	★
Ceramics						●	●	●						●		★	●	
Cesium Clocks								★	★	●								
Chemistry																		★
Coatings	★																	
Compact Cryogenics																		
Composites			●		★	★	★	★	★		○	●	●				★	★
Correlation Sonar									●									
Crystal Growth	★																	
Displays										●				★				
Elastomerics																	★	
Electronics, High-power					○								○					★
Encryption																		
Explosives Chemistry			●			○	○	○	★		○	●		●	★	○		★
Fiber Optics																		
Gas Bearing									●									
Heat Lamp																○		
High Power Battery																		
High Pressure Pumps																		
Hydraulic Press Design															○			
Hydraulics																		
Instrumentation																		
Know-how		●									○		●	●		●		●
Laser Detector									●		○					○		
Laser																○		
Machining		★	●		○				★	★	●	○	★	●	★	★	●	★
Magnetostrictive Devices																		
Manufacturing	★								●								●	
Materials	★		●		○		●	●	★		★		★	●		○	●	★
Matrix Detector Prod																		
Metals						●	●	●			★	●	●		★	★	●	★
Microelectronics		★	★		●	★	●	●	★	★	●	○	★	★	●	★	★	★
Monomolecular Fluid									●	★								
Optics	★																	
Phase Shifters		●																
Piezoceramics																		
Power Source																○		
Radar Sensor									★									
Receiver						●	●	●										
Sensors																		
Signal Processor						●	●	●										
Software		★	★	●	●			●	★	●	●	○		★		★	★	
Spectroscopy																		
Superconductors													○					★
Telecommunications														★				

○ HELPFUL ● IMPORTANT ★ ESSENTIAL

FUTURE SOVIET WEAPONS SYSTEMS: Microelectronics Equipment and Technology Required

Figure 5

	A-A Missile	Acoustic ASW Sensors	Acoustic Sensing System	Air Superiority Fighter	Air-launched Anti-ship Cruise Missile	Air-to-surface Missile	Aircraft Bombs	An-12 Class Tactical Transport	An-124 Class Strategic Transport	Anti-personnel Weapon	Antiaircraft Gun	Antisensor Laser	Artillery Ammunition	Artillery	ASAT	Astronomy Satellite	ASW Missile	Attack Helicopter	Ballistic Missile Radars	Bomber
Automated Production	★	★	★	★	★	★					★		●		★	●	●	★	★	★
CAD Equipment	★		●	★	★	★					★		●		★	●	●	★	★	★
Chemical Plasma Etchers	★		●	★	★	★					★		●		★	●	●	★	★	★
Clean Room Design and Filters	★	★	★	★	★	★					★		●		★	●	●	★	★	★
Czochralski Crystal Pullers	★	★	★	★	★	★					★		●		★	●	●	★	★	★
E-Beam Mask Makers	★		●	★	★	★					★		●		★	●	●	★	★	★
Epitaxial Growth (VPE, MBE)	★	★	★	★	★	★					★		●		★	●	●	★	★	★
High-power Packaging Know-how	●			★							★				★		●	★	★	★
High-purity Polysilicon	★	★	★	★	★	★					★		●		★	●	●	★	★	★
High-speed Gate Know-how	★	★	★	★	★	★					★		●		★	●	●	★	★	★
Ion Implanters	★		●	★	★	★					★		●		★	●	●	★	★	★
Ion Millers	★		●	★	★	★					★		●		★	●	●	★	★	★
Know-how to Optimize Military Applications				★							★							●	★	★
Low-pressure CVD	★		●	★	★	★					★		●		★	●	●	★	★	★
Magnetically-enhanced Sputtering	●			★							★				★		●	★	★	★
Materials Characterization	★	★	★	★	★	★					★		●		★	●	●	★	★	★
Optimized Layout Know-how	★	★	★	★	★	★					★		●		★	●	●	★	★	★
Parametric Testers	★	★	★	★	★	★					★		●		★	●	●	★	★	★
Reactive Ion Etchers	★		●	★	★	★					★		●		★	●	●	★	★	★
Scanning and Stepping Projection Aligners	★		●	★	★	★					★		●		★	●	●	★	★	★
VLSI Circuit Testers	★		●	★	★	★					★		●		★	●	●	★	★	★
Wafer Probe Testers	★		●	★	★	★					★		●		★	●	●	★	★	★
Wire Bonders	★		●	★	★	★					★		●		★	●	●	★	★	★
100-plus-pin Packaging Know-how	●			★							★				★		●	★	★	★

	BW CW Munitions and Protection	Carrier Based CTOL Fighter	Counterair Fighter	Cruise Missile Attack Submarine	Endoatmospheric ABM	Exoatmospheric ABM	Ground Attack Fighter	Ground Based AD Radar	Handheld ATGM	Handheld SAM	Heavy ICBM	Helicopter Launched ATGM	High Performance Platform	Il-76 Class Strategic Tactical Transport	Imaging Satellite Systems	Interceptor	Large ALCM	Large CTOL Aircraft Carrier	Large GLCM	Large SLCM
Automated Production	★	★	★	★	●	★	★	★		★	●	★	★		●	★	★	★	★	★
CAD Equipment	★	★	★	★	●	★	★	★		★		★	★		●	★	★	★	★	★
Chemical Plasma Etchers	★	★	★	★	●	★	★	★		★		★	★		●	★	★	★	★	★
Clean Room Design and Filters	★	★	★	★	●	★	★	★		★	●	★	★		●	★	★	★	★	★
Czochralski Crystal Pullers	★	★	★	★	●	★	★	★		★	●	★	★		●	★	★	★	★	★
E-Beam Mask Makers	★	★	★	★	●	★	★	★		★		★	★		●	★	★	★	★	★
Epitaxial Growth (VPE, MBE)	★	★	★	★	●	★	★	★		★	●	★	★		●	★	★	★	★	★
High-power Packaging Know-how		★	★				★	★				○	★			★	★	★	★	★
High-purity Polysilicon	★	★	★	★	●	★	★	★		★	●	★	★		●	★	★	★	★	★
High-speed Gate Know-how	★	★	★	★	●	★	★	★		★	●	★	★		●	★	★	★	★	★
Ion Implanters	★	★	★	★	●	★	★	★		★		★	★		●	★	★	★	★	★
Ion Millers	★	★	★	★	●	★	★	★		★		★	★		●	★	★	★	★	★
Know-how to Optimize Military Applications			★				★													
Low-pressure CVD	★	★	★	★	●	★	★	★		★		★	★		●	★	★	★	★	★
Magnetically-enhanced Sputtering		★	★				★	★				○	★			★	★	★	★	★
Materials Characterization	★	★	★	★	●	★	★	★		★	●	★	★		●	★	★	★	★	★
Optimized Layout Know-how	★	★	★	★	●	★	★	★		★	●	★	★		●	★	★	★	★	★
Parametric Testers	★	★	★	★	●	★	★	★		★	●	★	★		●	★	★	★	★	★
Reactive Ion Etchers	★	★	★	★	●	★	★	★		★		★	★		●	★	★	★	★	★
Scanning and Stepping Projection Aligners	★	★	★	★	●	★	★	★		★		★	★		●	★	★	★	★	★
VLSI Circuit Testers	★	★	★	★	●	★	★	★		★		★	★		●	★	★	★	★	★
Wafer Probe Testers	★	★	★	★	●	★	★	★		★		★	★		●	★	★	★	★	★
Wire Bonders	★	★	★	★	●	★	★	★		★		★	★		●	★	★	★	★	★
100-plus-pin Packaging Know-how		★	★				★	★				○	★			★	★	★	★	★

	Launch Detection Satellite	Light Combat Vehicle	Liquid SLBM	Long-range SAM	Med-range SAM	Mobile Comms and Command Posts	Multiple Rocket Launcher	Naval AWACS	Naval Gun	Navigation Satellite	Non-acoustic ASW	Nuclear Weapons Control System	Nuclear Weapons Targeting System	Precision Guided Munition	Radioelectronic Combat	Reconnaissance and Intel Collection	Reconstitution	Sea-launched Anti-ship Cruise Missile	Ship-to-air Missile	Shipborne Laser Weapon
Automated Production	★	●	★	★	★	●		★		●	★	★	★	★	●	★	●	★	★	
CAD Equipment		●	★	★	★	●		○		●	★	★	●	★	●	★	●	★	★	
Chemical Plasma Etchers		●	★	★	★	●		○		●	★	★	●	★	●	★	●	★	★	
Clean Room Design and Filters	★	●	★	★	★	●		★		●	★	★	★	★	●	★	●	★	★	
Czochralski Crystal Pullers	★	●	★	★	★	●		★		●	★	★	★	★	●	★	●	★	★	
E-Beam Mask Makers		●	★	★	★	●		○		●	★	★	●	★	●	★	●	★	★	
Epitaxial Growth (VPE, MBE)	★	●	★	★	★	●		★		●	★	★	★	★	●	★	●	★	★	
High-power Packaging Know-how				★	★						●								★	
High-purity Polysilicon	★	●	★	★	★	●		★		●	★	★	★	★	●	★	●	★	★	
High-speed Gate Know-how	★	●	★	★	★	●		★		●	★	★	★	★	●	★	●	★	★	
Ion Implanters		●	★	★	★	●		○		●	★	★	●	★	●	★	●	★	★	
Ion Millers		●	★	★	★	●		○		●	★	★	●	★	●	★	●	★	★	
Know-how to Optimize Military Applications				●																
Low-pressure CVD		●	★	★	★	●		○		●	★	★	●	★	●	★	●	★	★	
Magnetically-enhanced Sputtering				★	★						●								★	
Materials Characterization	★	●	★	★	★	●		★		●	★	★	★	★	●	★	●	★	★	
Optimized Layout Know-how	★	●	★	★	★	●		★		●	★	★	★	★	●	★	●	★	★	
Parametric Testers	★	●	★	★	★	●		★		●	★	★	★	★	●	★	●	★	★	
Reactive Ion Etchers		●	★	★	★	●		○		●	★	★	●	★	●	★	●	★	★	
Scanning and Stepping Projection Aligners		●	★	★	★	●		○		●	★	★	●	★	●	★	●	★	★	
VLSI Circuit Testers		●	★	★	★	●		○		●	★	★	●	★	●	★	●	★	★	
Wafer Probe Testers		●	★	★	★	●		○		●	★	★	●	★	●	★	●	★	★	
Wire Bonders		●	★	★	★	●		○		●	★	★	●	★	●	★	●	★	★	
100-plus-pin Packaging Know-how				★	★						●								★	

	Shipborne Phased Array Radar	Short Range Attack Missile	Short-range SAM	Sigint Satellite	Small ALCM	Small GLCM	Small SLCM	Solid SLBM	Space Event Support Ship	Space Station	Space Tug	SSBN	Surface Combatant	Tank-launched ATGM	Tank	Tilt-rotor	Torpedo Attack Submarine	Torpedo
Automated Production	★	★		●	★	●	●	★	★	●	○	★	★	●	★	★	★	★
CAD Equipment	★	★		●	★	●	●	★	★	●	○	★	★	●	★	★	★	★
Chemical Plasma Etchers	★	★		●	★	●	●	★	★	●	○	★	★	●	★	★	★	★
Clean Room Design and Filters	★	★		●	★	●	●	★	★	●	○	★	★	●	★	★	★	★
Czochralski Crystal Pullers	★	★		●	★	●	●	★	★	●	○	★	★	●	★	★	★	★
E-Beam Mask Makers	★	★		●	★	●	●	★	★	●	○	★	★	●	★	★	★	★
Epitaxial Growth (VPE, MBE)	★	★		●	★	●	●	★	★	●	○	★	★	●	★	★	★	★
High-power Packaging Know-how		●		●	●	●	●		★				★		○			★
High-purity Polysilicon	★	★		●	★	●	●	★	★	●	○	★	★	●	★	★	★	★
High-speed Gate Know-how	★	★		●	★	●	●	★	★	●	○	★	★	●	★	★	★	★
Ion Implanters	★	★		●	★	●	●	★	★	●	○	★	★	●	★	★	★	★
Ion Millers	★	★		●	★	●	●	★	★	●	○	★	★	●	★	★	★	★
Know-how to Optimize Military Applications																		
Low-pressure CVD	★	★		●	★	●	●	★	★	●	○	★	★	●	★	★	★	★
Magnetically-enhanced Sputtering		●		●	●	●	●		★				★		○			★
Materials Characterization	★	★		●	★	●	●	★	★	●	○	★	★	●	★	★	★	★
Optimized Layout Know-how	★	★		●	★	●	●	★	★	●	○	★	★	●	★	★	★	★
Parametric Testers	★	★		●	★	●	●	★	★	●	○	★	★	●	★	★	★	★
Reactive Ion Etchers	★	★		●	★	●	●	★	★	●	○	★	★	●	★	★	★	★
Scanning and Stepping Projection Aligners	★	★		●	★	●	●	★	★	●	○	★	★	●	★	★	★	★
VLSI Circuit Testers	★	★		●	★	●	●	★	★	●	○	★	★	●	★	★	★	★
Wafer Probe Testers	★	★		●	★	●	●	★	★	●	○	★	★	●	★	★	★	★
Wire Bonders	★	★		●	★	●	●	★	★	●	○	★	★	●	★	★	★	★
100-plus-pin Packaging Know-how		●		●	●	●	●		★				★		○			★

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