ANALYZING KNOWLEDGE PRODUCTION IN SOVIET BIOWEAPONS DEVELOPMENT:

A New Approach for Assessing Brain Drain Proliferation Threats

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Executive Summary[1]

The collapse of the Soviet Union and its subsequent economic and political turmoil has ushered in security concerns regarding the proliferation of its sensitive biological weapons (BW)-related personnel, materials, and equipment to countries and terrorist groups hostile to the United States. The underlying influences and transfer mechanisms involved in the so-called "brain drain" threats, i.e., the proliferation of sensitive BW-related knowledge and skills, remain poorly understood. This paper will apply concepts from the field of Science and Technology Studies (S&TS) regarding technological knowledge production and technology transfer to explore the questions: What knowledge and skill sets are involved in creating biological weapons? What can such information tell us about the brain drain proliferation problem involving former Soviet bioweaponeers?

Using a case study approach, the paper will apply these S&TS concepts to Soviet bioweapons development at a former production facility in Kazakhstan. The results from this paper will show that the development of a militarily useful biological weapon is complex and not merely reducible to money, recipes, equipment, and infrastructure. The development of a mass casualty biological weapon involves certain tacit knowledge and skill sets, which are not readily available, and reside in the cumulative experiences of former bioweaponeers. These findings have direct policy implications for U.S. nonproliferation assistance program to the FSU, as well as challenge existing public assumptions about the ease by which terrorists could develop mass casualty biological weapons. [2]

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[2] From January 2003-January 2004, Vogel is on leave from the University of New Mexico serving as a William C. Foster Fellow in the Office of Proliferation Threat Reduction, Bureau of Nonproliferation, U.S. Department of State.

I. Introduction

The collapse of the Soviet Union and its subsequent economic and political turmoil has ushered in security concerns regarding the proliferation of its sensitive biological weapons (BW)-related personnel, materials, and equipment to countries and terrorist groups hostile to the United States. Several academic, media, and government reports have called attention to these threats.[3] In spite of these reports, the underlying influences and transfer mechanisms involved in the so-called "brain drain" threats, i.e., the proliferation of sensitive BW-related knowledge and skills, remain poorly understood.

This is due to various factors including: (1) limited open source information on the former Soviet BW program and its bioweaponeers; and (2) limited policy studies on what comprises BW knowledge and how such knowledge can be transferred.[4] On the latter factor, the social science field of Science and Technology Studies (S&TS) can provide new insights and avenues of research to elucidate BW knowledge production and technology transfer issues.

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[3] Amy E. Smithson, *Toxic Archipelago: Preventing Proliferation from the Former Soviet Chemical and Biological Weapons Complexes Report No. 32* (Washington, DC: The Henry L. Stimson Center, 1999); Jonathan B. Tucker, "Bioweapons from Russia: Stemming the Threat," *Issues in Science and Technology,* (Spring 1999). Anthony Rimmington, "Fragmentation and Proliferation? The Fate of the Soviet Union's Offensive Biological Weapons Programme," *Contemporary Security Policy* Vol. 20, No. 1 (April 1999), pp. 86-110; Maria Katsva and Derek Averre, "Chemical and Biological Weapons Export Controls," in Gary K. Bertsch and William C. Potter, eds., *Dangerous Weapons, Desperate States: Russia, Belarus, Kazakhstan, and Ukraine* (New York: Routledge, 1999), pp. 103-130; United States General Accounting Office, *Biological Weapons: Effort to Reduce Former Soviet Threat Offers Benefits, Poses New Risks, GAO/NSIAD-00-138* (Washington, DC: U.S. General Accounting Office, April 2000); Sonia Ben Ouagrham, "Biological Weapons Threats from the Former Soviet Union," (forthcoming); R. Jeffrey Smith, "Russians Admit Firms Met Iraqis; Plant That Could Make Germs Weapons at Issue," *Washington Pos*t, February 18, 1998, p. A16; Michelle Stem Cook and Amy F. Woolf, *Preventing Proliferation of Biological Weapons: U.S. Assistance to the Former Soviet States, CRS Report for Congress* (Washington, DC: Congressional Research Service, April 10, 2002); Judith Miller, Stephen Engelberg, and William Broad, *Germs: Biological Weapons and America's Secret War* (Simon & Schuster, 2001); Carnegie Endowment for International Peace and Russia American Nuclear Security Advisory Council, *Reshaping U.S.-Russia Threat Reduction; New Approaches for the Second Decade* (Washington, DC: Carnegie Endowment for International Peace and the Russian-American Nuclear Security Advisory Council, 2002); Victor Alessi, "The Brain Drain Problem," in Robert J. Einhorn and Michele A. Flourney, eds., *Protecting Against the Spread of Nuclear, Biological, and Chemical Weapon: An Action Agenda for the Global Partnership Vol. 2: The Challenges* (Washington, DC: Center for Strategic and International Studies, January 2003), pp. 1-22; Anne M. Harrington, "Redirecting Biological Weapons Expertise: Realities and Opportunities in the Former Soviet Union," *Chemical Weapons Convention Bulletin*, No. 29 (September 1995), pp. 2-5.

[4] For an interesting discussion on the proliferation of BW technology see: Milton Leitenberg, "Biological Weapons an Bioterrorism in the First Years of the 21st Century," accessed 29 March 2003 at: http://www.fas.org/bwc/.

To probe these S&TS concepts this paper sets out to explore the following questions:

- What knowledge and skill sets are involved in creating weapons technologies?
- What can such information tell us about the brain drain proliferation problem involving former Soviet bioweaponeers?

These two questions will be examined in this paper through the following four sections. Section I will provide the context surrounding brain drain proliferation threats from former Soviet bioweaponeers. Then, the paper will introduce key S&TS concepts on knowledge production relevant to the development of biological weapons technologies. Using a case study approach, the third section of the paper will apply these S&TS concepts to bioweapons development at a former Soviet facility in Kazakhstan and conduct a preliminary analysis of the existing brain drain threat from this facility. Finally, the paper will conclude with an analysis of how additional social science research could further disentangle some of these brain drain issues from bioweaponeers at the Kazakh BW facility and other facilities that were associated with the former Soviet BW complex.

II. The Problem: BW Proliferation in the Former Soviet Union (FSU)

The USSR's BW program involved an extensive number of research institutes, production facilities, and testing sites spread across Russia and several of the former Soviet republics.[5] Although dating back to the 1920s, the BW program was greatly expanded after the

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[5] More detailed information regarding the former Soviet BW program can be found in: Ken Alibek with Stephen Handelman, *Biohazard: The Chilling True Story of the Largest Covert Biological Weapons Program in the World—Told From Inside by the Man Who Ran It* (New York: Random House, 1999); Anthony Rimmington, "Invisible Weapons of Mass Destruction: The Soviet Union's BW Programme and its Implications for Contemporary Arms Control," *The Journal of Slavic Military Studies*

USSR signed and ratified the Biological and Toxin Weapons Convention in the early 1970s.[6] For example, a number of new BW activities were initiated in facilities under several Soviet government agencies to include the Ministries of Agriculture, Chemical Industry, Defense, Health, Microbiological Industries, the Academy of Sciences, and the KGB. By the early 1990's, the defection of key individuals associated with the Soviet BW program began to reveal the extent of Soviet offensive BW capabilities to the international community. It is difficult to determine the exact composition of the USSR's entire BW program due to the compartmentalization, dual-use nature, and lingering secrecy regarding Soviet BW activities. Available open source information suggests that more than forty institutes, employing up to as many as 15,000 Soviet specialists, were involved in offensive and defensive BW activities.[7]

The collapse of the Soviet Union has created an unstable environment for many of these former BW facilities. The dire economic situation facing these weapons facilities and their bioweaponeers, as well as poor export controls on sensitive BW knowledge and materials in

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Vol. 13, No. 3 (September 2000), pp. 23-28; Igor Domaradskij and Wendy Orent, "Memoirs of an Inconvenient Man: Revelations About Biological Weapons Research in the Soviet Union," *Critical Reviews in Microbiology*, Vol. 27, No. 4, pp. 239-266 (2001); Milton Leitenberg, "Biological Weapons Arms Control," *Contemporary Security Policy* Vol. 17, No. 1 (April 1996), pp. 1-79; Milton Leitenberg, "The Conversion of Biological Warfare Research and Development Facilities to Peaceful Uses," in Erhard Geissler and John P. Woodall, eds., *Control of Dual-Threat Agents: The Vaccines for Peace Programme*, (Oxford: Oxford University Press, 1994), pp. 77-105; Tom Mangold and Jeff Goldberg, *Plague Wars: A True Story of Biological Warfare* (New York: St. Martin's Press, 1999); Jonathan Ban, "Agricultural Biological Warfare: An Overview," *The Arena*, Vol. 9 (Alexandria: The Chemical and Biological Arms Control Institute, 2000); Christopher J. Davis, "Nuclear Blindness: An Overview of the Biological Weapons Programs of the Former Soviet Union and Iraq," *Emerging Infectious Diseases*, Vol. 5, No. 4 (July-August 1999), pp. 509-512; Milton Leitenberg, "The Possibilities and Limitations of Biological Weapons Conversion," in Erhard Geissler, Lajos Gazso, and Ernst Buder, eds., *Conversion of Former BTW Facilities: Development and Production of Prophylactic, Diagnostic, and Therapeutic Measures for Countering Diseases* (Dordrecht: Kluwer, 1998), pp. 125-131; Anthony Rimmington, "The Soviet Union's Offensive Program: The Implications for Contemporary Arms Control," in Susan Wright, ed., *Biological Warfare and Disarmament: New Problems, New Perspectives* (Lantham, MD: Rowman & Littlefield, 2002), pp. 103-148.

[6] Milton Leitenberg, "The Conversion of Biological Warfare Research," pp. 90-97; Anthony Rimmington, "Invisible Weapons of Mass Destruction: The Soviet Union's BW Programme and its Implications for Contemporary Arms Control," pp. 23-28; Valentin Bojtov and Erhard Geissler, "Military Biology in the USSR, 1920-1945," in Erhard Geissler and John Ellis van Courtland Moon, eds., *Biological and Toxin Weapons: Research, Development, and Uses from the Middle Ages to 1945* (Oxford: Oxford University Press for the Stockholm International Peace Research Institute, 1999), pp. 153-189; Michael Moodie, "The Soviet Union, Russia, and the Biological and Toxin Weapons Convention," *The Nonproliferation Review* (Spring 2001), pp. 59-69; Petra Lilja, Roger Roffey, and Kristina S. Westerdahl, *Disarmament or Retention: Is the Soviet Biological Weapons Programme Continuing in Russia?* (Umea: FOA Defence Research Establishment, December 1999).

[7] United States General Accounting Office, *Biological Weapons: Effort to Reduce Former Soviet Threat Offers Benefits, Poses New Risks*, p. 10.

Russia and the New Independent States (NIS), has underscored the concern over continuing proliferation. These worries are not unfounded. By the late 1990's, unclassified government reports revealed that some proliferation of sensitive BW knowledge had already likely occurred.[8]

In particular, Iran has been aggressively trying to recruit former Soviet BW scientists. Their efforts have included offers of salaries as high as $5,000 per month to relocate to Iran, as well as separate contracts for consultancy work and other types of questionable scientific and educational exchanges.[9] So far, from open source information, it appears that only a small number of bioweaponeers have left the former Soviet republics to work in Iran and other countries of proliferation concern.[10] Yet, it is difficult to gauge the impact that these scientists and additional former Soviet bioweaponeers might have on a developing state offensive BW program. Because of these concerns, BW proliferation threats from the former Soviet Union remain a key U.S. national security concern.

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[8] See: Central Intelligence Agency, *Unclassified Report to Congress on the Acquisition of Technology Related to Weapons of Mass Destruction and Advanced Conventional Munitions, 1 January through 30 June 2001,* released 30 January 2002 on: http://www.odci.gov/cia/publications/bian/bian_jan_2002.htm; United States General Accounting Office, *Biological Weapons: Effort to Reduce Former Soviet Threat Offers Benefits, Poses New Risks.*

[9] For example, in 1991, Gennady Lepyoshkin, the former director of a former BW facility in Stepnogorsk, Kazakhstan, said that he had been approached by Iranian middlemen who disguised themselves as private businessmen looking for joint biotech commercial ventures. Although rebuffed in Kazakhstan, a scientific advisor for Iranian President Mohammad Khatami and delegations of Iranian clerics have traveled to several former Soviet BW facilities in Russia seeking research collaborations involving a variety of pathogens, as well as exchanges for broader scientific training in genetic engineering techniques. Russian scientists have acknowledged that at least five of their colleagues have gone to work in Iran for either consultancy or teaching contracts. In 1997, Iranian officials visited the All-Russian Institute of Phytopathology in Golitsino, Russia. This visit was designed to explore possibilities for scientific exchanges on plant pathology projects. It is known that four scientists from this facility have visited Tehran on business trips. That same year, the Russian Ministry of Science and Technology sponsored a biotechnology trade fair in Tehran. More than 100 leading biologists from former Soviet BW institutes attended the meeting. American and Russian government officials admit that these recruitment efforts have continued. See: Judith Miller and William J. Broad, "Iranians, Bioweapons in Mind, Lure Needy Ex-Soviet Scientists," *The New York Times*, December 8, 1998, p. A1; Central Intelligence Agency, *Unclassified Report to Congress on the Acquisition of Technology Related to Weapons of Mass Destruction and Advanced Conventional Munitions, 1 January through 30 June 2001,* released 30 January 2002 on: http://www.odci.gov/cia/publications/bian/bian_jan_2002.htm; Judith Miller, "Flying Blind in a Dangerous World," *The New York Times,* February 6, 2000, p. D5.

[10] According to Milton Leitenberg, by 1997 a few hundred scientists had left the Russian Biopreparat BW establishment. Of these, approximately 90 percent had gone to either Israel, Western European countries, or the United States. Of the remaining 10 percent, the majority of these scientists had gone to work in developing countries that do not have BW programs. Milton Leitenberg, telephone interview with author, 19 October 2001; Milton Leitenberg, "Biological Weapons in the Twentieth Century," accessed 29 March 2003, http://www.fas.org/bwc/papers/review/prolif.htm.

A. U.S. Policy Responses to the FSU BW Threat

In 1991, Congress passed the Soviet Nuclear Threat Reduction Act to start addressing Russia's proliferation and offensive threats to U.S. national security.[11] The Act, renamed the Cooperative Threat Reduction (CTR) Program in 1993, was designed to downsize former Soviet arsenals of weapons of mass destruction and associated infrastructures, and redirect its former weapons scientists to peaceful purposes. Since its inception, CTR activities have expanded to include Russia and several of the former Soviet republics.

In 1998, the CTR program formally established, in conjunction and coordination with related U.S. government agencies and international programs, a Biological Weapons Proliferation Prevention Program (BWPP). Under guidance from the U.S. National Academy of Sciences, this program was designed to engage the former Soviet BW establishment through a series of projects to dismantle and demilitarize excess and outdated infrastructure, safeguard dangerous pathogen collections, and redirect former bioweaponeers to legitimate public health and biodefense activities.[12] Since 1998, additional bio-engagement programs have been established under the Departments of Agriculture, Energy, Health and Human Services, State, and the Environmental Protection Agency, as well as the Civilian Research and Development Foundation.[13]

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[11] See: Soviet Nuclear Threat Reduction Act, http://www.fas.org/nuke/control/ctr/docs/hr3807.html.

[12] U.S. National Academy of Sciences, *Controlling Dangerous Pathogens: A Blueprint for U.S.-Russian Cooperation, A Report to the Cooperative Threat Reduction Program of the U.S. Department of Defense* (Washington D.C.: U.S. National Academy of Sciences, 1997); Office of the Coordinator of U.S. Assistance to the NIS, *U.S. Government Assistance to and Cooperative Activities with the New Independent States of the Former Soviet Union: FY 1998 Annual Report* (Washington, DC: U.S. Department of State, January 1999), pp. 159, 172.

[13] The State Department launched its own Biological Weapons Redirection Program in 1998. Since then, this Program involves four components: (1) Bio-Chem Redirect Program, (2) BioIndustry Initiative, (3) Freedom Support Act funds, and the (4) Science Center. The Bio-Chem Redirect Program provides funds to support collaborative projects between Soviet bioweaponeers and the Departments of Agriculture, Health and Human Services, and the Environmental Protection Agency. The BioIndustry Initiative is geared towards the reconfiguration of former biological weapons production facilities, with associated efforts to support the accelerated development of new drugs and vaccines for highly infectious diseases. Freedom Support Act funds support

Proponents of these Nunn-Lugar programs[14] argue that such cooperative engagements have helped open up many of Russia's former BW facilities to U.S. and international oversight, thereby eliminating or reducing proliferation concerns at specific sites. In addition, government officials emphasize that Nunn-Lugar programs provide a forum for maintaining ongoing discussions with the Russian government regarding dismantlement activities at key BW production facilities[15] and future conversion activities for one of its former Ministry of Defense (MOD) facilities.[16] Former Soviet bioweaponeers have also pointed out that Nunn-Lugar funding allows them to maintain some measure of political autonomy and financial independence from hawks within the Russian government that secretly desire to retain a Russian offensive BW program.

In terms of dealing with the "tangible" proliferation threats, the BWPP activities can be hailed as a success. One former production facility in Stepnogorsk, Kazakhstan has been

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collaborative biological research through the Civilian Research and Development Foundation. The Science Centers provide funding for the International Science and Technology Center (ISTC) and the Science and Technology Center in Ukraine (STCU). The Department of Energy's Initiatives for Proliferation Prevention Program also provides opportunities for commercially viable collaborative R&D activities between Soviet bioweaponeers, U.S. national laboratories, and commercial enterprises. Previously, the U.S. National Academy of Sciences, Defense Advanced Research Projects, and National Aeronautics and Space Administration have also carried out collaborative research projects. Office of the Coordinator of U.S. Assistance to the NIS, *U.S. Government Assistance to and Cooperative Activities with the New Independent States of the Former Soviet Union: FY 1998 Annual Report* (Washington, DC: U.S. Department of State, January 1999), pp. 159, 172.

[14] The CTR Program, and associated U.S. interagency programs, are frequently referred to as the "Nunn-Lugar" programs in honor of Senators Sam Nunn and Richard Lugar who co-sponsored the original bill.

[15] At the time of this writing there have been no dismantlement activities at Russian BW facilities. This is because the CTR program is awaiting Russian government concurrence for a CTR implementing agreement, under the existing CTR umbrella agreement, which allows for dismantlement work at biological facilities. Remarks made by U.S. Department of Defense official, "Cooperative Threat Reduction, Biological Weapons Proliferation Prevention Program In-Process Projects Review Meeting," McLean, VA, 25-29 October 2001; Also, see: "Biological Weapons Proliferation Prevention Dismantlement," http://www.dtra.mil/ctr/project/projrus/ctr_facility_disman.html.

[16] One former BW facility under the Ministry of Defense has become a quasi-civilian entity. As of 2001, the Kirov-200 Institute of Microbiology in Strizhi, Russia, has been transferred from the jurisdiction of the Ministry of Defense to the Ministry of Education. Through informal discussions Kirov-200 officials have expressed interest in receiving U.S. nonproliferation assistance, and there are ongoing discussions for plans to allocate some State and DOD funding for dismantlement and redirection projects. It is important to note that Kirov-200 officials made this request for assistance after hearing of the Nunn-Lugar activities at other former BW institutes, as well as through subsequent dialogues with U.S. government officials. U.S. government official, telephone interview by author, 26 March 2002.

dismantled,[17] a key BW testing ground on Vozrozhdeniye Island in Uzbekistan has been demilitarized,[18] and several security enhancements of dangerous pathogen collections are completed or underway.[19]

In spite of these successes, however, controversy abounds as to the effectiveness of U.S. assistance programs directed at employing former Soviet bioweaponeers, the so-called "brain drain" nonproliferation programs. In public and private discussions about these programs the same questions continually arise: How effective are these programs? How can we measure their nonproliferation value? These are pressing policy questions that continue to circulate through various branches of the U.S. government, as well as in academic circles. To date, it has been difficult to find satisfactory answers to these questions due to the lack of an appropriate framework by which to evaluate such programs.

B. Difficulties in Assessing the Effectiveness of U.S. Government Nonproliferation Efforts

Part of the problem lies in the fact that there have been no rigorous, qualitative studies in the open source on what constitutes a brain drain threat. For example, is it just the transfer of Soviet BW recipes and protocols to countries of proliferation concern which is of greatest proliferation concern? Or is Soviet bioweapons knowledge embedded in people? If this knowledge is embedded in people, what exactly does this mean? What is this type of knowledge

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[17] Sonia Ben Ouagrham and Kathleen M. Vogel, *Conversion at Stepnogorsk; What the Future Holds for Former Bioweapons Facilities Peace Studies Occasional Paper #28* (Ithaca: Peace Studies Program, February 2003); Roger Roffey and Kristina S. Westerdahl, *Conversion of Former Biological Facilities in Kazakhstan: A Visit to Stepnogorsk*, FOI-R-0082-SE (Umea; FOI Swedish Defence Research Agency, May 2001).

[18] "VOZ ISLAND Biological Test Facility Aral Sea Region, Uzbekistan," http://www.dtra.mil/ctr/project/projuzb/ctr_voz_island.html.

[19] Kathleen M. Vogel, "Pathogen Proliferation: Threats from the Former Soviet BioWeapons Complex," *Politics and the Life Sciences* Vol. 19, No. 1 (March 2000), pp. 3-16; "Biological Weapons Proliferation Prevention Security Enhancements," see http://www.dtra.mil/ctr/project/projrus/ctr_security_enhance.html; U.S. General Accounting Office, *Weapons of Mass Destruction: Additional Russian Cooperation Needed to Facilitate U.S. Efforts to Improve Security at Russian Sites GAO-03-482* (Washington, DC: U.S. General Accounting Office, March 2003).

and how easily can it be transferred? Does it merely involve writing down the recipe for a Soviet biological weapon in an email message and firing it off to the highest bidder? Or is the successful transfer of such weapons technology more complex than that? Is it possible for this type of bioweapons knowledge or skills to erode over time? If so, how?

Answers to these difficult questions are critical in determining: (1) what the brain drain problem really is; (2) what the various U.S. brain drain nonproliferation programs are actually accomplishing; and (3) appropriate exit strategies for U.S. and international assistance targeted at these threats. Getting answers to these questions is difficult and will involve qualitative, as well as quantitative, data. Such information can be useful in designing appropriate frameworks and metrics for evaluating the progress of these brain drain assistance programs.

Obtaining more qualitative information on brain drain issues involves using research methods similar to solving any scientific problem, i.e., establishing a testable hypothesis and then collecting data to support or refute that hypothesis. To date, however, the BW policy community has not explored theoretical frameworks or hypotheses through which to examine these brain drain issues. What are appropriate theories and testable hypothesis for these difficult and ambiguous brain drain issues?

A significant body of research in the field of Science and Technology Studies (S&TS) has developed relevant theories and hypothesis on many of these “brain drain” or better put, knowledge-based questions. Core sub-disciplines in the S&TS field have focused on analyzing the production and transfer of technological knowledge for a range of civilian, dual-use, and military technologies. Important research within these sub-disciplines has revealed how many technologies are shaped by social factors and that certain types of technological knowledge and skills reside exclusively in people.

III. S&TS Concepts on Technological Knowledge Production and Technology Transfer

A. Alternative Views of Technology

Generally speaking, there are different, in fact opposing, views on how to define technology.[20] These views can be summarized as falling into one of two ideological camps: the reductionist versus the holistic. These two different perspectives influence how one understands the generation and diffusion of technological knowledge.

The reductionist[21] view emphasizes technology as a distinct artifact, the final product of human workmanship (e.g., machines, widgets, weapons).[22] Here, technology is considered as explicit and reducible to tangible forms such as blueprints, patents, or recipes. Within this school of thought, technology and its associated knowledge are viewed as being publicly available, impersonal, easy to reproduce, and able to diffuse freely. Technological development and technology transfer are seen as straightforward, direct, and inevitable.[23]

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[20] Kelvin W. Willoughby, *Technology Choice: A Critique of the Appropriate Technology Movement* (Boulder: Westview Press, 1990), pp. 25-43.

[21] A related concept frequently paired to reductionism is technological determinism: the belief that the products of technology are the primary or preeminent driving force of social change. Technological historian Thomas P. Hughes explains this perspective, "Technological development thus takes place in a hermetically sealed world of invention, engineering, and science until the fruit of thought and labor is loosed on the world to have its "social impact." Some equate technological determinism with the notion of a "technological imperative," which holds that once technological developments are underway, they are unstoppable, inevitable, and irreversible." Currently, technological determinism and technological imperative perspectives underpin some BW threat analyses. For example, certain scholars working on biological weapons issues hold that the progressive pace of biotechnology will inevitably usher in a new and deadly form of biological weapons. In these perspectives, the development of such malevolent technology by states or terrorist groups is seen as unavoidable. An interesting counterargument to this perspective comes from historian Michael Shallis who points out, "The Chinese discovered gunpowder but chose not to develop the gun." In this paper I will not discuss the arguments for or against technological determinism but it is a topic worthy of further exploration by BW research scholars. For a description of these perspectives see: Thomas P. Hughes, "From Deterministic Dynamos to Seamless-Web Systems," *Engineering as a Social Enterprise* (Washington DC: The National Academy of Sciences, 1999), pp.8-9; Daniel Chandler, "Technological or Media Determinism," accessed at website: http://www.aber.ac.uk/media/Documents/tecdet/tdet07.html; Michael Shallis, *The Silicon Idol: The Micro Revolution and its Social Implications* (Oxford: Oxford University Press, 19840, pp. 64-65.

[22] Science studies scholar Bruno Latour uses an interesting metaphor to describe technology under the reductionist perspective, "…employing these terms would be like watching a rugby game on TV where only a phosphorescent ball was shown. All the running, the cunning, the excited players would be replaced by a meaningless zigzagging spot." Bruno Latour, *Science in Action: How to Follow Scientists and Engineers Through Society* (Cambridge: Harvard University Press, 1987), p. 107.

[23] Some reductionist examples in historical accounts of technological development can be found in: C. Singer, E.J. Holmyrard, A. Hall, and T. Williams, eds. *A History of Technology* (New York: Oxford University Press, 1978).

In contrast, another view adopts a more holistic perspective of technology that emphasizes its technical and social influences. [24] In this perspective, technology encompasses not only end products, but also the social, political, and economic relationships that influence the development of the product. Certain scholars advocating this perspective argue that technology consists of important socially constructed factors, involving knowledge and skills that are private and local.[25] Technological historian Thomas P. Hughes writes that this view more accurately reflects the messy and complex nature of technological development.[26]

These two different concepts of technology raise interesting questions related to the prospects of proliferation involving Soviet BW technology. In the first definition, if BW technology can be merely reduced to a strain, recipe, or munition design, then these "artifacts" could be easily transferred or reconstituted. Such ease would increase the likelihood and severity of the proliferation of sensitive BW technology from Soviet BW facilities to states and terrorist groups. This conclusion would tend to support the importance of various U.S. nonproliferation programs in the FSU geared towards safeguards, demilitarization, and dismantlement. This conclusion, however, would also make so-called "brain drain" assistance programs difficult to

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[24] This camp is interested in contextual and constructivist perspectives of technology. The establishment of The Society for the History of Technology (SHOT) marked formalization of this perspective. See: http://shot.press.jhu.edu/; Michel Callon, "Is Science a Public Good. Fifth Mullins Lecture, Virginia Polytechnic Institute, 23 March 1993," *Science, Technology and Human Value*s Vol. 19, No. 4 (1994), pp. 395-424. In addition, researchers within the field of economics have examined the social influences on technology development and innovation. See: Giovanni Dosi, "Sources, Procedures, and Microeconomic Effects of Innovation," *Journal of Economic Literature*, Vol. 26, Issue 3 (September 1988), pp. 1120-1171l; Partha Dasgupta and Paul A. David, "Toward a New Economics of Science," *Research Policy*, Vol. 23 (September 1994), pp. 487-521; E.. Autio, E and T. Laamanen. "Measurement and evaluation of technology transfer: review of technology transfer mechanisms and indicators." *International Journal of Technology Management* Vol. 10, No. 7/8 (1995); Richard R. Nelson and Sidney G. Winter, *An Evolutionary Theory of Economic Change* (Cambridge: Harvard University Press, 1982), pp. 72-107; John Galtung, *Development, Environment, and Technology: Towards a Technology for Self-Reliance* (Geneva: United Nations, 1979).

[25] One of the most influential scholars in this subject is sociologist H.M. Collins from the University of Cardiff, U.K.. For interesting economic perspectives on this issue see: The Technology Atlas Team, "Components of Technology for Resources Transformation," *Technological Forecasting and Social Change*, Vol. 32 (1987), pp. 19-35; Eric von Hippel, "Sticky Information and the Locus of Problem Solving: Implications for Innovation," *Management Science*, Vol. 40, No. 4 (April 1994), pp. 429-439; Sidney G. Winter, "Knowledge and Competence as Strategic Assets," in *The Competitive Challenge: Strategies for Industrial Innovation and Renewal*, edited by David J. Teece (Cambridge: Ballinger, 1987), pp. 159-184.

[26] Thomas P. Hughes, "The Seamless Web: Technology, Science, Etcetera, Etcetera," *Social Studies of Science*, Vol. 16, Issue 2 (May 1986), p. 283.

justify since some would argue that Soviet BW technology could be easily reconstituted from available recipes and such information could be rapidly transferred via the Internet.

On the other hand, if a holistic definition of technology is adopted, then important human factors come into the proliferation equation. BW technology will then involve knowledge and skill-sets that reside exclusively in people. This finding would increase the validity of "brain drain" assistance programs and the need to support redirection and conversion assistance efforts to deal with these people-related knowledge components. The next section of this paper will describe in more detail these S&TS concepts that address human influences on technological knowledge and technology transfer.

B. Tacit Knowledge: The Human Dimension of Technology

Within the field of S&TS, technological knowledge is described as possessing two distinct knowledge components: (1) explicit knowledge, and (2) implicit knowledge, or what is more commonly referred to as "tacit" knowledge. Explicit knowledge is defined as information or instructions that can be formulated in words, symbols, formulas, or diagrams. Such information can be stored, copied, or transferred between scientists by impersonal means, such as in research notes, lab notebooks, or computer files. In contrast, tacit knowledge is knowledge, or in many cases those skills or abilities, that have not been, and perhaps cannot be, transmitted explicitly. This knowledge can only be passed between scientists by personal contact.[27] In layman's terms, this would involve skills acquired and developed through years of experience working alongside experts.

In the late 1950s, physical chemist-philosopher Michael Polyani was an early proponent of the notion that technology contains some distinctly human characteristics. In his book,

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[27] H.M. Collins, "Tacit Knowledge, Trust, and the Q Sapphire," *Social Studies of Science*, Vol. 31, No. 1 (2001), pp. 71-85.

Personal Knowledge, Polyani describes that scientific (and by analogy, technological) knowledge is based on unwritten information that is passed on by certain traditions and modes of personal interaction between scientists and engineers.[28] Many times, these "tacit" components are referred to in the scientific and lay communities as "know-how" or "tricks of the trade." Without these "tricks," an experiment or protocol can fail. For example, the absence of tacit knowledge has been found to hinder experimental work and repetition of published results even when materials and methods are explicitly specified in published sources.[29]

In technological development, different tacit components exist depending on the type of information or skills involved. Sociologist H.M. Collins, who has written extensively on this issue, has described five different types of tacit knowledge in his analysis of scientific and technological work:[30]

(1) ***Concealed Knowledge:*** Researcher "A" does not want to tell his tricks of the trade to others (usually competitors) and therefore does not include some critical experimental information in journal articles or research reports. Here, limitations in knowledge are related to certain logistical issues or to deliberate concealment. A laboratory visit or information exchange reveals this missing information.

(2) ***Mismatched Salience***: Most experiments involve a host of different variables that must be controlled. For example, Researcher "A" does not realize that researcher "B" needs to be told to do things in a certain way and "B" does not know the right questions to ask. The problem is resolved when "A" and "B" watch each other work.

(3) ***Ostensive Knowledge***: Words, diagrams, or photographs cannot convey information that can be understood only between Researchers "A" and "B" by direct pointing, demonstrating, or feeling.

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[28] Michael Polyani, *Personal Knowledge* (Chicago: University of Chicago Press, 1958).

[29] H.M. Collins, "The TEA Set: Tacit Knowledge and Scientific Networks," *Science Studies*, Vol. 4 (1974), pp. 165-186.

[30] H.M. Collins, "Tacit Knowledge, Trust, and the Q Sapphire," pp. 71-73.

(4) ***Unrecognized Knowledge***: Researcher "A" conducts an experiment in a certain manner; Researcher "B" picks up the same habit or "trick" during a laboratory visit to "A," but neither party realizes that anything important has been passed between them.

(5) ***Unrecognized/Uncognizable Knowledge***: Humans accomplish certain tasks or functions without knowing how they do it. For example, people learn to speak in proper grammatical phrases in their native language without knowing how they do it. Such abilities can be passed on only through interaction with others. This category can apply to brand-new scientific or technical discoveries, which are not fully understood. Certain aspects of the skills required to do them will be passed between Researcher "A" and "B" only tacitly.

Although category #1, "Concealed Knowledge," can be made explicit, categories #2-5 remain problematic to the transfer of technology even when a particular researcher has no intention to hide or obscure information.

Some of these tacit elements, however, can become less tacit over a period of time. For example, certain skills may become routine. As scientists interact, those things which were not clear from the beginning may become obvious. Furthermore, as understanding of the science or technology grows, scientists can learn how to make certain elements of tacit knowledge more explicit to others and this knowledge can be passed on without personal contact.[31] However, this is not always the case; some tacit components may still be outside the realm of explicit articulation through speech or words due to specific environmental factors, local workforce characteristics, or to some other peculiar social element unique in a laboratory's practices.[32]

How is tacit knowledge acquired? Typically, tacit knowledge is acquired via two mechanisms: (1) learning this particular type of knowledge or skill on one's own effort, i.e., "learning by doing," or (2) learning by watching and emulating others, i.e., "learning by

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[31] H.M. Collins, "Tacit Knowledge, Trust, and the Q Sapphire."

[32] Judith V. Reppy, "Dual-Uses Technology: Back to the Future?" in Ann R. Markusen and Sean S. Costigan, eds., *Arming the Future: A Defense Industry for the 21st Century*, (New York: Council on Foreign Relations, 1999), p. 278. H.M. Collins argues that, "while one can make more and more aspects of traditional knowledge explicit, explicit knowledge, however much of it there is, must always rest on unarticulated knowledge." H.M. Collins, "What is Tacit Knowledge?" in Theodore R. Schatzki, Karin Knorr Cetina, and Eike von Savigny, eds., *The Practice Turn in Contemporary Theory* (London: Routledge, 2001), p. 114.

example." Classic and simple examples used to illustrate these two concepts involve learning how to ride a bicycle, becoming an expert wine taster or medical diagnostician, or crafting a Stradivarius violin.[33] For example, in learning how to ride a bicycle, no one ever masters how to ride a bicycle by reading or listening to a detailed set of instructions or by deciphering the laws of physics associated with bicycle riding. Instead, one learns to ride a bicycle through a process of trial and error, either by individual effort or by watching someone ride a bicycle and then imitating her or him. The acquisition of tacit knowledge related to technologies involves a similar mechanism.

Tacit knowledge also involves some other unique characteristics related to technological development. Tacit knowledge involves specialized knowledge and skills sets that are not widespread or widely disseminated within the mainstream scientific or technological communities. [34] In contrast to explicit knowledge, it is not information that can be found in textbooks, journal papers, or even listening to detailed conference presentations.

Due to its specialized nature, tacit knowledge tends to be localized and embodied in specific individuals or groups of people. For complex technologies, such knowledge is embodied in larger, restricted groups sometimes referred to as "communities of practitioners."[35] Through his detailed examination of the development of steam turbines, water wheels, and the

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[33] Polyani was one of the first to use these examples as illustrations of tacit knowledge. Michael Polyani, *Personal Knowledge* (Chicago: University of Chicago Press, 1958), pp. 53-54.

[34] H.M. Collins, "The TEA Set: Tacit Knowledge and Scientific Networks," pp. 165-186.

[35] E.W. Constant II, "The Social Locus of Technological Practice: Community, System, or Organization," in Wiebe E. Bijker, Thomas P. Hughes, and Trevor J. Pinch, eds., *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology*, (Cambridge: MIT Press, 1994), pp.223-242; E.W. Constant II, "Communities and Hierarchies: Structure in the Practice of Science and Technology," in Rachel Laudan, ed., *The Nature of Technological Knowledge: Are Models of Scientific Change Relevant?* (Dordrecht: Reidel, 1984), pp. 27-46; Edward W. Constant II, The Origins of the Turbojet Revolution (Baltimore: The Johns Hopkins University Press, 1980); Walter G. Vincenti, *What Engineers Know and How They Know It: Analytical Studies from Aeronautical History* (Baltimore: The Johns Hopkins University Press, 1990); James Fleck, "Artefact-Activity: The Coevolution of Artifacts, Knowledge, and Organization in Technological Innovation," in John Ziman, ed., *Technological Innovation as an Evolutionary Process* (Cambridge: Cambridge University Press, 2000), p. 258.

turbojet, technological historian E.W. Constant finds that all of these technologies stem from traditions of practice that come from well-defined communities of technological practitioners.[36] Constant emphasizes that what distinguishes a practitioner is adherence to the tradition, and acquiring the relevant know-how, not education in a specific field of science or engineering. Understanding the knowledge base of these communities requires diagramming the flow of information and analyzing how this information is organized and shared. This type of analysis will help determine how the different domains and niches of experts fit together for accomplishing some common purpose."[37]

These communities will typically consist of a diverse collection of specialists, involving scientists, engineers, and other technical staff who work together to develop both individual and communal types of tacit knowledge.[38] These communities are involved in the maintenance, articulation, development, and innovation of the received technological tradition.[39] This is accomplished through continual practice and replication of technical activities. These communities frequently develop a culture of "testing" to confirm the successful integration of tacit and explicit communal knowledge into a working and reliable technology.[40]

Although tacit knowledge resides within people, it can be transmitted between people and locations. In both types of transfer, however, this process is not cursory. Between people, S&TS studies have shown that this transfer typically occurs through prolonged, direct personal working

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[36] Constant, "The Social Locus," p. 224; Constant, *The Origins of the Turbojet Revolution*; E.W. Constant II, "On the Diversity and Co-Evolution of Technological Multiples: Steam Turbines and Pelton Water Wheels," *Social Studies of Science* Vol. 8 (1978), pp. 183-210.

[37] Mary A. Meyer, Ray C. Paton, *Interpreting, Representing, and Integrating Scientific Knowledge from Interdisciplinary Projects, LA-UR-00-1448* (Los Alamos: Los Alamos National Laboratory), p. 21.

[38] Constant, "The Social Locus," p. 224

[39] Constant, "The Social Locus," p. 225.

[40] Constant, "The Social Locus," p. 226; Trevor Pinch, "Testing, One, Two, Three—Testing: Towards a Sociology of Testing," *Science, Technology & Human Values* Vol. 18 (1993), pp. 25-41.

relationships, such as between a master and apprentice.[41] For example, a senior specialist works closely with a novice and transfers his "tricks of the trade" over a period of time. Constant describes these interactions as intense and persistent.[42] Studies have shown that such knowledge transfer involves not only packages of information, but familiarity with the technology. In his studies of laser technology, H.M. Collins found that scientists and engineers who had all the necessary explicit information, but had not themselves built one, frequently failed to build a new type of laser. Collins writes, "No one could act as a middle man unless he himself was practiced in the skill. The scientist, his culture and skill are an integral part of what is known."[43]

Although tacit knowledge can also be transmitted between locations this is not necessarily a straightforward process. Frequently, the transfer of the new technology involves "translating," or adapting the technology to fit the new context.[44] S&TS studies have shown that this translation process often requires that the original inventors or specialists who created the technology oversee or work to translate the technology to fit a new system or environment.[45] This familiarity with the technology can be critical in moving the technology from working in a bench laboratory setting, to something that works in other locations without specialized operators. This familiarity cannot be completely written down; it is solely acquired through the development process.[46] Yet, even with the original developers, the translation process can

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[41] Polyani, *Personal Knowledge*, pp. 52-53.

[42] Edward W. Constant II, "Communities and Hierarchies: Structure in the Practice of Science and Technology," in Rachel Laudan, ed., *The Nature of Technological Knowledge* (Dordrecht: D. Reidel Publishing Company, 1984), p. 35.

[43] H.M. Collins, "The TEA Set: Tacit Knowledge and Scientific Networks," p. 183.

[44] See: Michel Callon, "Four Models for the Dynamics of Science," in Sheila Jasanoff, Gerald E. Markle, James C. Petersen, Trevor Pinch, eds., *Handbook of Science and Technology Studies* (Thousand Oaks: Sage, 1995), p. 49.

[45] Fleck, "Artefact-Activity," p. 260, 264-265.

require significant amounts of new scientific and technical work in order to adapt the technology to fit the new context. For example, being able to use the technology in different and diverse circumstances by users with little or no experience requires that those critical aspects of tacit knowledge be removed or made explicit as much as possible.[47]

Another interesting feature of tacit knowledge is that this type of knowledge can be lost over time if it is not used, practiced, or transmitted to a new generation of specialists.[48] For example, a particular skill that has not been used for a period of a generation may be lost completely. Polyani writes, "These losses are usually irretrievable. It is pathetic to watch the endless efforts—equipped with microscopy and chemistry, with mathematics and electronics---to reproduce a single violin of the kind the half-literate Stradivarius turned out as a matter of routine more than 200 years ago.[49]

Although there have been no academic studies that have examined the role of tacit knowledge in the development of BW technologies, there have been important studies that have looked at the role of tacit knowledge in nuclear weapons technology and in molecular biology. The following section will provide a brief overview of the key findings of these studies.

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[46] Graham Spinardi, "Defence Technology Enterprises: A Case Study in Technology Transfer," *Science and Public Policy*, Vol. 19, No. 4 (August 1992), p. 205.

[47] One striking example of this comes from the Defence Technology Enterprise (DTE), a U.K. company set up in 1985 to transfer technologies created in the British MOD research laboratories. Unfortunately, DTE was not successful. One of the reasons for its failure was DTE's reliance on simply transferring blueprints or hardware. This was found to be insufficient due to the absence of some "know-how" for the technology which existed only in the heads of the inventors. As a result, getting the technology to work at a different site posed major problems. Ultimately, this know-how had to be relearned or re-invented before the technology could be recreated at the new site, which proved to be a difficult, lengthy, and costly process. Graham Spinardi, "Defence Technology Enterprises: A Case Study in Technology Transfer," pp. 202, 205.

[48] For discussion of this see: H.M. Collins, "What is Tacit Knowledge?" in Theodore R. Schatzki, Karin Knorr Cetina, and Eike von Savigny, eds., *The Practice Turn in Contemporary Theory* (London: Routledge, 2001), p. 109; H.M. Collins, "The TEA Set: Tacit Knowledge and Scientific Networks," pp. 165-186. This point is also argued by Donald MacKenzie in: Donald MacKenzie, "Theories of Technology and the Abolition of Nuclear Weapons," in Donald MacKenzie and Judy Wajcman, eds., *The Social Shaping of Technology*, 2nd edition (Buckingham: Open University Press, 1999), p. 426.

[49] Michael Polyani, *Personal Knowledge*, p. 53.

C. Tacit Knowledge in Nuclear Weapons Technology

In 1995, sociologists Donald MacKenzie and Graham Spinardi published a landmark study detailing the importance of tacit knowledge in the design, engineering, and testing processes involved in the development of nuclear weapons.[50] The researchers used three pieces of evidence to support their conclusion: (1) historical information on the Manhattan project, (2) open source information on the proliferation of subsequent state nuclear weapons programs, and (3) 50 detailed interviews with current and retired staff from U.S. and U.K. nuclear weapons laboratories.

In examining these pieces of information, MacKenzie and Spinardi found that explicit knowledge of physics and the possession of fissile material was not enough to design and construct a workable and reliable prototype implosion nuclear weapon. This was due to the surprising need to solve a multitude of difficult engineering and interdisciplinary scientific problems not previously known.[51] Solving these problems required hiring thousands of technical specialists to develop a unique knowledge base, and the building of extensive and unique indigenous infrastructure.[52]

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[50] Donald MacKenzie and Graham Spinardi, "Tacit Knowledge, Weapons Design, and the Uninvention of Nuclear Weapons," *American Journal of Sociology*, Vol. 101, No. 1 (July 1995), pp. 44-99.

[51] These problems included: hydrodynamics issues related to implosion, purification and metallurgy of plutonium, constructing an appropriate lens structure for placement of high explosives, design of a workable initiator, building components that would withstand high altitude drops, short-circuiting in the detonators, as well as the need for new procedures and new instrumentation to monitor implosion experiments. MacKenzie and Spinardi, "Tacit Knowledge, Weapons Design, and the Uninvention of Nuclear Weapons," pp. 54-58. Also see: Lillian Hoddeson, "Mission Change in the Large Laboratory: The Los Alamos Implosion Program, 1943-1945," in Peter Galison and Bruce Hevly, eds., *Big Science: The Growth of Large-Scale Research* (Stanford: Stanford University Press, 1992), pp. 265-289.

[52] These problems were not anticipated, and it was assumed by many physicists within the Manhattan project that making an implosion weapon would be trivial. As MacKenzie and Spinardi relate, Edward Teller was warned by his friend, the future Nobel Laureate Eugene Wigner, not to join the new laboratory since the only presumed difficulty was the production of plutonium. Once that hurdle was overcome it was assumed that it would be easy and obvious to put together an atomic bomb. This faulty assumption has been made again by a recent article describing the ease by which terrorists could build a nuclear

In examining subsequent state nuclear programs, MacKenzie and Spinardi find similar evidence. For example, it is known that the Soviet Union and United Kingdom had access (through illicit and legitimate means, respectively) to explicit information and diagrams on early U.S. nuclear bomb designs. Yet, this explicit information was not enough to allow these countries to construct a copy of the U.S. design in a shorter or equal length of time compared to the Manhattan project.[53] Again, a multitude of engineering problems (not specified in the explicit information) surfaced which necessitated the Soviet and U.K. scientists to work out many of the details, essentially recreating many aspects of the Manhattan project.[54] Therefore, the amount of experimental work required for the U.K. and Soviet Union was not reduced, in spite of the explicit information. Examination of other state nuclear programs reveals that these countries have more the character of independent invention rather than simple copying of available information (through open or intelligence sources) on nuclear weapons technologies; all took longer than the original Manhattan project.

MacKenzie and Spinardi's interviews with weapons designers at Los Alamos and Livermore National Laboratories provide support that human factors still play an important role

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bomb. The article uses the example of the U.S. government's Nth country experiment in the 1960s, where it was shown that three post-docs with no nuclear knowledge could build a credible atom bomb. Although the post-docs did create a usable design for a nuclear weapon, the author assumes that this would lead to a working bomb with nuclear yield. However, the hypothetical design was never tested. Therefore, it is impossible to say whether the bomb would have actually worked. In fact, an official expert critique of the U.S. government Nth country report states that, "They [post-docs] correctly observe that they have very little firm information about the criticality of their system." MacKenzie and Spinardi's painstaking research illustrates that the design process was one of the simpler feats in constructing a nuclear weapon. The U.S., U.K., and Soviet nuclear programs experienced a number of problems in bringing their design to a working weapon due to a host of engineering and experimental problems that subsequently arose. Therefore, the assumption is flawed that a design would directly lead to a working nuclear weapon. MacKenzie and Spinardi, "Tacit Knowledge," p. 54; Dan Stober, "No Experience Necessary," *Bulletin of the Atomic Scientists* Vol. 59, No. 2 (March 2003), pp. 56-63; F.S. Eby and L.S Germain, "Critique of the Nth Country Weapon Design," in Lawrence Radiation Laboratory, Declassified, *Summary Report of the Nth Country Experiment, UCRL-50249*, edited by W.J. Frank (March 1967), accessed 30 March 2003 at internet website: http://www.thebulletin.org/issues/2003/ma03/ma03stober_doc.html.

[53] MacKenzie and Spinardi, "Tacit Knowledge," pp. 68-73.

[54] The U.K. case is particularly interesting since many British scientists were involved in the Manhattan project. However, MacKenzie and Spinardi find that British scientists were not positioned in all aspects of the nuclear weapons design, development, and testing processes. Therefore, gaps in certain types of technical knowledge and skills existed. MacKenzie and Spinardi, "Tacit Knowledge," pp. 70-73.

in nuclear weapons design. Even with the availability of powerful computer codes to assist nuclear weapons design, weapons designers argue that these codes require confirmation with human judgment. This judgment is attainable only through years of work with theory, codes, production processes, and the results of testing. Such expertise is gained through master-apprentice relationships from senior designers to junior designers, as well as through communal means, via close working relationships with different nuclear and weapons specialists across the weapons laboratory.[55]

In a separate study, anthropologist Laura McNamara's ethnographic dissertation of knowledge loss at Los Alamos National Laboratory elucidates the importance of "communities of practice," and testing to nuclear weapons technology.[56] McNamara finds that nuclear weapons knowledge at Los Alamos was, "located in a nexus of relationships that linked many different kinds of weapons experts to each other and to the nuclear artifacts they created."[57] Discussions and negotiations among various technical staff, including designers, experimental physicists, engineers, geologists, diagnosticians, machinists, and electricians were crucial to transforming a new nuclear design vision into a working high explosive device.[58]

Testing was paramount to the Los Alamos nuclear weapons community. Test preparations required a carefully coordinated effort among the design team and various sub-communities in the laboratory to turn its prototype weapon into a full-scale nuclear event.[59]

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[55] Mackenzie and Spinardi, "Tacit Knowledge," p. 63.

[56] Laura A. McNamara, "Ways of Knowing About Weapons: The Cold War's End at the Los Alamos National Laboratory," Ph.D. dissertation (Albuquerque: the University of New Mexico, May 2001).

[57] McNamara, "Ways of Knowing About Weapons," pp. 115-116.

[58] McNamara, "Ways of Knowing About Weapons," p. 133; For another relevant reference see: Hugh Gusterson, *Nuclear Rites: A Weapons Laboratory at the End of the Cold War* (Berkeley: University of California Press, 1996).

[59] McNamara, "Ways of Knowing About Weapons," p. 136.

Experienced weapons scientists adamantly insisted that the only way to acquire certain types of weapons knowledge was through cooperative, hands-on experience gained via the design, engineering, and testing cycle. This cycle created unique types of communal tacit nuclear weapons knowledge that could not be separated into individual, explicit components. These tacit skills were most crucial in the design and testing of new nuclear weapons.

McNamara finds that testing provided, "…material evidence that the weapons community had successfully integrated its many ways of knowing."[60] Each iteration of a design and test cycle allowed the weapons community to sustain, as well as build, heterogeneous, communally constructed weapons related knowledge.[61] From this study, McNamara concludes that nuclear weapons knowledge is a form of situated knowledge, being produced and transmitted experientially within certain boundaries.[62] These boundaries are such that tacit understandings and skills involved in nuclear weapons development are not easily replicated across time and space.[63]

D. Tacit Knowledge in Molecular Biology

Moving beyond nuclear weapons technologies, several S&TS studies have also revealed the importance of local culture and tacit knowledge in molecular biological research and techniques.[64] In particular, two key sociological studies worth noting discuss the role of tacit

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[60] McNamara, "Ways of Knowing About Weapons," p. 174.

[61] McNamara, "Ways of Knowing About Weapons," p. 148.

[62] McNamara, "Ways of Knowing About Weapons," p. 25.

[63] McNamara, "Ways of Knowing About Weapons," p. 279.

[64] For example, see: Karin Knorr Cetina, *Epistemic Cultures: How the Sciences Make Knowledge* (Cambridge: Harvard University Press, 1999), and references therein.

knowledge in the techniques of plasmid purification and isolation, otherwise known as the "plasmid prep,"[65] and hybridoma technology.[66]

Sociologists Kathleen Jordan and Michael Lynch's ethnomethodological study[67] of the plasmid prep finds that although the technique is well established and documented, human factors still play an important role in its successful use. Novice researchers still encounter a number of persistent problems associated with "doing" the technique from standardized manuals. Jordan and Lynch find that many of these problems stem from the fact that the plasmid prep tends to vary from lab-to-lab and scientist-to-scientist, depending on variations in experimental materials, equipments, and methods.[68] Standardized procedures are frequently streamlined and personalized depending on particular preferences and applications. In many cases, the prep is reinvented on each occasion of its use. Jordan and Lynch find that plasmid prep technology is mastered largely through repeated (and at times, solitary) practice, that typically varies depending on local knowledge and experience within the laboratory. Therefore, in spite of being a standardized tool in molecular biology, construction of the plasmid prep is a process that still embodies elements of localized, tacit laboratory knowledge.

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[65] The plasmid prep is used in recombinant DNA research to amplify plasmids and associated genetic material. The technique involves the insertion of plasmids and a gene of interest into a bacterial medium, such as E. coli. As the bacteria grow and multiply, the plasmid is also amplified.

[66] Hybridoma technology is a diagnostic and research tool used to produce monoclonal antibodies. This technique involves the fusion of cells producing antibodies with a particular type of cancer cells. The resultant hybrid, a "hybridoma," possesses both the capacity to produce a specific type of antibody and the growth characteristics of cancer cells that facilitates the cultivation of hybridomas. The specific antibodies secreted by the clones of a single hybridoma are called monoclonal antibodies. See: Gary Walsh, *Biopharmaceuticals: Biochemistry and Biotechnology* (Chichester: John Wiley & Sons, 1998), pp. 343-346.

[67] Kathleen Jordan and Michael Lynch, "The Sociology of a Genetic Engineering Technique: Ritual and Rationality in the Performance of the "Plasmid Prep," in Adele E. Clarke and Joan H. Fujimura, eds., *The Right Tools for the Job: At Work in Twentieth Century Life Sciences* (Princeton: Princeton University Press, 1992), pp. 77-114.

[68] For example, some laboratories that used a high-speed vertical rotor for mixing ingredients modified existing protocols for the plasmid prep. This is because the rotor cut down the amount of time to do the cesium-chloride gradient---from two days to a few hours. One postdoctoral researcher comments on doing the prep, "Oh sure, there's a bloody great textbook by Maniatis, which is the Bible for this type of thing, so you can refer to that. But there are some mistakes in that book, and you're never sure that this is the right way...I started to get irritable about the fact that for what appeared to be a very simple process there were many different procedures." Kathleen Jordan and Michael Lynch, "The Sociology of a Genetic Engineering Technique," pp. 85-86; 88.

In another study, Alberto Cambrosio and Peter Keating have investigated the importance of local knowledge in daily laboratory practices involving hybridoma technology.[69] Hybridoma technology is composed of a series of interdisciplinary skills and expertise involving immunization, immunochemistry, cell culture, sterile manipulation, virology, and bacteriology. In using these skills, several differences can exist between the standardized protocols used in different laboratories and even within the same laboratory. In many instances, certain "shortcuts" are used which do not appear in the written protocols.[70] As a result of these variations, hybridoma technology often requires apprenticeships to master the technique in a particular setting. Cambrosio and Keating find that when apprentices are taught the technique, the instructor usually stresses the importance of visual and motor aspects or of the procedure that are not documented.[71] Many of the scientists interviewed by Cambrosio and Keating describe certain aspects of their knowledge and skills on hybridoma technology as "art" and "magic" due to the role of localized, unarticulated knowledge.

These four social science studies raise intriguing notions of the role of tacit knowledge in the proliferation of weapons technologies. If tacit knowledge is an important component to the development of biological weapons, then important human factors come into the proliferation equation. BW technology will then involve certain knowledge and skill sets that are solely embedded in people and not reducible to written forms. And, such expertise can degrade over

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[69] Alberto Cambrosio and Peter Keating, "Going Monoclonal: Art, Science, and Magic in the Day-to-Day Use of Hybridoma Technology," *Social Problems*, Vol. 35, No. 3 (June 1988), pp. 244-260.

[70] For example, rather than go through the painstaking process of individually counting B cells and myelomas under the microscope, it is possible to simply "eyeball" the proper volume proportions of these two cell types. This type of judgment is learned only through oral and visual communication between scientists. Cambrosio and Keating, "Going Monoclonal," p. 252.

[71] Cambrosio and Keating describe how a post-doc in a particular laboratory had a unique way of shaking test tubes containing recently fused cells. This technique was quickly adopted by other researchers in the laboratory who pointed out that it could make the difference between success and failure of a fusion. This particular shaking technique was not articulated through written form, but only through interaction with the postdoc. Cambrosio and Keating, "Going Monoclonal," p. 250.

time if not used. These conclusions would support the importance of nonproliferation assistance programs to redirect former bioweaponeers.

With this in mind, what role does tacit knowledge play in Soviet bioweapons development? What could this have to tell us about assessing current brain drain threats from the remaining bioweaponeers within the Soviet BW complex and how to design effective nonproliferation assistance programs?

IV. A Pilot Case Study: The Stepnogorsk Scientific and Experimental Production Base (SNOPB)

A. Methodology

To date, there has been no detailed open source analysis on the knowledge and skill sets involved in Soviet BW development.[72] In order to test out the role of tacit knowledge on Soviet bioweapons development, I will use the Stepnogorsk Scientific and Experimental Production Base (SNOPB) as a case study. Specifically, I will analyze the technological development of SNOPB's anthrax weapon during the years 1983-1987. During this period, SNOPB conducted research, development, and large-scale pilot production to work out the protocols and certify the Soviet Union's most potent anthrax biological weapon.[73] Focusing on anthrax weapons activities at SNOPB over a five-year time period allows for exploration of how weapons knowledge was created and transmitted among bioweaponeers within a specific Soviet BW facility.

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[72] However, two key, ongoing studies on the former Soviet BW program are worth noting: (1) Milton Leitenberg, at the University of Maryland, and Raymond Zilinskas, at the Monterey Institute of International Studies are finishing a book on the history of the former Soviet BW program; (2) Sonia Ben Ouagrham and Raymond Zilinskas, Monterey Institute of International Studies, are currently conducting a detailed study of the Soviet anti-plague system, which was involved in Soviet defensive BW activities.

[73] There is no publicly available information which provides definitive proof that SNOPB stockpiled the anthrax agent produced at the facility.

Such a historical analysis and resulting data can be useful in providing a baseline or points of reference for evaluating how various weapons related knowledge and skill sets have altered since the collapse of the Soviet Union. These types of evaluations can have important nonproliferation applications since current debates on the nature of proliferation threats tend to center on the role of individual facilities and scientists. Historical analyses on Soviet BW development can provide one important component in more qualitatively assessing current brain drain proliferation concerns at specific facilities.

Using SNOPB as a case study is ideal for the following reasons: (1) the favorable political and social climate in Kazakhstan has provided some open source information regarding Soviet BW activities at the facility; [74] (2) interviews with the former director, Ken Alibek, are possible since he lives in the Washington, DC area;[75] (3) the SNOPB facility is unique in that it included R&D, production, and weaponization workshops, which would facilitate a study of the various Soviet BW development processes; and (4) SNOPB refined and ultimately standardized a large-scale production process of the Soviet Union's premier anthrax biological weapon.

Data for this pilot study have been obtained through open source documents on the SNOPB, as well as interviews with relevant U.S. and former Soviet officials and scholars. Since many former Soviet bioweaponeers in Kazakhstan are still reluctant to talk about offensive BW activities during the Soviet period, this study is based on limited available open source information. The reader is cautioned that the conclusions drawn are preliminary and not intended to reflect an exhaustive analysis of the weapons developments processes at SNOPB.

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[74] In contrast, information on the process of Soviet biological weapons development in Russian facilities is considered extremely sensitive and difficult to acquire through interviews or published material.

[75] Alibek (formerly known as Kanatjan Alibekov) was deputy director, then director, of SNOPB when it became operational in 1983. Over the next four years he was directly involved in overseeing the development of the Soviet's anthrax biological weapon and other biological agents.

An additional caveat should be made with the findings of this study. The anthrax weapons development process at SNOPB may not be an accurate representation of all the factors influencing Soviet BW technology; what went on in Stepnogorsk may be different from what occurred at other BW facilities.[76] In addition, the big picture of Soviet BW development is likely to have been influenced by varying foreign and domestic political issues.[77] Although analysis of the larger political context affecting Soviet BW technology is important, it is not a focus area for this study; this research is focused exclusively on understanding local, tacit factors on BW development at a particular facility.

The following pages will provide a historical description of anthrax BW work that occurred at SNOPB in the early to mid-1980s. The first section will provide a brief historical background of SNOPB to describe its place in the larger Soviet BW program. The subsequent two sections will illustrate some unique local knowledge components involved in the development of the anthrax weapon at the facility.

B. Historical Context[78]

SNOPB, located in the small town of Stepnogorsk, in northwest Kazakhstan was officially established in 1982 by a secret edict from Communist Party Secretary General Leonid

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[76] This would not be a surprising finding since weapons laboratories bear some of their own unique characteristics and signatures. For example, U.S. nuclear weapons laboratories each possess their own research culture that involves different roles and responsibilities among its members, the types of tools used, and varying practices. As Laura McNamara explains, “assembly engineering as practiced at Los Alamos is different from assembly engineering as practiced at other laboratories: e.g., Livermore or Sandia National Laboratory…even particular styles of designing a nuclear weapon that stamp a device as uniquely Los Alamos or uniquely Livermore.” McNamara, “Ways of Knowing About Weapons,” p. 215.

[77] Various political and S&TS studies have examined the role of political and economic factors in the development of various Soviet military technologies. See: Matthew Evangelista, *Innovation and the Arms Race* (Ithaca: Cornell University Press, 1988); Nikolai Sokov, *Russian Strategic Modernization: Past and Future* (Rowman and Littlefield, 2000); David Holloway, *The Soviet Union and the Arms Race* (New Haven: Yale University Press, 1983).

[78] A significant portion of this background information comes from Sonia Ben Ouagrham and Kathleen M. Vogel, *Conversion at Stepnogorsk*; see additional references therein.

Brezhnev.[79] As with many Soviet bioweapons facilities, the SNOPB was a covert part of a larger dual-use civilian biopesticide facility known as the Progress Scientific and Production Association in order to conceal its military activities.[80] SNOPB had two functions: (1) to develop pilot and large-scale production methods for a variety of Soviet biological weapons, and (2) to serve as a dormant mobilization facility.

Although the official establishment of SNOPB took place in 1982, plans to build the entire civilian and military complex were already being developed in the 1960s. The civilian part, a biopesticide production plant called Plant Progress, was built first. The construction of SNOPB started in the second half of the 1970s. The BW assembly lines, bunkers, and storage buildings were built first. This was followed by construction of the main BW production buildings.[81]

In 1979, the construction of one of the production buildings was still under way when an accidental release of anthrax bacteria occurred at a Ministry of Defense (MOD) BW facility in Sverdlovsk, Russia.[82] When the need arose to relocate BW production activities from Sverdlovsk, Stepnogorsk was one of three facilities being considered. Ultimately, Stepnogorsk was chosen since it was not yet completed and could be modified to accommodate large scale

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[79] This is in spite of the fact that the USSR had signed and ratified the Biological and Toxins Weapons Convention, which entered into force in 1975. SNOPB was in blatant violation of this treaty, as was the rest of the Soviet BW program.

[80] The civilian part had two functions: (1) to produce pesticides for civilian use, and (2) to serve as a cover for the production of biological weapons taking place at SNOPB.

[81] These buildings were completed in 1981.

[82] In 1979, an accidental release of anthrax bacteria from the Sverdlovsk facility killed at least 200 people and brought international scrutiny to the facility, raising suspicions of continuing offensive BW activity in the USSR. See: Matthew Meselson, Jeanne Guillemin, Martin Hugh-Jones, Alexander Langmuir, Ilona Popova, Alexi Shelokov, Olga Yampolskaya. “The Sverdlovsk Anthrax Outbreak of 1979,” *Science* Vol. 266 (18 November 1994), pp. 1202-1208; “The Accidental Explosion at a Secret Biological Weapons Plant at Sverdlovsk,” Document compiled by U.S Air Force from classified U.S. Air Force Records, Unclassified, n.d.(ca.9/80)p.1.;Source:USAF FOIA; obtained at: http://www.gwu.edu/~nsarchiv/NSAEBB/NSAEBB61/.

BW production.[83] By 1982, a decision by the Soviet government had been made to utilize the existing fermentors in Stepnogorsk for manufacturing anthrax biological weapons. Kanatjan Alibekov was nominated to be the head of SNOPB that same year.

When SNOPB was first opened, it faced two main objectives: (1) to improve the potency of anthrax on a large scale, and (2) to create the organizational capacity to manufacture the Soviet anthrax 836 biological weapon.[84] In order to accomplish these tasks, SNOPB eventually expanded to include several large buildings and support structures in a complex spanning two square kilometers. By 1987, the development of new production methods at Stepnogorsk yielded a capability of producing 300 metric tons of anthrax per year, at a rate of approximately two tons per day.[85]

C. SNOPB Anthrax 836: Old Weapon, New Design, New Problems[86]

Prior to SNOPB work, the MOD had already developed a wool-based 836 formulation.[87] Using special drying methods, spores of *Bacillus anthracis* would be embedded in the shredded wool. Due to the added weight of the wool, the resulting material was quite heavy and would

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[83] Ken Alibek, Interview with author, Manassas, VA, August 22, 2001.

[84] The Soviet's Anthrax 836 weapon was based on a highly virulent, Russian strain of *Bacillus anthracis* bacteria isolated by Soviet MOD scientists. The high virulence of this strain was based on several factors, including a thick protective capsule and an ability to produce large amounts of toxins. Initial research, development, and production of Anthrax 836 were conducted at a military microbiological facility in Sverdlovsk, Russia. Later, SNOPB also developed the production capability for glanders, plague, and tularemia biological weapons. See: Ken Alibek with Stephen Handelman, *Biohazard*, p. 87; Jonathan B. Tucker, "Biological Weapons in the Former Soviet Union: An Interview with Dr. Kenneth Alibek," *The Nonproliferation Review*, Vol. 6, No. 3 (Spring-Summer 1999), p. 2.

[85] Gulbarshyn Bozheyeva, Yerlan Kunakbayev, and Dastan Yeleukenov, *Former Soviet Biological Weapons Facilities in Kazakhstan: Past, Present, and Future, Occasional Paper No. 1* (Monterey: Monterey Institute of International Studies, June 1999), p. 11; Ken Alibek, *Biohazard*, p. 105.

[86] Unless otherwise noted, information on SNOPB and Anthrax 836 work in the following sections is based on interviews with Ken Alibek, Manassas, VA, dated August 22, 2001, July 23, 2002, and July 27, 2002.

[87] Alibek speculates that this preparation method was obtained by the Soviets from the Japanese biological warfare 731 unit, after the 2nd World War. The shredded wool was used as a carrier for the anthrax bacteria, as well as facilitating entry of the bacteria into the body.

settle rapidly upon dissemination. Upon dispersal, this resulted in a high Q_{50} level---approximately 16 kilos/km^2.[88] This was deemed unsatisfactory for military use. Therefore, the MOD decided it was necessary to improve upon the existing 836 technology. MOD scientists went back to the drawing board and developed a paper-based concept for a new 836 weapon.

The new weapon would abandon the use of sheep's wool and incorporate a unique encapsulation technology based on beads of polyvinyl chloride (PVC).[89] The chemical properties of PVC would facilitate viability of the anthrax bacteria during and after explosive dissemination.[90] The MOD calculated that this new weapon would yield a much lower Q_{50} (4-5 kilos/km^2) for the anthrax agent. From this design, the MOD tasked SNOPB to turn this paper-based concept into a working, reliable, and militarily useful biological weapon. The MOD developed the technical task for SNOPB, which stipulated that the facility be capable of producing no less than 250 tons of anthrax per year, with a Q_{50} level of no more than 5 kilos/km^2.

In order to facilitate work at SNOPB, the MOD provided the facility with extensive technical papers and plans. This information included a report (approximately 400-600 pages in length) summarizing previous MOD work in developing the Anthrax 836 strain as a biological weapon. The report described different parameters, equipment, and biosafety conditions for the cultivation and production of the anthrax 836 strain. Other documents detailed how to fill and assemble bombs and warheads, how these munitions would be transported from the facility, and the various suppliers for all the raw materials. Interestingly, however, the report did not include

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[88] Q_{50} is the amount of BW agent necessary to cover 1 km^2 of territory with the dosage to give a lethal dose to 50% of the population in the area.

[89] Interview with a U.S. government official, Washington, DC, November 22, 2002.

[90] PVC is a polymer compound that resists fire and water and so is frequently used in making raincoats and shower curtains. It is also resistant to acids and bases, chemical agents, and sunlight, as well as chargeable with negative static electricity. When PVC is burned, chlorine is released which inhibits combustion. See: http://www.psrc.usm.edu/macrog/pvc.htm

certain details about the development of the MOD's 836 weapon, since some of this information was deemed restricted to MOD use only.

In spite of the extensive reports and documents provided by the MOD, the original SNOPB staff found direct application of this information to their facility to be problematic. The technical documentation as given was specific to MOD fermentors and equipment. As a result, SNOPB technical staff experienced difficulties even in trying to replicate previous MOD anthrax work in SNOPB's 20,000 liter fermentors.[91] SNOPB staff found that they could only use the MOD documentation as guidelines; they had to adapt the MOD production protocols and develop new materials (such as new types of nutrient media) and methods to fit the SNOPB system. As Ken Alibek states, "This [SNOPB] equipment was established and put together to manufacture things in a totally different way. Technological parameters described in that [MOD] report wouldn't be usable because you have different equipment and you need to develop techniques for different equipment."[92]

Other problems were encountered in scale-up from laboratory cultivation to large-scale production. Ken Alibek explains, "You can't use just small equipment and then after you finish this work you start working in big reactors. It wouldn't work. It is very difficult to scale up from 10 liters to 20 tons because you can't create the same parameters unless you change the characteristics…you have technological problems, safety problems."[93] All of these technical issues required not only additional bench scientific and development work, but solving a multitude of engineering tasks across the spectrum of weapons development.

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[91] This is in spite of the fact that the existing MOD anthrax weapon formulation had been developed at the Sverdlovsk facility which possessed 100,000 L fermentors. Interview with U.S. government official, Albuquerque, NM, November 7, 2002.

[92] Ken Alibek, Interview with author, Manassas, VA, July 27, 2002.

[93] Ken Alibek, Interview with author, Manassas, VA, July 27, 2002.

For example, the need to turn the virtually dormant facility into one capable of mass producing weaponized anthrax resulted in major engineering problems at SNOPB.[94] Initially, although all of the relevant infrastructure and equipment were on-site, none of the equipment was in working condition. In part, this was due to the fact that some of the equipment had not been assembled properly or ever been used.[95] SNOPB staff had to check the installation of all equipment and conduct tests on the equipment under specified parameters and real-world conditions to ensure proper functioning. First, the biosafety engineering systems, such as autoclaves, disinfectant chambers, fume hoods, air handling and filtration systems, negative pressure systems, and the hermetic seal of the building needed to be checked. Next, the larger technological systems, such as the fermentors, needed to be tested. This involved checking the anti-foaming and agitator blocking systems, as well as all connectors and heat-exchange units. In total, this involved testing and repairing hundreds to thousands of pieces of equipment.

Other engineering problems then surfaced in integrating the various individual pieces of equipment and infrastructure into an efficient technological chain. As described previously, portions of SNOPB (assembly lines, bunkers, storage buildings) were first constructed in the late 1970s. This was followed by construction of the main BW production buildings. Because these buildings were constructed at different times, there was no overall integration of the resulting infrastructure. SNOPB staff needed to integrate all of these existing buildings, along with assembling new batteries of equipment such as fermentors, drying, milling, and bomb filling machines. Other new infrastructure such as underground storage and pipelines were also added.[96] Ken Alibek explains, "the major issue and problem was coordinating all of the seemingly

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[94] Ken Alibek with Stephen Handelman, *Biohazard,* p. 88.

[95] SNOPB was constructed by prisoners who did not have any BW related background.

unrelated entities and pieces of equipment to work as a relatively well-oiled machine…..a disbalance in one system (e.g., engineering, technological parameters, scientific work) could result in significant trouble.[97]

To deal with these varying scientific and engineering problems, many more technical staff were hired to work at SNOPB. Some of these new employees were local; others came from Soviet BW facilities in Russia. By 1984, over 200 new employees were added to SNOPB.[98] Eventually, at the peak of SNOPB's activities, over 970 employees worked at the facility; one-third of whom were directly involved in BW activities.

In spite of these technical and engineering hurdles, SNOPB was successful in its MOD mandate. In 1987, approximately five years after the facility was commissioned, SNOPB successfully tested the new Anthrax 836 weapon on Vozrozhdeniye Island. The new weapon was then certified to be able to be used in the Soviet MOD arsenal.[99]

D. Local, Specialized Knowledge at SNOPB

For security reasons, SNOPB was established in an extremely remote location in northern Kazakhstan. As mentioned earlier, although infrastructure for the facility had been built in the 1970s, SNOPB was not an active facility until it was commissioned in 1982. As a result, even by 1983, the facility only possessed about 40 employees, including only 4 or 5 engineers. Virtually none of these original employees possessed prior BW experience or knowledge in large-scale weapons production. It is likely that this lack of experienced personnel contributed to

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[96] Ken Alibek with Stephen Handelman, *Biohazard*, p. 88.

[97] Ken Alibek, Interview with author, Manassas, VA, July 23, 2002.

[98] Ken Alibek with Stephen Handelman, *Biohazard*, p. 99.

[99] Ken Alibek with Stephen Handelman, *Biohazard*, p. 105.

the early problems in adapting MOD technical documentation to SNOPB and getting the facility on-line.

Due to these early SNOPB technical difficulties, the MOD decided to transfer 65 BW specialists from MOD facilities in Sverdlovsk and Kirov to SNOPB in 1984.[100] These individuals had specialized expertise in research and manufacturing techniques for anthrax bacteria. For example, Alibek's deputy, Gennady Lepyoshkin was a biosafety expert. Lt. Col. Kozhenvnikov was an expert in concentration, drying, and testing techniques, whereas Lt. Col Kiryenko had expertise in cultivation, and Lt. Col. Chernyshov was a specialist in drying and milling techniques.[101] Other MOD transfers had expertise in aerosolization methods and in filling and assembling of biological munitions.

These MOD staff were placed in all of the managerial positions within SNOPB, such as deputy directors, department chiefs, laboratory heads, senior engineers, and senior scientists. Other MOD majors, captains, and senior lieutenants took key technological, manufacturing, and biosafety positions. Ken Alibek describes, "…depending on their knowledge I would establish them in such a way so that these people would be responsible for some basic, critical points of production, critical equipment, critical processes."[102] These former MOD personnel also served as master trainers and provided the initial on-site scientific training, lasting 2-3 months, to all new BW technical recruits.

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[100] This transfer occurred within a six-month period.

[101] Ken Alibek, Interview with author, Manassas, VA, July 27, 2002; Ken Alibek with Stephen Handelman, *Biohazard*, pp. 83-84.

[102] Ken Alibek, Interview with author, Manassas, VA, July 27, 2002.

Of SNOPB's 300-plus BW specialists, around 125 consisted of senior, or highly experienced, bioweaponeers.[103] The remainder involved technicians, engineering, and support staff with varying skills devoted to BW activities. These BW specialists were organized in interdisciplinary teams across the various technological processes across R&D, production, and weaponization. At SNOPB, there were no separate divisions for research and scale-up. For example, joint divisions were established for cultivation that brought together scientists, engineers, and other technicians.

These interdisciplinary groups would work together on various aspects of research, development and production processes. Ken Alibek explains this work structure, "I developed this in such a way that we didn't have separate divisions for research and separate divisions for scale-up because I felt that as soon as you establish different entities, you increase the opposite…in this new structure, they would interact."[104] Alibek favored this arrangement in order to have multiple staff capable to assuming different technological functions if needed, as well as to facilitate production activities.

In order to facilitate exchanges between the scientific and technological parts of the facility, technical personnel were allowed to have open discussions and collaborations. Secrecy and compartmentalization, a characteristic of work at other Soviet BW facilities, was absent within the walls of SNOPB. As Ken Alibek explains, "When you talk about science and technology you cannot keep everything separate. If you only provide the necessary information, you can get into trouble. It was permitted to collaborate and cooperate, at least in my facility. In

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[103] Interview with U.S. government official, Washington, DC, November 22, 2002.

[104] Ken Alibek, Interview with author, Manassas, VA, July 27, 2002.

our facility everything was interconnected, from all standpoints, so it would have been stupid to impose any secrets between different departments, divisions, and labs."[105]

On the R&D end, teams of specialists were involved in the storage, cultivation, small-scale fermentation, and aerosol testing of the anthrax agent. For example, traditional bench microbiologists were involved in working with the 836 strain to establish ideal growth conditions. Once the strain moved to the development phase, which involved aerosol testing, additional specialists consisting of expertise in aerobiology, as well as explosives, engineers, and other physical scientists were involved in order to understand and control the dissemination dynamics that would occur during the testing phase.[106]

The large-scale production activities involved industrial microbiologists and process engineers. Weaponization of the agent (i.e., drying, milling) involved SNOPB microbiologists, chemical & mechanical engineers, as well as additional off-site collaborations with engineers at MOD munition design bureaus and other Biopreparat facilities.[107] Finally, even the open air testing on Vozrozhdeniye Island consisted of small (10-15 person) interdisciplinary teams of SNOPB specialists who worked with resident MOD support personnel.[108] Testing was a pre-requisite for establishing the military utility of a Soviet biological weapon.

Throughout the weapons activities at the facility, SNOPB maintained scientific exchanges and collaborations with other BW facilities in Obolensk and Leningrad, as well as MOD munition design bureaus.[109] These interactions helped to solve research problems, expand

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[105] Ken Alibek, Interview with author, Manassas, VA, July 27, 2002.

[106] Interview with U.S. government official, Washington, DC, November 22, 2002, Interview with U.S. government official, Albuquerque, NM, November 7, 2002.

[107] Interview with U.S. government official, Washington, DC, November 22, 2002.

[108] Interview with U.S. government official, Albuquerque, NM, November 7, 2002.

the scientific capabilities of the facility, and improve the development of SNOPB's anthrax formulation.[110]

V. Discussion

The preceding sections reveal that in SNOPB's development of the Soviet Union's new anthrax 836 biological weaponx, some elements that are consistent with the tacit knowledge were present. This tacit knowledge involved "learning by example," from knowledge and skills acquired through transfer of 65 experienced MOD bioweaponeers, as well as significant "learning by doing," via painstaking trial and error problem solving involving materials, techniques, and infrastructure unique to SNOPB. Certain categories of tacit knowledge are also evident. These include what H.M. Collins describes as concealed knowledge, mismatched salience, and ostensive knowledge.

First of all, although SNOPB did receive several hundred pages of technical documents involving previous MOD anthrax work, some classified information was not sent to SNOPB. This type of intentionally concealed experimental tacit knowledge would only come via personal communication with the original developers of the anthrax 836 weapon. Therefore, it is probable that some technical problems experienced by early, inexperienced SNOPB staff in working with the anthrax bacteria resulted from a lack of information on certain parameters or protocols in MOD documents. Subsequent transfer of the 65 experienced MOD staff to SNOPB likely solved these problems.

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[109] Interview with U.S. government official, Washington, DC, November 22, 2002.

[110] In 1990, a group of SNOPB military scientists went to Vector to assist in the development of a new smallpox weapon. Ken Alibek, interview with author, Manassas, VA, August 22, 2001; Interview with U.S. government official, Washington, DC, November 22, 2002.

Beyond the concealed knowledge, however, additional engineering and industrial problems at SNOPB surfaced related to its unique equipment and infrastructure. These types of problems, which also would not have been specified in the MOD documentation, relate to the tacit categories of mismatched salience and ostensive knowledge. Solving these problems would have involved a trial and error process utilizing knowledge and skills obtained through previous hands-on experience in working with fermentation, biosafety, drying, and milling equipment. Again, transfer of the 65 experienced MOD staff was likely critical to deciphering these types of tacit skills and adapting existing MOD protocols to work at SNOPB. These MOD staff also served important roles as master teachers to new technical recruits, transferring additional tacit knowledge and skill sets to a new generation of weapons personnel. In addition, SNOPB also maintained periodic exchanges and collaborations with other Soviet BW facilities to consult on related technical issues.

However, even with the transfer of experienced MOD staff to SNOPB, developing the new 836 technology was not trivial. It is interesting to note that it took five years to develop the new anthrax 836 technology---even though this weapon was based on an already developed anthrax strain.[111] Much of the delay was related to solving different types of new scientific and engineering problems that were not anticipated or specified in existing MOD documentation and were unique to SNOPB. Turning the paper-based MOD weapons concept into a working technology required the indigenous development of new materials, protocols, equipment, infrastructure, as well as the hiring of several hundred additional personnel. Addressing all of these issues likely contributed to the lengthy development of the new weapon. The difficulties experienced by SNOPB illustrate some of the problems in translating certain technologies behind

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[111] The original Soviet nuclear bomb took less time--approximately four years to create. In contrast to the new 836 anthrax biological weapon developed at SNOPB, the Soviet nuclear weapon was based on an entirely new technology in a new industry.

creating biological weapons with particular military and industrial specifications. As the SNOPB case shows, it was difficult to develop the new 836 weapon to operate in a new context and under new requirements even with unlimited funds, resources, critical infrastructure, and experienced personnel at Soviet disposal.

Also, contrary to popular opinion, the development of a militarily useful biological weapon requires not only bench microbiologists or virologists, but a host of other specialists to deal with various scientific and engineering problems. For example, solving issues related to the drying and milling process are equally important as fermentation to creating and effectively disseminating a viable mass casualty biological agent. Therefore, similar to the development of nuclear weapons, creating a militarily useful biological weapons requires a range of interdisciplinary specialists working together to create a unique knowledge base.

Similar to other technological communities, testing was a critical component of this unique knowledge base at SNOPB. Testing was required to determine the military characteristics and utility of the new weapon. A new Soviet BW weapon, such as the anthrax 836 weapon, was not certified as a reliable, military usable weapon until it went through successful open-air tests on Vozrozhdeniye Island. The testing process also involved a cadre of interdisciplinary BW specialists. Testing on Voz Island served to confirm the successful integration of the explicit and tacit knowledge and skills embedded in the new weapon from the interdisciplinary team of specialists at SNOPB.

VI. Present-Day Policy Relevance

Historical analysis of the weapons development process at SNOPB can provide a baseline for evaluating changes in the weapons knowledge base at the facility. Since the mid 1990s

SNOPB has stopped its weapons activities and has been engaged in a number of cooperative bilateral and multilateral assistance programs. These programs have opened up the facility and its remaining weapons scientists to the U.S. and its allies. As a result, it is possible to begin qualitatively assessing how the weapons knowledge base has been altered since the Soviet period.

Some changes are evident beginning towards the end of the Soviet period. Starting in 1987, once the major anthrax 836 work had been completed, SNOPB had begun to downsize.[112] This reduction in personnel involved the gradual return of some of the original design, production, and testing teams back to MOD and other Soviet BW facilities. This migration of technical personnel back to Russian facilities continued through and subsequent to, the break-up of the USSR.

Furthermore, mounting concerns over Western intelligence and potential inspections led to the Soviet government decision to destroy and dismantle critical weapons infrastructure at SNOPB. In 1990, the unique 300 m^3 explosive aerosol test chamber was destroyed, and biological-agent filling lines for weaponization were sent back to Russian facilities.[113] With the collapse of the USSR, more severe personnel and infrastructure changes occurred at SNOPB. Starting in 1993, SNOPB was moth balled and all weapons activities ceased.[114] Therefore, for almost ten years, from 1993 to 2003, no weapons-related work has been conducted at the facility. This implies that there has been no practice or use of specific weapons-related skills or knowledge sets, particularly in the use of large fermentation and aerosol testing equipment.

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[112] It is important to note, however, that some offensive work continued at SNOPB after 1987 on BW agents such as plague, glanders, and tularemia. Ken Alibek, Interview with author, August 22, 2001, Manassas, VA.

[113] Brian Hayes, presentation, “Protection of Biological Weapons Proliferation through Cooperative Threat Reduction Programs,” at conference on “Former Biological Weapons Facilities: Dismantlement and Prospects for Conversion,” Stepnogorsk, Kazakhstan, July 24, 2000; Ken Alibek, Interview by author, Manassas, VA, August 22, 2001; Ken Alibek with Stephen Handelman, *Biohazard*, p. 190.

[114] Interview with U.S. government official, Washington, DC, November 22, 2002.

Furthermore, since 1993, no new generation of bioweaponeers have been trained at SNOPB. Instead, as mentioned above, the facility has undergone a continual downsizing. From SNOPB's heyday where over 300 BW specialists worked at the facility, only about forty BW specialists currently remain on-site.[115]

In addition, Nunn-Lugar assistance has also contributed to changes in the weapons knowledge base at SNOPB.[116] Since 1997, the Department of Defense's CTR program has been involved in dismantling the facility. As of September 2000, all weapons-related infrastructure has been dismantled and the existing buildings are slated for demolition. Since CTR work has commenced at SNOPB there has been stringent oversight and confirmation that no weapons activities have occurred on-site during the dismantlement contract. Furthermore, Nunn-Lugar programs through the Environmental Protection Agency and the Departments of Energy and State have provided financial assistance for various redirection projects for former SNOPB personnel. All of these projects have involved peaceful research activities with non-BW agents. Therefore, certain offensive knowledge and skill sets involved in working with anthrax, tularemia, glanders, and plague agents have not be used for approximately six years.

Therefore, with all of these personnel and infrastructure changes over the past ten years, the weapons knowledge base has changed at SNOPB. Some elements of tacit knowledge have likely eroded through lack of use. The involvement of U.S. and international assistance in dismantlement and redirection activities highlights the role that such programs can play in helping to erode tacit weapons knowledge, decreasing certain brain drain proliferation threats over time.

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[115] Sonia Ben Ouagrham and Kathleen M. Vogel, *Conversion at Stepnogorsk: What the Future Holds for Former Bioweapons Facilities*, p. 59.

[116] For more details on Nunn-Lugar assistance at the Stepnogorsk facility see: Sonia Ben Ouagrham and Kathleen M. Vogel, *Conversion at Stepnogorsk.*.

However, it is important to point out some caveats with these preliminary conclusions. It is impossible to evaluate whether tacit weapons knowledge has eroded for former MOD personnel or other experienced BW specialists from SNOPB who returned to Russian MOD facilities. Also, in contrast to SNOPB, it is more difficult to assess the erosion of tacit knowledge if former BW facilities continue to work with BW agents and retain weapons-related infrastructure. Although this does not apply to SNOPB, this does become an issue for other former BW facilities in Russia and other former Soviet republics.[117] These issues should be taken into account when designing appropriate dismantlement and redirection activities at additional former Soviet BW facilities.

There is still much to be learned about BW development at SNOPB during the Soviet period. A number of outstanding questions would be worthy of further investigation---either in a classified or unclassified venue. These include the following:

- What were the specific skills and knowledge sets possessed by these interdisciplinary BW "specialists" for the development of particular weapons at SNOPB?
- How did these different communities of specialists work together to develop BW technologies? How were key technological problems solved?
- How was technology developed at SNOPB transferred and translated to other BW facilities? What problems existed in this transfer process? Were any SNOPB personnel transfers required? Or, was the explicit information sufficient?
- What information did SNOPB have about the U.S./U.K. anthrax biological weapons? How helpful was this information?
- How many of the original 65 MOD personnel returned back to MOD facilities? What scientific/technical work did they accomplish?

Such questions could be answered through a multi-year study involving detailed interviews with 40-50 former SNOPB bioweaponeers that were involved across SNOPB's weapons development chain. Getting answers to these questions would better characterize and

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[117] United States General Accounting Office, *Biological Weapons: Effort to Reduce Former Soviet Threat Offers Benefits, Poses New Risks*.

elucidate the role of tacit knowledge in Soviet BW development and the proliferation threat that remains from the forty bioweaponeers that remain on-site. This additional information would better qualify the nature of the remaining brain drain proliferation threat from former SNOPB bioweaponeers.

Moving beyond Stepnogorsk, many of the same questions raised in this paper could be asked of other Soviet BW facilities. For example, what technological communities constituted other research, production, and testing facilities and munition design bureaus? How did these communities integrate their knowledge into a working technology? What problems did they encounter and how did they solve them? How did they translate their knowledge to other facilities? Answering these types of questions can provide a more qualitative understanding of the historical weapons knowledge base at Soviet BW facilities. Such information can help guide U.S. assistance programs to better identify key former Soviet bioweaponeers and their associated networks, redirect them towards peaceful activities to degrade these tacit skills, and thereby decrease their long term proliferation threat.

Finally, the results from this paper imply that the development of a militarily useful biological weapon is complex and not merely reducible to recipes, equipment, and infrastructure. People-related influences on weapons technologies are equally as important in BW development. This has direct implications for concerns regarding the ease by which terrorists could develop a mass casualty biological weapon. Even certain countries with covert offensive BW programs, such as Iraq, have experienced numerous difficulties in turning their biological agents into workable mass casualty weapons. With ample resources and time, terrorists could acquire these tacit skills via the painstaking process of trial and error. More research needs to be done on the ability of terrorist groups to develop tacit knowledge and skill sets involved in creating a mass casualty BW capability.

This paper has only examined one aspect, the role of tacit knowledge, in weapons development. However, other important S&TS studies have also examined the role of organizational management, various actors, networks, and systems influencing the development of specific military technologies. Conducting additional social science research studies on these issues can provide a more holistic picture of the factors influencing proliferation threats involving BW, not only in the former Soviet context, but also in other regions of the world.