Keep Your Enemies Safer: Technical Cooperation and Transferring Nuclear Safety and Security Technologies

Jeffrey Ding[1]

November 2022

Abstract

Even during the fiercest periods of the Cold War, the U.S. and the Soviet Union cooperated on nuclear safety and security. Since an accidental or unauthorized nuclear detonation by another nation would threaten peace everywhere, it seems straightforward that states more experienced in developing nuclear safety and security technologies would transfer such methods to other states. Yet, the historical record is mixed. Why? Existing explanations focus on the motivations of the transferring state, emphasizing the political costs and proliferation risks of sharing nuclear safety and security technologies. This article argues that specific technological features condition the feasibility of assistance. For more complex nuclear safety and security technologies, robust technical cooperation is crucial to build the necessary trust for scientists to transfer tacit knowledge without divulging sensitive information. Leveraging a wealth of elite interviews and archival evidence, my theory is supported by four case studies: U.S. sharing of basic nuclear safety and security technologies with the Soviet Union (1961-1963); U.S. withholding of complex nuclear safety and security technologies from China (1990-1999) as well as from Pakistan (1998-2003); and U.S. sharing of complex nuclear safety and security technologies with Russia in the Warhead Safety and Security Exchange (1994-2007). My findings suggest the need to examine not only the motivations behind sharing nuclear safety and security technologies but also the process by which nuclear assistance occurs and the features of the technologies involved. These findings also bear on how states cooperate to manage the global risks of emerging technologies, especially as policymakers and scholars reference nuclear assistance as a historical template.

[1] Assistant Professor of Political Science, George Washington University. Correspondence email: jeffreyding@gwu.edu

For helpful comments and feedback, I thank: Markus Anderljung, Joslyn Barnhart, Stephen Buono, Alexis Carlier, Fiona Cunningham, Allan Dafoe, Ben Garfinkel, Rose Gottemoeller, Sig Hecker, David Holloway, Alla Kassianova, Karen Miller, Kristin Olofsson, Steve Pifer, Toby Shevlane, Lauren Sukin, Robert Trager, Sanne Verschuren, Waqar Zaidi, and participants at the University of Oxford's Centre for the Governance of AI seminar, Stanford University's Nuclear Reading Group, and a panel at the American Political Science Association. I am especially grateful to Scott Sagan for his encouragement on this project and to Dan Caldwell for sharing his private papers with me.

I. Introduction

Even during the fiercest period of technological competition in the Cold War, the U.S. took great pains to help the Soviet Union in one technological domain: nuclear safety and security. While no protective measure is a cure-all, states have developed methods to reduce risks associated with accidental nuclear detonations (*safety technologies)* and unauthorized use of nuclear weapons (*security technologies)*. Environmental sensing devices (ESDs), for example, which differentiate between normal weapon trajectories and abnormal ones (e.g., a fall from a loading truck), can enhance nuclear safety. In the nuclear security domain, the U.S. shared information with the Soviet Union on permissive action links (PALs), electro-mechanical locks that limit unauthorized launches by requiring the input of an enabling code.

An accidental or unauthorized nuclear explosion anywhere threatens peace everywhere. Thus, it seems straightforward that states more experienced in developing nuclear safety and security technologies would transfer such methods to other states. In a crisis, states may misinterpret a nuclear accident as an attack, leading to unwanted escalation. States should also be invested in other states' nuclear security, including that of hostile rivals, so as to reduce the likelihood of an unintentional nuclear war. On the subject of PALs, Harold Agnew, former director of the Los Alamos National Laboratory, once stated, "Anybody who joins the club should be helped to get this. Whether it's India or Pakistan or China or Iran, the most important thing is that you want to make sure there is no unauthorized use."[2]

The historical record, however, is mixed. While the U.S. shared nuclear safety and security technologies with Britain, France, the Soviet Union, and Russia, it withheld key

[2] Sanger, David E., and William J. Broad. "U.S. Secretly Aids Pakistan in Guarding Nuclear Arms." *The New York Times*, November 18, 2007, https://www.nytimes.com/2007/11/18/washington/18nuke.html.

techniques from China and Pakistan.[3] Even in cases when the U.S. ultimately provided nuclear safety and security assistance, key participants seemed almost bewildered by the presence of any resistance. For instance, John H. Morse, former U.S. Deputy Assistant Secretary of Defense for European and NATO affairs, once commented on nuclear cooperation with France, "The subject is safety of nuclear weapons wherein as a matter of principle we should be working closely with interested allies at all times anyway, and even with our potential enemies on occasions. I find it hard to understand why we have not pressed this matter before."[4]

Why do states withhold nuclear safety and security technologies from other states? Existing studies address this puzzle by further unpacking the motivations of the transferring state. They point out that the decision to share nuclear safety and security technologies is more complicated than meets the eye. Transferring states must also grapple with the disadvantages of this type of assistance, including proliferation risks and political costs. First, sharing nuclear safety and security technologies could signal approval of nuclear weapons, incentivizing other states to cross the nuclear threshold. Another related concern is that, after they receive help on guarding against accidental and unauthorized use, recipient states will adopt riskier nuclear postures. Transferring states also face political consequences. When deliberating over nuclear safety and security assistance, decision-makers are often concerned about public perceptions that they are giving away nuclear secrets. Taken together, this scholarship offers a more comprehensive accounting of the costs and benefits faced by the transferring state.[5]

---

[3] On U.S. nuclear assistance to Britain and France, see Caldwell, Dan. "Permissive Action Links: A Description and Proposal." *Survival* 29, no. 3 (May 1, 1987): 224–38. https://doi.org/10.1080/00396338708442358; Feaver, Peter D. "Command and Control in Emerging Nuclear Nations." *International Security* 17, no. 3 (1992): 160–87. https://doi.org/10.2307/2539133; Ullman, Richard H. "The Covert French Connection." *Foreign Policy*, no. 75 (1989): 3–33. This article covers U.S. assistance to the other four countries in this list.

[4] Morse, John H. "Memorandum for M. Nutter from John H. Morse," January 4, 1971. John H. Morse papers, box 3, folder 2. Hoover Institution Library and Archives.

[5] Caldwell, "Permissive Action Links: A Description and Proposal"; Feaver, "Command and Control in Emerging Nuclear Nations"; Feaver, Peter D., and Emerson M. S. Niou. "Managing Nuclear Proliferation: Condemn, Strike, or

This approach is helpful but insufficient for explaining why states share nuclear security and safety technologies with other states. Namely, it fails to account for cases when the balance of incentives still points toward sharing but the transferring state withholds. In this article, I argue that the feasibility of technology transfer is a key determinant of nuclear assistance. Specifically, an institutional basis for regular exchanges between nuclear engineers is a necessary condition for the transfer of more complex nuclear safety and security technologies. This explanation suggests the need to examine not only the transferring state's *motivations* but also the *process* by which nuclear assistance occurs and the *features* of the technologies involved.[6]

Not all safety and security technologies are created equal. More complex safety and security techniques demand more intensive transfer processes. Consider a simple illustration from the civilian domain. If one party seeks to transfer automobile safety technologies to another party, the process is very different for automatic emergency braking systems than seatbelts. Whereas the latter can be successfully transferred by sharing the general concept of a seatbelt, transferring the former demands more comprehensive discussions between engineers from both parties.

Assist?" *International Studies Quarterly* 40, no. 2 (1996): 209–33. https://doi.org/10.2307/2600957; Giles, Gregory F. "Safeguarding the Undeclared Nuclear Arsenals." *Washington Quarterly* 16, no. 2 (1993): 173–86; Miller, Steven E. "Assistance to Newly Proliferating Nations." In *New Nuclear Nations: Consequences for U.S. Policy*, 97–131. Council on Foreign Relations Press, 1993; Rehbein, Robert E. "Managing Proliferation in South Asia: A Case for Assistance to Unsafe Nuclear Arsenals." *The Nonproliferation Review* 9, no. 1 (March 1, 2002): 92–111. https://doi.org/10.1080/10736700208436876. My work builds on but is distinct from the literature on sensitive nuclear assistance, defined as aiding a *nonnuclear weapon state* with building a nuclear arsenal. For example, U.S. nuclear safety and assistance to France, which is covered by my theory, does not qualify as sensitive nuclear assistance. Kroenig, Matthew. *Exporting the Bomb: Technology Transfer and the Spread of Nuclear Weapons*. Cornell University Press, 2010, 201-202.

[6] Not limited to hardware, nuclear safety and security technologies also encompass organizational knowledge, such as guidelines for personnel reliability programs, which aim to only allow trustworthy individuals access to nuclear weapons. For other examples of nuclear security and safety measures, see Feaver, Peter D. *Guarding the Guardians: Civilian Control of Nuclear Weapons in the United States*. 1st edition. Ithaca, N.Y: NCROL, 1992, 14-18; Miller, "Assistance to Newly Proliferating States."

I theorize that transferring more complex nuclear safety and security technologies, such as advanced versions of ESDs and PALs, presents two challenges that necessitate technical cooperation between nuclear weapons experts. First, this process requires transferring substantial amounts of *tacit knowledge*, know-how which is not codified and cannot be passed along via technical specifications alone. A wide range of scholarship finds that, absent repeated social interactions between engineers from each side, it is very difficult to spread this type of specialized knowledge from one organization to another.[7]

Second, similar to the way an automatic emergency braking system connects with the automotive system, more complex nuclear safety and security technologies are integrated with the entire nuclear weapon system. For these technologies, information sharing requires a very high degree of trust because each side fears exposing vulnerabilities in their own nuclear arsenals.[8] Sharing PAL designs with other states, for instance, could give them information for devising countermeasures against the transferring state's own nuclear systems.[9] Institutional channels that allow regular technical consultations cultivate the trusting relationships needed to discuss sensitive methods without disclosing too much information.

Leveraging elite interviews and archival evidence, I test my theory with four case studies: U.S. sharing of basic nuclear safety and security technologies with the Soviet Union (1961-1963); U.S. withholding of complex nuclear safety and security technologies from China (1990-

---

[7] Collins, H.M. "The TEA Set: Tacit Knowledge and Scientific Networks." *Science Studies* 4, no. 2 (April 1, 1974): 165–85; Gilli, Andrea, and Mauro Gilli. "Why China Has Not Caught Up Yet: Military-Technological Superiority and the Limits of Imitation, Reverse Engineering, and Cyber Espionage." *International Security* 43, no. 3 (February 1, 2019): 141–89.

[8] Contrary to the orientation of existing studies, concerns may be enhanced on the recipient side. Multiple interviews with people knowledgeable about U.S. decision-making on nuclear assistance emphasized that potential recipients feared that accepting U.S. help on nuclear safety and security would expose them to backdoors. Author interview with co-founder of the Stimson Center Michael Krepon, phone, November 2021; author interview with former member of the U.S. State Department's Policy Planning Staff Neil Joeck, phone, November 2021; author interview with former chief of the State Department's China Division Thomas Fingar, Stanford, California, December 2021.

[9] Caldwell, "Permissive Action Links: A Description and Proposal," 236.

1999) as well as from Pakistan (1998-2003); and U.S. sharing of complex nuclear safety and security technologies with Russia in the Warhead Safety and Security Exchange (1994-2007). In addition to providing variation in the outcome of nuclear assistance and technological complexity, which entails differing levels of technical cooperation, the cases allow me to control for confounding variables, such as characteristics related to the recipient state.

In all four cases, U.S. decision-makers concluded that the benefits of transferring nuclear safety and security technologies outweighed the costs; however, the outcomes differed. In line with theoretical expectations, the U.S. could share basic nuclear security technologies with the Soviet Union by demonstrating general technological concepts, a process which did not require a strong basis of technical cooperation.

On the other hand, U.S. assistance to China and Pakistan on complex nuclear safety and security technologies was hampered by the lack of technical cooperation between the U.S. nuclear weapons scientists and their Chinese and Pakistani counterparts, a necessary precondition for transferring more complex technologies. This contrasts with the U.S.-Russian case, in which experiences from past technical exchanges allowed the U.S. to share information on more complex nuclear safety and security technologies.

This research contributes to key academic and policy questions related to the determinants of nuclear cooperation. By arguing that differences in technological complexity condition the level of technical cooperation needed to manage sensitive information, I develop a novel theory for why states transfer nuclear safety and security technologies. My theory demonstrates that more attention should be paid to technological specifics and potential recipient states' concerns in the process of nuclear safety and security assistance. While focusing on how transferring states weigh risks linked to proliferation and political blowback is helpful, it neglects crucial considerations about the feasibility of assistance, especially regarding the recipient state's trust that the process will not expose weaknesses in their nuclear weapons capability.[10]

Second, unlocking how states share nuclear safety and security technologies also bears on current discussions about risks associated with emerging technologies such as artificial intelligence (AI). Jason Matheny, former Deputy Director for National Security at the U.S. Office of Science and Technology, once stated, "The United States even during its deepest competition with the Soviet Union still found ways to cooperate on things that were of mutual benefit...we need to find effectively the *Permissive Action Link for AI*, that is a safety technology that you would want your competitors to use, just as you'd want yourself to use it."[11] Similarly, the U.S. National Security Commission on AI's final report recommended that the U.S. should "double down" on researching techniques that prevent unauthorized use of autonomous weapons and, if appropriate, share these technologies with Russia, China, and other countries.[12] Notably, the reference for this recommendation highlights the historical case of PALs.[13] With policymakers relying on nuclear safety and security assistance as a template for managing the risks of emerging technologies, it is important to ensure that they are not learning the wrong lessons.

[10] Earlier work has also pointed out that the recipient state must also trust the transferring state to not abuse information shared about technical characteristics of its nuclear program. Miller, "Assistance to Newly Proliferating States."

[11] Smith, Craig. "Marshaling AI Cooperation." National Security Commission on AI, 2020, https://www.nscai.gov/podcasts/. On the subject of AI governance, Elsa B. Kania and Andrew Imbrie write, "In some cases, it may be mutually beneficial to transfer technologies or techniques to prevent accidents — even to rivals or potential adversaries. During the Cold War, the United States developed and offered to share permissive action links as a cryptographic control to guard against unauthorized employment of nuclear weapons." Kania, Elsa B., and Andrew Imbrie. "Great Powers Must Talk to Each Other About AI." Defense One, January 28, 2020. https://www.defenseone.com/ideas/2020/01/great-powers-must-talk-each-other-about-ai/162686/.

[12] National Security Commission on Artificial Intelligence. "Final Report." Washington, D.C.: NSCAI, March 2021. https://www.nscai.gov/2021-final-report/, 101.

[13] National Security Commission on Artificial Intelligence, "Final Report," 106.

The rest of this article proceeds as follows. To begin, I explicate my argument for why the feasibility of technology transfer serves as a key determinant of nuclear safety and security assistance. I first position my explanation against the existing literature, which centers on the transferring state's assessment of costs and benefits. I then show why transferring more complex nuclear safety and security technologies, due to their high levels of tacit knowledge and integration with the overall weapon system, demands transnational channels for technical cooperation. Next, I present the results of my four case studies. Lastly, I conclude by summarizing the implications of these findings for managing the risks of nuclear weapons and emerging technologies.

II. Transferring Safety and Security

Why do states share nuclear safety and security technologies with other states? At first glance, the case for transferring security technologies seems straightforward. Such assistance would serve the transferring state's interests by reducing the chance of accidents and unauthorized launches linked to the recipient state's nuclear weapons systems, which can have far-reaching negative consequences. It is not difficult to map out scenarios in which accidental or unauthorized launches escalate to a full-blown nuclear exchange.[14]

Balance of motivations

Contrary to this basic logic, states do not always share nuclear safety and security technologies. To explain the varied pattern of nuclear assistance, scholars have identified drawbacks to nuclear assistance. First, decision-makers confront two types of proliferation risks.

---

[14] Blair, Bruce G. *The Logic of Accidental Nuclear War*. Brookings Institution Press, 1993; Caldwell, Dan, and Peter Zimmerman. "Reducing the Risk of Nuclear War with Permissive Action Links." In *Technology and the Limitation of International Conflict*, edited by Barry M. Blechman. Johns Hopkins Foreign Policy Institute, 1989, 155.

In the case of horizontal proliferation, it is possible that sharing safety and security technologies encourages other countries to adopt dangerous systems. If fear of accidents and unsanctioned launches deters nuclear ambitions, then providing nuclear assistance could signal to other states that help with controlling the bomb would be forthcoming, thereby incentivizing them to seek nuclear arsenals.[15] Decision-makers in the potential transferring state might ask themselves: "How can we preach nuclear abstinence while at the same time, with our aid, apparently condone the behavior of those who cross the threshold anyway?"[16]

Vertical proliferation refers to the effect of sharing safety and security improvements on a nuclear-weapon state's acceptance of riskier deployment postures. Studies on automobile safety have tackled similar issues related to the effect of seatbelts on riskier driving behavior.[17] Nuclear assistance to other states may encourage them to adopt risker nuclear postures, such as by mating warheads and delivery systems.[18] As Peter Feaver comments with respect to sharing PALs with other nuclear powers, "You may be encouraging the very activity you don't want. You're better off if they keep them [i.e., the nuclear weapons] disassembled and at a lower state of readiness."[19]

Second, transferring states must also contend with domestic political costs. They may refrain from sharing safety and security technologies to avoid public controversy.[20] Again, even

[15] Dunn, Lewis. *Controlling the Bomb : Nuclear Proliferation in the 1980s*. First Edition. New Haven: Yale Univ Pr, 1982, 150; Giles, "Safeguarding the Undeclared Nuclear Arsenals."
[16] Feaver, "Command and Control in Emerging Nuclear Nations," 184; see also Dunn, *Controlling the Bomb*, 150.
[17] Peltzman, Sam. "The Effects of Automobile Safety Regulation." *Journal of Political Economy* 83, no. 4 (1975): 677–725.
[18] Jeffrey Lewis, The Minimum Means of Reprisal: China's Search for Security in the Nuclear Age (Cambridge, Mass.: MIT Press, 2007).
[19] Broad, William J. "Guarding the Bomb: A Perfect Record, But Can It Last." *New York Times*, January 29, 1991, B8.
[20] The recipient state may also seek to avoid domestic costs, such as the perception that their nuclear systems were not independently developed. The extent to which the U.S. helped Pakistan establish reliable nuclear safeguards was kept secret because the Bush administration sought to avoid exacerbating anti-American sentiment in Pakistan. Sanger, David E., and Thom Shanker. "A Nuclear Headache: What If the Radicals Oust Musharraf?" *The New York*

with U.S. nuclear cooperation with allies, this was a salient consideration. John Morse, a DoD official who initiated nuclear safety talks between the U.S. and the French, once commented on opening up discussions about nuclear safety issues with the French, "A number of news media and public representatives will fight any move toward relaxation."[21] Historically, U.S. nuclear assistance has encountered Congressional and military opposition.[22]

In sum, the decision calculus to share nuclear safety and security technologies is multifaceted. While reducing the risks of global disaster provides an initial impetus and enduring rationale for nuclear assistance,[23] the transferring state must also weigh these benefits against proliferation and political risks. This balance-of-motivations approach is a useful starting point, but, as the following section will argue, it neglects the process of technology transfer, which entails more attention to the features of the technologies involved as well as the motivations of the recipient state.

Technical cooperation and complex safety and security technologies

Why do states still withhold nuclear safety and security technologies, even when the costs and benefits point toward sharing? Differences in the complexity of nuclear safety and security

Times, December 30, 2003, sec. World. https://www.nytimes.com/2003/12/30/world/a-nuclear-headache-what-if-the-radicals-oust-musharraf.html.

[21] January 11, 1971 draft memo titled "Sharing Information with Allies." John H. Morse Papers from Hoover Institute Archives.

[22] In other cases, Congress has led the way on pushing for more nuclear assistance, most notably with the Soviet Nuclear Threat Reduction Act of 1991.

[23] Two additional benefits deserve mention. Nuclear assistance could allow the transferring state to gain more knowledge about another state's nuclear arsenal. Exchanges on nuclear safety and security can also facilitate broader nuclear and defense cooperation. Both of these were present in U.S. policymakers' rationale for assisting France on nuclear safety in the 1970s. One National Security Council memo argued that such assistance would "increase our knowledge of French nuclear weapons." Report of the National Security Council Staff, "NSSM 100 – Military Cooperation with France (Analytical Summary)," n.d. [circa December 1970], Top Secret. Another key U.S. official framed nuclear safety issues as "logical, harmless and easy starters that could help or even compensate for possible U.S. inhibitions in more difficult areas like relaxed computer restrictions, missile help to the French, and more cooperative sharing on R&D or weapon production." Morse, John H. "Memorandum for M. Nutter from John H. Morse."

technologies affect the feasibility of transferring such systems. Concretely, with respect to more complex nuclear safety and security technologies, states may want to share but find it infeasible to do so.

To start, it's important to establish that the complexity of nuclear safety and security technologies varies. Taking complexity as the interconnectedness of a technological system, this paper measures complexity by the intricacy of causal interaction patterns among a system's components.[24] We can also see stark differences in the complexity of nuclear security technologies. In 1981, two decades after the first PAL was invented, mechanical locks still protected around half of the U.S. nuclear weapons in Europe.[25] On the other end of the spectrum, advanced PALs are protected by lengthy digital keys and encapsulate the trigger mechanism of a nuclear weapon, such that any attempt to penetrate the system disables the weapon itself.[26] In the nuclear safety context, insensitive high explosives function as substitute explosives that guard against accidental detonations in case of fire, while ESDs add more features (e.g., timers, monitors, and arming elements) that increase the number of causal linkages with other parts of the nuclear weapon system.[27]

Unpacking the dynamics behind nuclear assistance in complex safety and security technologies reveals two conditions for successful transfer. First, the process involves transmitting a great degree of tacit knowledge. Engineers cannot learn how to apply these

---

[24] Perrow, Charles. *Normal Accidents: Living with High Risk Technologies*. New York: Basic Books, 1984; Sagan, Scott D. *The Limits of Safety*. Princeton University Press, 1993.
[25] Stein, Peter, and Peter Feaver. *Assuring Control of Nuclear Weapons: The Evolution of Permissive Action Links*. CSIA Occasional Paper, no. 2. [Cambridge, Mass.] : Lanham, MD: Center for Science and International Affairs, Harvard University ; University Press of America, 1987, 55.
[26] "PAL Control of Theater Nuclear Weapons," Mark E. Bleck and Paul R. Souder, Command and Control Division, Sandia National Laboratories, SAND82-2436, March, 1984 (SECRET/FORMERLY RESTRICTED DATA/declassified).
[27] Cotter, Donald R. "Peacetime Operations: Safety and Security." *Managing Nuclear Operations*, 1987, 17–74. I am grateful to participants at the Nuclear Reading Group at Stanford University for insights on this point.

techniques in their nuclear systems by reading blueprints alone; they need to interact with other engineers who have more experience with the technology and can provide guidance on points not spelled out in technical specifications.[28] In fact, this aligns with findings that highlights the significance of tacit knowledge in acquiring the bomb in the first place. Alex Montgomery has argued that even states that receive nuclear materials and specifications for uranium conversion plants will struggle to develop nuclear weapons, absent ties to experts and access to tacit knowledge in states with deep experience in nuclear weapons production.[29]

Second, transferring complex nuclear safety and security technologies also involves transmitting sensitive information about technologies that are highly integrated with the overall weapons system. Since ESDs, for example, are "engineered into the design of the weapon itself," sharing information about these devices could provide intelligence to other states for devising countermeasures against one's own nuclear weapons system.[30] Both the transferring state and recipient state must trust that the transfer process does not expose shortcomings in their nuclear weapons capability. This was a concern even with U.S. nuclear assistance to close allies. In guidance for talks with the French on nuclear safety, U.S. officials emphasized the need to walk a fine line between sharing information about the types of electrical and mechanical components in nuclear safety and security technologies and withholding data on nuclear weapons design.[31]

Therefore, nuclear safety and security assistance in more complex technologies must strike a delicate balance: share substantial amounts of tacit information but refrain from exposing

[28] MacKenzie, Donald, and Graham Spinardi. "Tacit Knowledge, Weapons Design, and the Uninvention of Nuclear Weapons." *American Journal of Sociology* 101, no. 1 (1995): 44–99.
[29] Montgomery, Alexander H. "Ringing in Proliferation: How to Dismantle an Atomic Bomb Network." *International Security* 30, no. 2 (2005): 153–87.
[30] Feaver, *Guarding the Guardians*, 14.
[31] Rogers, William P. "Cable from William P. Rogers to American Embassy Paris, 'Military Relations with France,'" November 15, 1971. RG 59, Subject-Numeric Files, 1970-73 Top Secret Files, box 1, AE 1-1 70-71. National Archives.

sensitive information about one's own nuclear weapons system. To meet both conditions, there must be a strong basis of technical cooperation between scientists from the transferring and recipient state.[32] Regarding the importance of scientific collaboration for tacit knowledge transfer, MacKenzie and Spinardi write, "The recipients and the originators of such knowledge would have to be members of the same or similar technical cultures in order that the recipients can bring tacit background knowledge to bear in order to 'repair' the insufficiency of explicit instruction."[33]

Additionally, linkages between technical experts in the transferring state and recipient state provide the maneuvering room for sharing information about safeguards that are very connected to nuclear weapons capability.[34] These institutional channels are crucial for both parties to trust that the other side will not be able to exploit any sensitive information in the process of transferring safety and security technologies.[35] Oftentimes, managing this balance relies on enduring trust built up from past technical exchanges. For example, Rodion I. Voznyuk, who worked at one of Russia's nuclear labs for 46 years, attributes the Warhead Safety and Security Exchange's success at handling sensitive information to earlier encounters with U.S. scientists at joint nuclear tests in the late 1980s. "The tests created fertile ground for communication between the technical specialists of the USSR and the United States and the development of trust through increased personal communication, especially those between

---

[32] Related literature has explored how institutional and personal relationships between scientists aided nonproliferation programs and arms control. Bunn, Matthew. "Cooperation to Secure Nuclear Stockpiles: A Case of Constrained Innovation." *Innovations: Technology, Governance, Globalization* 1, no. 1 (2006): 115–37; Evangelista, Matthew. *Unarmed Forces: The Transnational Movement to End the Cold War*. Cornell University Press, 1999; Talmadge, Caitlin. "Striking a Balance." *The Nonproliferation Review* 12, no. 1 (March 1, 2005): 1–35; Weiner, Sharon K. *Our Own Worst Enemy?: Institutional Interests and the Proliferation of Nuclear Weapons Expertise*, 2011.

[33] Mackenzie and Spinardi, "Tacit Knowledge, Weapons Design, and the Uninvention of Nuclear Weapons," 66.

[34] Adler, Emanuel. "The Emergence of Cooperation: National Epistemic Communities and the International Evolution of the Idea of Nuclear Arms Control." *International Organization* 46, no. 1 (ed 1992): 101–45; Giles, "Safeguarding the Undeclared Nuclear Arsenals," 182.

[35] Miller, "Assistance to Newly Proliferating Nations."

technical specialists," he reflects.[36] When these channels for technical cooperation are weak or nonexistent, transferring more complex safety and security technologies will be infeasible.

Alternative factors

Before turning to the empirical analysis, it's necessary to examine two other factors that bear upon the share-withhold decision. First, "whether" to share may depend on "who" receives nuclear safety and security assistance.[37] States might be more likely to share nuclear safety and security technologies with allies than rivals. The recipient state's nuclear posture is also relevant. If the recipient state's command and control system is "delegative," in the sense that there are few constraints on military operators to follow central guidance, a transferring state may be more motivated to provide nuclear safety and security assistance. Conversely, if the potential recipient already prioritizes preventing unauthorized or accidental nuclear use, such as by highly centralized control over launch decisions, transferring states may feel less compelled to share safety and security techniques.[38]

Legal issues also influence the share-withhold decision. In transferring nuclear safety and security technologies, the Nonproliferation Treaty (NPT) presents a possible bottleneck because it forbids signatories from assisting non-nuclear states to "manufacture or otherwise acquire nuclear weapons."[39] In debates over whether the U.S. should share PALs with Pakistan, for instance, State Department lawyers argued that these transfers were illegal under the NPT.[40] In

---

[36] Voznyuk, Rodion I. "WSSX Cooperation at RFNC-VNIITF." In *Doomed to Cooperate*, edited by Siegfried S. Hecker. Bathtub Row Press, 2016, 47.
[37] Miller, "Assistance to Newly Proliferating Nations," 103.
[38] For a more nuanced version of this argument based on whether a recipient state has developed an "imbalanced command and control system," see Feaver, "Command and Control in Emerging Nuclear Nations," 181-187.
[39] The concern is that the "otherwise acquire" language covers nuclear safety and security technologies. McDermott, Anna. "PALs for Pals: The U.S. and Pakistan." *Global Tides* 3 (2009).
[40] Sanger and Broad, "U.S. Secretly Aids Pakistan in Guarding Nuclear Arms."

the U.S. case, the Atomic Energy Act of 1946 and other domestic legislation also limited the ability of the U.S. to provide nuclear assistance.[41] Any explanation for the pattern of nuclear security assistance must deal with these alternative factors.

III. Empirical Analysis

I assess my theory with four historical case studies (Table 1): U.S. sharing of basic nuclear safety and security technologies with the Soviet Union (1961-1963); U.S. withholding of complex nuclear safety and security technologies from China (1990-1999) as well as from Pakistan (1998-2003); and U.S. sharing of complex nuclear safety and security technologies with Russia in the

Table 1. Case Selection for Empirical Analysis

		Outcome of nuclear assistance	
		Withhold	Share
Complexity level of safety and security technologies	Low → lessened demands for technical cooperation	*	U.S.-Soviet Union (1961-1963)
	High → elevated demands for technical cooperation	U.S.-China (1990-1999); U.S.-Pakistan (1998-2003)	U.S.-Russia Warhead Safety and Security Exchange (1994-2007)

*Sometimes states withhold nuclear safety and security assistance for reasons unrelated to complexity and attendant demands for technical cooperation (e.g., the possibility that the U.S. did not aid China with nuclear safety and security in the 1960s because it assumed that the Soviet Union would do so). Such cases where both the cause and outcome are absent are not helpful for testing mechanism-based theories.[42]

Warhead Safety and Security Exchange (1994-2007). Holding constant the U.S. as the transferring state provides explanatory leverage for assessing how technical cooperation mediates the feasibility of technology transfer. Practical considerations also influenced this decision, given how difficult it already is to investigate decision-making regarding nuclear safety

[41] Miller, "Assistance to Newly Proliferating Nations."
[42] Beach, Derek, and Rasmus Brun Pedersen. *Process-Tracing Methods: Foundations and Guidelines*. University of Michigan Press, 2019, 90-96.

and security assistance in the U.S. context, which is considerably more open on this subject than other potential transferring states.[43]

By exploiting variation in technological complexity, which maps onto differing requirements for technical cooperation, these cases help test whether my argument about the feasibility of nuclear safety and security assistance holds. In the U.S.-Soviet Union case, Category A PALs, which were the version installed on U.S. nuclear weapons in 1962, functioned as basic coded switches. They were disconnected from digital systems — batteries in the decoders sometimes ran out without warning — and were relatively easy to bypass.[44] By the 1990s, when the U.S.-China, U.S.-Pakistan, and U.S.-Russia cases unfold, nuclear safety and security technologies had become more complex. The type of PAL that Chinese scientists sought help on, a Category F PAL, functions as an electronic code system with limited-try and tamper-proof capabilities.[45] No longer just a coded switch that linked detonators and a battery, this security technology is deeply integrated with the weapon system.[46]

These cases also provide variation in the outcome, both between and within cases. During the Warhead Safety and Security Exchange, the U.S. shared information on complex access-control technologies and automated monitoring systems with Russia. In contrast, the U.S.-China and U.S.-Pakistan cases feature the non-transfer of complex nuclear safety and security technologies. For these historical episodes, since they involved discussions of sharing both basic

---

[43] There is evidence that Russia has considered providing nuclear safety and security assistance to other states. Coll, Steve. "The Man Inside China's Bomb Labs." *Washington Post*, May 16, 2001; Mann, Zia. "Commanding and Controlling Nuclear Weapons." In *Confronting the Bomb: Pakistani and Indian Scientists Speak Out*, edited by Pervez Hoodbhoy. Karachi: Oxford University Press, 2013.
[44] In one black hat exercise, a Sandia engineer picked the PAL by listening to gear movements. Schlosser, Eric. *Command and Control: Nuclear Weapons, the Damascus Accident, and the Illusion of Safety*. Penguin, 2009, 313.
[45] Stein and Feaver, "Assuring control of nuclear weapons," 55-56; Cochran, Thomas, William M. Arkin, and Milton M. Hoenig. *Nuclear Weapons Databook: Volume I - U.S. Nuclear Forces and Capabilities*. Cambridge, Mass: Ballinger, 1984; Bleck and Souder, "PAL Control of Theater Nuclear Weapons."
[46] Lewis, Jeffrey. "No PALs For Paks." *Arms Control Wonk* (blog), November 18, 2007.

and more complex technologies, I can leverage within-case variation to analyze the significance of technical cooperation for nuclear safety and security assistance.

Lastly, I chose four cases that are similar in other features that could influence the share-withhold decision. In all four cases, the balance of motivations pointed toward sharing, and U.S. decision-makers at the highest level gave serious consideration to transferring nuclear safety and security technologies. Recipient characteristics were comparable. The U.S. viewed all recipients as either rival great powers or uncertain allies that lacked adequate protections against unauthorized and accidental nuclear launches. With the exception of Pakistan, all recipients were acknowledged nuclear weapon states, which limits the purchase of legal explanations.[47]

To reconstruct debates over transferring nuclear safety and security technologies, I draw on a wealth of elite interviews and archival materials. My efforts drew on materials at the Gerald R. Ford Presidential Library, Hoover Institution, John F. Kennedy Presidential Library, the National Archives, Richard Nixon Presidential Library, and UC San Diego's Special Collections and Archives.[48] I also conducted over 20 interviews with experts and key officials familiar with U.S. decision-making on nuclear safety and security assistance. These interviewees came from communities connected to the nuclear labs, U.S. government agencies, think tanks, and academia.

[47] My analysis of the U.S.-Pakistan case considers how Pakistan's status as a non-nuclear weapon state under the NPT complicated decisions about nuclear safety and security assistance.
[48] I am grateful to librarians at all these institutions for responding to my Freedom of Information Act and Mandatory Declassification Review requests.

A. U.S. sharing of basic nuclear safety and security technologies with the Soviet Union (1961-1963)

During the early 1960s, even as both sides were locked in a fierce technological race, the U.S. shared information about nuclear safety and security procedures with the Soviet Union. In December 1962, Pentagon General Counsel John McNaughton detailed the use control devices and procedures for U.S. nuclear weapons in a public speech at a symposium in Ann Arbor, Michigan. McNaughton's address emphasized the U.S.'s desire that the Soviet Union would take comparable actions, and U.S. diplomats flagged the speech to Soviet counterparts. Second, McNaughton briefed American academics on PALs, who then discussed the concept with Soviet scientists at the 1963 Pugwash Conference.[49] In addition, McNaughton also passed along information on PALs to Soviet officials in a 1963 Chicago meeting.[50] By the end of the 1960s, it was believed that the Soviets adopted PALs on their nuclear weapons.[51] One of the Soviet representatives at that Chicago meeting, V.F. Tolubko, later wrote an article noting that Soviet strategic missiles had implemented electronic locks to prevent unauthorized use.[52]

In the case analysis, I first supply evidence that the balance-of-motivations among U.S. decision-makers tilted toward assisting the Soviet Union with nuclear safety and security. If my theoretical expectations hold, the historical evidence should demonstrate that the low complexity of technologies involved, which suggests lessened requirements for technical cooperation, played

---

[49] Bennett, M. "Rivals, PALS, and Norms: The U.S. Decision to Share Nuclear-Control Technology with the Soviets." Washington, D.C., 1991; Stein and Feaver, "Assuring control of nuclear weapons," 83.

[50] Notes from an interview with Stephen Meyer conducted by Dan Caldwell on April 9, 1985. Caldwell (Dan) papers. Hoover Institution Library and Archives.

[51] Bennett, "Rivals, PALS, and Norms," 5; Blair, *The Logic of Accidental Nuclear War*, 280. Into the late 1980s there was still some uncertainty over whether the Soviets employed PALs. Meyer, Stephen. "Soviet Nuclear Operations." In *Managing Nuclear Operations*, edited by Ashton B. Carter, John D. Steinbruner, and Charles A. Zraket. Washington, DC: The Brookings Institution, 1987, 521.

[52] Meyer, Stephen M. "Soviet Perspectives on the Paths to Nuclear War." In *Hawks, Doves, and Owls: An Agenda for Avoiding Nuclear War*, edited by Graham Allison, Albert Carnesale, and Joseph S. Nye, 167–206, 1985.

a critical role in the U.S.'s willingness to share nuclear safety and security technologies with the Soviet Union.

Balance-of-motivations

In the early 1960s, the U.S. became increasingly concerned about the risks of unintended nuclear escalation. Efforts to share PALs with the Soviet Union had been preceded by the publication of "dozens of newspaper and magazine articles, radio, and television programs" that disclosed precautions the U.S. had taken to avoid accidental nuclear war.[53] In 1961, the *Saturday Evening Post* published an article on PALs, with the Pentagon's permission and active assistance.[54]

Motivations against sharing centered primarily on vertical proliferation risks and domestic political costs.[55] In the case of the former, some U.S. officials argued that the Soviet Union's lack of security and safety techniques constrained its risk posture in crisis scenarios.[56] The concern was that if the U.S. helped the Soviet Union solve these issues, "they would be more likely to go to a full missile alert during any subsequent East-West confrontation...If it ever came to war, that readiness would inevitably be translated into tens of millions of additional American deaths."[57] In addition, key decision-makers in the Kennedy Administration acknowledged the possible domestic backlash to sharing nuclear safety and security technologies.[58]

---

[53] "Hearing, Eighty-Seventh Congress, First Session, on S. 2180." U.S. Government Printing Office, August 14, 1962.
[54] Wyden, Peter. "The Chances of Accidental War." *The Saturday Evening Post*, June 3, 1961; Larus, Joel. *Nuclear Weapons Safety and the Common Defense*. Ohio State University Press, 1967, 63n57.
[55] Horizontal proliferation risks were less relevant, since the Soviet Union was an established nuclear power.
[56] Bennett, "Rivals, PALS, and Norms."
[57] Klein, Edward, and Robert Littell. "Shh! Let's Tell the Russians." *Newsweek*, May 5, 1969, 8
[58] Bennett 1991. Congress was more supportive of nuclear assistance. Worried about accidental and unauthorized nuclear use, influential legislators, such as Senator Hubert Humphrey, advocated for the Soviet Union to disclose more information about its nuclear safety and security procedures. Haworth 1962.

On the whole, the balance of motivations in this case inclined toward sharing. In the early 1960s, after the U.S. began to develop PALs, Peter Stein and Peter Feaver state "there was a realization in the Office of the Secretary of Defense that, on balance, U.S. security interests were served by Soviet knowledge of these developments."[59] In particular, the Cuban Missile Crisis in October 1962 marked a turning point in the U.S. decision to provide assistance to the Soviet Union with PAL technology. Following the crisis, the Kennedy Administration became worried about Soviet control over their nuclear weapons.[60] These concerns traced back, in part, to a key point of contention among senior U.S. officials during the crisis over whether Soviet officers in charge of a missile battery in Cuba or leaders in Moscow would decide the retaliatory response to a U.S. military action in Cuba.[61]

Complexity, technical cooperation, and U.S.-Soviet Union nuclear assistance

The basic features of PALs in this period made it relatively feasible for the U.S. to transfer PALs. Since these PALs had limited interconnections with the overall nuclear weapons system, there was no need for close technical collaborations between the U.S. and Soviet experts. It was sufficient for U.S. officials to highlight unclassified literature and point Soviet officials to summaries of the general concept behind PALs.[62] On sharing early versions of PALs, Thomas Schelling commented, "Once you have the concept, a 12-year-old could comprehend the mechanics within minutes."[63] While Schelling exaggerates the simplicity of early PALs —

[59] Stein and Feaver 1987, 83. This quote indicated that several people in the Office of Secretary of Defense confirmed this calculus. Author interview with Peter Feaver, phone, November 2021.
[60] Klein and Littell, "Shh! Let's Tell the Russians."
[61] Trachtenberg, Marc. "The Influence of Nuclear Weapons in the Cuban Missile Crisis." *International Security* 10, no. 1 (1985): 137–63, 154.
[62] Bennett, "Rivals, PALS, and Norms"; Giles, "Safeguarding the Undeclared Nuclear Arsenals," 180; Miller, "Assistance to Newly Proliferating Nations," 104.
[63] Klein and Littell, "Shh! Let's Tell the Russians," 47.

technical personnel had to work through numerous reliability issues for early PALs — his overall point accurately diagnoses how technological specifics conditioned the ease of sharing.[64]

Other types of nuclear safety and security assistance in this period were also limited to relatively basic concepts. For instance, the U.S. reportedly shared a film on the two-man rule with the Soviet Union during this period.[65] This rule outlines procedures for at least two people to be involved in every stage of maintaining and using nuclear weapons.

Given the low complexity of technologies involved in this case, U.S. nuclear assistance was not constrained by the limited technical cooperation. While Soviet and U.S. scientists discussed arms control throughout the Cold War, both countries' nuclear weapons lab technicians had little contact with each other.[66] It was not until 1986, when the two countries committed to developing verification techniques to ratify a test ban treaty, that technical exchanges between U.S. and Soviet nuclear weapons specialists were initiated.[67]

B. U.S.-China non-transfer of complex nuclear security and safety technologies (1990-1999)

Starting in the spring of 1990, technical communities in the U.S. and China began to engage on nuclear safety and security issues. Between 1990 and the summer of 1999, U.S. nuclear weapons scientists made nine trips to China, and U.S. scientists welcomed senior

[64] I thank David Fort, deputy director at the National Archives and Records Administration, for helping me process MDRs. "Letter to Honorable McGeorge Bundy from the Alvin R. Luedecke re: Problems Resulting from Reliability of PAL Equipment," 17 October 1963, John F. Kennedy Presidential Library; "Letter from Roswel L. Gilpatric to Mr. Charles Johnson re: PAL Development Problems," September 13, 1963, John F. Kennedy Presidential Library.; "Memo for Mr. Spurgeon Keeny from Gerald W. Johnson re: Category 'A' PAL Development Problems," September 10, 1963, John F. Kennedy Presidential Library.

[65] Dunn, *Controlling the Bomb*, 10.

[66] Hecker, Siegfried S. "Adventures in Scientific Nuclear Diplomacy." *Physics Today* 64, no. 7 (July 1, 2011): 31–37.

[67] Hecker, "Adventures in Scientific Nuclear Diplomacy."

officials from China's nuclear weapons program to visit U.S. nuclear weapons labs in 1994.[68] On each of these exchanges, Chinese nuclear weapons specialists requested U.S. assistance with nuclear safety and security, especially PAL technologies.[69] An underlying consideration was the 1989 Tiananmen crisis, which had revealed internal rifts in the Chinese military, causing Beijing leadership to question the military's loyalty if another uprising took place. This made clear the risks associated with China's controllability of nuclear weapons.[70]

Under this "lab-to-lab" program, the U.S. did share basic nuclear security and safety mechanisms related to protecting nuclear assets. For example, Chinese scholars credit the lab-to-lab exchanges for the introduction of physical protection systems, including general techniques for ensuring personnel reliability, in Chinese nuclear labs.[71] However, the U.S. did not attempt to transfer PALs, ESDs, and other complex safety and security technologies.

What explains this outcome? The balance-of-motivations approach should provide a useful starting point, revealing a window of opportunity for the U.S. to share nuclear safety and security technologies with China. Yet, I also expect to find that the groundwork for technical cooperation conditioned the type of nuclear assistance that the U.S. could provide. Specifically, the historical evidence should show that the tenuous foundation for technical cooperation

---

[68] Coll 2001; Coll and Ottaway 1995; Stober and Hoffman, 93-94. I thank Sig Hecker for confirming some of these accounts in the U.S.-China lab-to-lab cooperation case. Author interviews with former Director of Los Alamos National Laboratory Sig Hecker, Zoom, December 2021 and March 2022.

[69] Coll, "The Man Inside China's Bomb Labs"; Coll, Steve, and David B. Ottaway. "Secret Visits Helped Define 3 Powers' Ties." *Washington Post*, April 11, 1995.

[70] White House interest in sharing PALs dates back to at least 1987. At a breakfast meeting during Commerce Secretary Malcolm Baldrige's visit to China in April 1987, a private citizen brought up the topic of whether the U.S. would transfer PALs to the Chinese. According to this private citizen, after the breakfast concluded, William Graham, Reagan's Science advisor, told him it was an intriguing idea. Letter from anonymous private citizen to Dan Caldwell, dated April 22, 1987. Caldwell (Dan) papers. Hoover Institution Library and Archives.

[71] Tang, Dan, Xiangdong Yin, Ni Fang, and Cao Guo. "Physical Protection System and Vulnerability Analysis Program in China." Beijing,China: Paper presented to the International Seminar on Disarmament and the Resolution of Conflict (ISODARCO), 2002.

constrained the ability for both sides to share sensitive information without revealing vulnerabilities in their nuclear weapons system.

Balance-of-motivations

There were many reasons for U.S. leadership to share nuclear safety and security technologies with China. First and foremost, the Tiananmen crisis resurfaced uncertainties about central control over China's arsenal. Past incidents had exposed vulnerabilities in China's nuclear arsenal to unauthorized launch by rogue or pressured military officers. In 1967, General Wang En-Mao, a military commander in China's Xinjiang autonomous region, threatened to take control of Chinese nuclear weapons at Lop Nor.[72] Concerned about nuclear conflict triggered by an unauthorized Chinese nuclear launch or Soviet fear of this possibility, scholars argued that transferring PALs to China would enhance crisis stability between China and the Soviet Union.[73]

In terms of disincentives to sharing, U.S. leaders were most worried about domestic political repercussions. In response to the Tiananmen crackdown, the U.S. Congress had implemented sanctions that restricted nuclear exports to China.[74] The Clinton administration "feared the backlash of seeming to sell another piece of critical technology to Beijing."[75] Nancy Hayden (née Prindle), who managed technical dialogues between U.S. and Chinese nuclear scientists during this period, recalls, "Everytime we met with the Chinese, we had to go in front

---

[72] Caldwell and Zimmerman, "Reducing the Risk of Nuclear War with Permissive Action Links." During the 1969 Sino-Soviet border dispute, Lin Biao, a Chinese military leader, became convinced that a plane carrying Soviet delegates to Beijing for peace negotiations was armed with nuclear weapons. On October 18th, 1969, bypassing approval protocols, he ordered China's Second Artillery to move to highest alert for immediate launch of nuclear-armed missiles. Cunningham, Fiona. "Nuclear Command, Control, and Communications Systems of the People's Republic of China." Tech4GS Special Reports, July 18, 2019, 13; Lewis, John Wilson, and Litai Xue. *Imagined Enemies: China Prepares for Uncertain War*. 1st edition. Stanford, Calif: Stanford University Press, 2006, 63-74.
[73] Caldwell, "Permissive Action Links: a description and proposal," 232.
[74] Holt, Mark, and Marty Beth D. Nikitin. "U.S.-China Nuclear Cooperation Agreement." Congressional Research Service, May 6, 2015.
[75] Sanger, David E. *The Inheritance*. Random House, 2009, 226.

of interagency, and you had journalists following every meeting…It's the perception – why are we working with the Chinese? They're bad."[76]

These barriers were serious but not insurmountable. Despite political risks, the Clinton administration still allowed U.S. nuclear labs to advance backchannels with their Chinese counterparts, including the 1994 guided tour of U.S. nuclear weapons labs, which marked the first time high-ranking officials from China's nuclear weapons program had visited U.S. labs.[77] Proliferation risks were more manageable. Since China was an established nuclear-weapon state, policymakers were less concerned by the possibility that nuclear assistance would encourage other states to seek nuclear weapons.[78]

Overall, the balance of motivations leaned in favor of nuclear safety and security assistance to China. In the late 1980s, Gerald Johnson, a nuclear expert who oversaw the introduction of PALs into the U.S. and NATO stockpiles, suggested that the U.S. start regular exchanges with other nuclear powers on PALs and other safety, security, and control issues. Johnson specifically noted, "In view of their recent relative openness in discussing nuclear weapons the Chinese might provide an early opportunity."[79] This fits with expectations derived from general patterns in U.S. nuclear cooperation with other nuclear weapon powers. Toward states that are established nuclear powers, including adversaries such as the former Soviet Union and China, U.S. nuclear assistance is "more the norm than the exception."[80] One formal model

---

[76] Author interview with Distinguished Member of the Technical Staff at Sandia National Laboratories Nancy Hayden (née Prindle), Zoom, April 2022.
[77] Coll and Ottaway, "Secret Visits Helped Define 3 Powers' Ties." Additionally, U.S. nuclear assistance to both China and Russia in material protection, control and accounting proved that policymakers were willing to bear the political costs. Author interview with Sig Hecker, Zoom, December 2021.
[78] To be clear, there were proliferation concerns related to Chinese assistance to Pakistan and Iran's nuclear weapons programs. Holt and Nikitin, "U.S.-China Nuclear Cooperation Agreement." These are distinct from the horizontal proliferation risks in my framework, though they definitely raised the political costs of nuclear assistance.
[79] Early draft of Gerald Johnson's paper on "Safety, Security, and Control of Nuclear Weapons" (undated paper). Caldwell (Dan) papers. Hoover Institution Library and Archives.
[80] Miller, "Assistance to Newly Proliferating Nations," 122.

for whether the U.S. would assist another state with nuclear security and safety issues expects "to find evidence of U.S. assistance to China, or at least of careful consideration of the same."[81]

Complexity, technical cooperation, and U.S.-China nuclear assistance

In the end, the transfer of complex nuclear safety and security technologies, including ESDs and PALs, did not occur. According to one report in 1995, "Washington could not decide what to do about the Chinese request [for PALs]."[82] A few years later, "the ax fell on US-China nuclear cooperation" with the release of The Cox Committee Report, which accused U.S. labs of transmitting nuclear weapons secrets to China.[83] The window for nuclear assistance had closed. In fact, to this day, it is still unclear whether Chinese nuclear weapons are equipped with PALs.[84]

For both the U.S. and China, a key barrier to sharing information on technologies like PALs and ESDs was the fear that this process would expose shortcomings in their nuclear weapons capability. U.S. officials were concerned that sharing such techniques would teach China too much about U.S. nuclear weapons systems.[85] Summarizing debates among U.S. policymakers on the subject, reporting by *The Washington Post* highlighted one specific worry: that "providing PALs might help the Chinese learn to pick U.S. nuclear locks."[86]

[81] Feaver and Niou 1996, "Managing Nuclear Proliferation," 230. They argue that providing nuclear security assistance to an enemy great power will not hurt the nonproliferation regime.
[82] Coll and Ottaway, "Secret Visits Helped Define 3 Powers' Ties," A16. Kurt Campbell, former Deputy Assistant Secretary of Defense for Asia and the Pacific in the Clinton administration, recounts a big debate over to what extent the U.S. should assist the Chinese with PALs. Quoted in Coll, "The Man Inside China's Bomb Labs."
[83] Hecker 2011; for a comprehensive assessment of the Cox report, see Johnston, Alastair Iain, Wolfgang KH Panofsky, Marco Di Capua, and Lewis R. Franklin. "The Cox Committee Report: An Assessment." *Carnegie Endowment*, 1999.
[84] For views that China has implemented PALs, see interview of Harold Agnew by Stuart Leslie on 2006 May 22, Niels Bohr Library & Archives, American Institute of Physics, College Park, MD USA; Pan Ziqiang, et al, Eds., Management of Nuclear and Radiological Terrorism Incidents (in Chinese) (Beijing: Science Press, 2005); for other views, see Lewis, *The Minimium Means of Reprisal*, 38) reports.
[85] Author interview with Sig Hecker, December 2021.. Sanger and Broad 2007. Stober and Hoffman 2001.
[86] Coll and Ottaway, "Secret Visits Helped Define 3 Powers' Ties," A16.

On the flip side, Chinese officials were also reluctant to accept American-made devices, especially those more connected to weapons systems.[87] China recognized that the U.S. took advantage of the lab-to-lab exchanges for information gathering purposes. As Chinese nuclear expert Wu Riqiang writes, "During this process, China was well aware that such exchanges would lead to the United States obtaining intelligence on China's nuclear weapons, just as it was aware that the visiting U.S. personnel included professional intelligence officers."[88] Thomas Fingar, who served as the chief of the State Department's China Division from 1986 to 1989, characterizes deliberations about assisting China with PALs along the lines of "They'll never take it from us, but can we let them steal it."[89]

Before the Cox report's publication, the lab-to-lab program was beginning to cultivate trusting channels that could transmit tacit knowledge while protecting sensitive information – the difficult balance needed to transfer complex security technologies like Category F PALs. Assessing the U.S.-China lab-to-lab technical exchanges in 1998, Nancy Hayden (née Prindle), writes, "Particular emphasis is given to demonstrating technical means for sharing selected information on nuclear materials and facilities to…participate in confidence-building measures, while at the same time protecting sensitive national security information."[90] It was conceivable that, eventually, the two sides could have exchanged knowledge about PALs while mitigating information risks, as discussions about use-control techniques were deemed unclassified, as long as they did not release design details that would aid adversaries in circumventing U.S. devices.[91]

---

[87] Author interview with Dan Caldwell interview, Stanford, California, December 2021. Sig Hecker relates, "Environmental sensing devices would have been much too sensitive for the Chinese." Author interview with Sig Hecker, December 2021.
[88] Riqiang, Wu. "How China Practices and Thinks about Nuclear Transparency." In *Understanding Chinese Nuclear Thinking*, edited by Li Bin and Tong Zhao, 2016, 235.
[89] Author interview with Thomas Fingar, December 2021.
[90] Prindle, Nancy. "The U.S.-China Lab-to-Lab Technical Exchange Program." *The Nonproliferation Review*, 1998.
[91] According to one guidance issued in 1986 by Sandia National Laboratories, unclassified PAL information included general location of PAL switches within the nuclear weapon system, as well as the fact that surface

In fact, the Clinton administration viewed this emerging backchannel as a way to “advance the U.S.’s quiet nuclear engagement with China.”[92]

Without a long track record of technical exchange, the U.S.-China lab-to-lab program was limited to cooperation on more basic capabilities. Up until the Cox report’s publication, U.S. and Chinese scientists were still trying to speak the same language. Workshops in the technical exchange program did not start until 1996, and their remit was merely to identify topics for collaboration.[93] At one point, Clyde Layne, former chief scientist of the Sandia National Laboratories and supervisor of the lab-to-lab program, realized that the Chinese side had confused PALs with a different nuclear safety system.[94] As of 1998, an English-Chinese glossary of material protection control and accounting terminology was still being reviewed by Chinese scientists.[95]

Alternative Factors

The nuclear posture of the recipient state may also shape the share-withhold decision. Conceivably, the U.S. may have withheld complex safety and security technologies because it assessed that China’s nuclear posture valued highly centralized control. In the U.S.-China case, this explanation is not convincing, mostly because U.S. leadership was highly uncertain about China’s nuclear posture. Leading experts, who had discussed use control capabilities and procedures with Chinese peers, did not know whether China’s nuclear arsenal was optimized for positive control or negative control.[96] In 1990, at the Second Beijing Arms Control Seminar,

---

integrity sensors were used on PALs. Letter from Robert Duff to Gerlad Johnson, box 25, folder 7, Gerald Johnson Papers, MSS 0206, Special Collections and Archives, UC San Diego. Robert Duff worked at the classification and sensitive information review department of Sandia National Laboratories.

[92] Coll and Ottaway, “Secret Visits Helped Define 3 Powers' Ties.”

[93] Prindle, “The U.S.-China Lab-to-Lab Technical Exchange Program,” 113; author interview with Nancy Hayden (née Prindle), April 2022.

[94] Author interview with former chief scientist of the Sandia National Laboratories Clyde Layne, Zoom, April 2022.

[95] Prindle, “The U.S.-China Lab-to-Lab Technical Exchange Program,” 117.

[96] Stein and Feaver, “Assuring control of nuclear weapons,” 88.

researchers involved with the "Nuclear Weapons Databook" project, the most authoritative reference work on nuclear capabilities, pointed out that less was known about Chinese nuclear forces than the other four acknowledged nuclear weapon states. One key question was "confusion in the West concerning the mechanism for political control of Chinese nuclear forces."[97]

C. U.S.-Pakistan non-transfer of complex nuclear security and safety technologies (1998-2003)

Pakistan's nuclear arsenal has long been considered one of the world's most unstable and vulnerable. After a dispute over Kashmir pushed India and Pakistan — both armed with undeclared nuclear arsenals at the time — to the brink of war in 1990, experts raised concerns about the enhanced risks of accidental and unintentional nuclear use in such crises. Pakistan's nuclear tests in May 1998, which were followed by a military coup in October 1999, further exposed the safety and security of its nuclear arsenal to greater international scrutiny. A few years later, the attacks of September 11, 2001, crystallized the grave risks of Pakistan's nuclear weapons falling into the hands of terrorist groups.

Yet, despite these dangers, the U.S. did not share complex nuclear safety and security technologies with Pakistan. Starting from the late 1990s, senior Pakistan officials pressed the U.S for help with measures that could reduce the accidental or unauthorized use of nuclear weapons.[98] In U.S.-Pakistan Track II backchannel dialogues during this period, participants

[97] Norris, Robert S., Thomas B. Cochran, and Richard W. Fieldhouse. "Chinese Nuclear Weapons and Arms Control," 1990. https://nuke.fas.org/norris/nuc_04049001a_92.pdf.
[98] Hersh, Seymour M. "Watching the Warheads." *The New Yorker*, October 28, 2001. https://www.newyorker.com/magazine/2001/11/05/watching-the-warheads; Khan, Tanvir Ahmad. "A Command and Control System." *Dawn*, February 15, 2000; Shahi, Agha, Zulfiqar Ali Khan, and Abdul Sattar. "Securing Nuclear Peace." *The News International* 5 (1999).

discussed cooperation on nuclear safety and security.[99] After September 11 and reports that two of Pakistan's nuclear experts had met with Osama bin Laden, the U.S. gave more serious consideration to providing Pakistan with ESDs and PALs.[100] Ultimately, the U.S. withheld these complex devices, though it did provide a substantial package of assistance on more basic nuclear security and safety technologies, such as double-fence security perimeters, motion sensors, and radiation-detection devices.[101]

What explains this decision? To support my argument about the necessity of technical ties for transferring complex nuclear safety and security technologies, I first provide evidence that U.S. decision-makers, especially after the September 11 attacks, wanted to provide nuclear assistance to Pakistan. I then show that the feasibility of sharing more complex nuclear safety and security technologies was constrained, as both sides needed to share sensitive information in a way that did not reveal too much about their respective arsenals. As the historical evidence will demonstrate, this balance could not be achieved due to the lack of ties between U.S. and Pakistani scientists.

Balance-of-motivations

During the 1990s, growing awareness about the risks of accidental and unauthorized nuclear detonations in South Asia pushed the U.S. to consider sharing nuclear safety and security technologies with Pakistan. U.S. officials became worried that Pakistan's domestic turmoil and embroilment in regional crises threatened its nuclear arsenal's safety and security. As one distillation of these fears, a hypothetical scenario involved a dispute over Kashmir that caused

[99] Scholars from Stanford University's Center for International Security and Cooperation participated in these dialogues from 1998 to 2001. Interview with Professor Scott Sagan, Stanford, California, November 2021.
[100] While experts also advocated for the U.S. to share nuclear safety and security technologies with India (Sechser, Todd. "Pakistan Coup Underscores Nuclear Dimension." *Defense News*, November 15, 1999; Subcommittee on Asia and the Pacific, "South Asia: Challenges in U.S. Policy." Washington, DC, March 3, 1999), the threat of nuclear terrorism elevated the priority of U.S. assistance to Pakistan.
[101] Sanger, *The Inheritance*, 223.

Pakistan and India to deploy their nuclear weapons at forward operating bases. If an accidental nuclear detonation were to occur at one of those Pakistani bases, in the middle of a crisis, Pakistani leadership might assume that India had launched a nuclear attack and respond in like terms.[102] After the attacks of September 11 highlighted the dangers of nuclear terrorism, U.S. nuclear assistance to Pakistan was elevated in priority.

Proliferation concerns constituted some of the main barriers to transferring nuclear safety and security technologies to Pakistan. Regarding *horizontal* proliferation risks, the U.S. was wary that providing nuclear assistance to Pakistan would encourage other potential proliferators to develop nuclear weapons, thereby undermining the nonproliferation regime.[103] Before September 11, senior officials at Sandia National Laboratory contemplated transferring PALs to Pakistan. According to Sumit Ganguly, a visiting fellow at Sandia's Cooperative Monitoring Center in 2000, the perception that the U.S. was endorsing Pakistan's possession of nuclear weapons served as the primary roadblock to such assistance.[104]

Nuclear assistance to Pakistan could also introduce *vertical* proliferation risks. Experts argued that PALs and other safety and security devices that were integrated with weapons systems should not be shared because their adoption could encourage Pakistan to adopt higher levels of operational readiness for its nuclear weapons.[105] According to this logic, even if such devices would make Pakistan's arsenal more secure and safe, the side effects of permitting more rapid deployment of nuclear weapons would outweigh these benefits.

---

[102] Giles, "Safeguarding the Undeclared Nuclear Arsenals," 183.
[103] Caldwell, "Permissive action links," 236; Feaver, "Command and Control in Emerging Nuclear Nations."
[104] Author interview with Sumit Ganguly, phone, January 2022.
[105] Albright, David. "Securing Pakistan's Nuclear Weapons Complex." In *U.S. Strategies for Regional Security: South Asia*, 2001. https://stanleycenter.org/publications/archive/SPC01D.pdf; Feinstein, Lee. "When Policy Priorities Converge: Us Relations with India and Pakistan." *A New Equation: US Policy Toward India and Pakistan After September* 11 (2002): 7.

Political costs also weighed against sharing. Both U.S. and Pakistani leadership were sensitive to the fact that U.S. nuclear assistance could exacerbate anti-American sentiment in Pakistan and embarrass the Pakistani government. Pakistani leaders, including then President Musharraf and Khalid Kidwai, former head of the Strategic Plans Division (which oversees Pakistan's nuclear arsenal), have stated in public interviews that even the slightest implication that the U.S. was exerting control over Pakistan's nuclear weapons would have spelled political disaster.[106] On the U.S. side, a formidable nonproliferation caucus in Congress was opposed to approaches that could undermine the goal of complete rollback of Pakistan's nuclear arsenal, as evidenced by the U.S. imposition of sanctions on Pakistan after its nuclear tests.[107]

Nevertheless, the historical evidence suggests that these proliferation and political risks could be overcome, and that the balance of motivations did point toward sharing nuclear safety and security techniques with Pakistan.

Even before September 11, analysts argued that the balance-of-motivations tilted toward providing ESDs and PALs to Pakistan. In 1993, regarding the provision of complex safety and security technologies to Pakistan and other undeclared nuclear weapon states, Gregory Giles, a defense analyst at Science Applications International Corporation weighed the benefits of U.S. nuclear assistance against the risk that such a move would signal "de facto approval of nuclear proliferation." He concluded, "On balance, such risks pale by comparison with the greater danger of a nuclear weapons catastrophe in the Middle East or South Asia."[108] In testimony to Congress in 1999, Richard Haass, who had formerly served as Senior Director for Near East and South Asian Affairs at the National Security Council, argued that transferring nuclear safety and

---

[106] Sanger, *The Inheritance*, 216.
[107] Hathaway, Robert M. "Confrontation and Retreat: The US Congress and the South Asian Nuclear Tests." *Arms Control Today* 30, no. 1 (2000): 7.
[108] Giles, "Safeguarding the Undeclared Nuclear Arsenals," 185.

security technologies would not send the wrong example to nuclear aspirants, as the U.S. had tolerated Pakistan's status as a de facto nuclear weapon state for over a decade.[109] The risk that nuclear safety and security devices would encourage elevated risk postures was mitigated by the recognition that in times of crisis — when nuclear risks were highest — Pakistan's nuclear weapons would likely be assembled quickly anyways.[110]

The events of September 11 dramatically shifted the balance-of-motivations. The severity of threats related to accidental and unauthorized use now overrode proliferation-related threats.[111] In the aftermath of the attacks, as the U.S. and Pakistan cooperated to combat terrorism and the U.S. lifted sanctions, the political costs of transferring nuclear safety and security technologies had been lessened. Moreover, U.S. officials believed that they could maintain secrecy around the assistance program, which would further blunt risks related to the credibility of the nonproliferation regime and domestic backlash. The resulting U.S. package of technical assistance to Pakistan on nuclear safety and security, which totaled $100 million, was not reported on in full until six years later.[112]

Complexity, technical cooperation, and U.S.-Pakistan nuclear assistance

On paper, U.S. nuclear safety and security assistance to Pakistan made sense; in practice, transferring complex technologies such as PALs and ESDs was unworkable because both sides could not ensure the protection of sensitive information. From the perspective of U.S. officials, sharing information about technologies that were highly integrated into weapon systems could expose vulnerabilities in the U.S. arsenal. In post-9/11 debates among U.S. policymakers

[109] Subcommittee on Asia and the Pacific, "South Asia: Challenges in U.S. Policy."
[110] Cotta-Ramusino, Paolo, and Maurizio Martellini. "Nuclear Safety, Nuclear Stability and Nuclear Strategy in Pakistan." *Concise Report of a Visit by Landau Network-Centro Volta* 21 (2002).
[111] Author interview with Michael Krepon, phone, November 2021.
[112] Sanger, *The Inheritance*, 217.

regarding PALs, fears that U.S. assistance "would teach Pakistan too much about American weaponry" presented a barrier to sharing.[113]

These information risks were magnified for Pakistani officials. Pakistan was concerned that the U.S. would leverage nuclear assistance as a "fishing expedition" to discover vulnerabilities in its nuclear arsenal.[114] One 2004 report from the Cooperative Monitoring Center at Sandia National Laboratories, authored by retired Pakistani Major General Mahmud Durrani, was particularly revealing. Leveraging access to influential thinkers and political leaders, Durrani — who became Pakistan's Ambassador to the U.S. a few years later — compiled recommendations for enhancing nuclear stability from Pakistani officials at the highest level. Parsing the multiple recommendations around greater cooperation with the U.S. on nuclear security and safety measures, Durrani emphasized the need to manage information risks. "The purpose of this cooperation would not be to open Pakistani military secrets to a foreign power, but for Pakistan to learn from the U.S. the technologies, system, and procedures for the protection of nuclear assets and the enhancement of nonproliferation regimes," he summarized.[115]

According to some accounts, Pakistani officials were also worried that accepting American PALs would give the U.S. a secret backdoor into their nuclear systems. Specifically, Pakistani distrust of a "kill switch" embedded in any American PAL hindered cooperation.[116] Regarding constraints to U.S. assistance on both ESDs and PALs, nuclear weapons experts and policymakers consistently highlighted Pakistan's concerns that the process of technology transfer

---

[113] Sanger and Broad, "U.S. Secretly Aids Pakistan in Guarding Nuclear Arms."
[114] Author interview with Michael Krepon, phone, November 2021.
[115] Durrani, Mahmud Ali. *Pakistan's Strategic Thinking and the Role of Nuclear Weapons*. Cooperative Monitoring Center, Sandia National Laboratories, 2004, 41.
[116] Narang, Vipin. "Posturing for Peace? Pakistan's Nuclear Postures and South Asian Stability." *International Security* 34, no. 3 (2010): 38–78, 68fn117; Sanger and Broad, "U.S. Secretly Aids Pakistan in Guarding Nuclear Arms."

would divulge too much information about its nuclear arsenal.[117] As Neil Joeck, who was responsible for India and Pakistan nuclear issues at the State Department's Policy Planning Staff from 2001-2003, recalls, "The Pakistanis were never going to trust us to give them assistance on PALs because it could prevent them from using them at all."[118]

Transferring tacit knowledge about ESDs and PALs while protecting sensitive information was impossible without enduring collaborations between U.S. and Pakistani scientists. Any lab-to-lab cooperation in the late 1990s and early 2000s was limited by Pakistan's suspicions toward giving U.S. scientists too much access to its nuclear program, which dated back to past U.S. campaigns to limit Pakistani access to nuclear technologies in the 1970s.[119] In 2000, K. Subrahmanyam, an influential thinker in India's strategic affairs community, declared in *The Times of India*, "American concerns and anxiety about South Asia's nuclear situation (are) not reflected in the American denial of technology cooperation with India and Pakistan on safety and security measures – especially those that involve interaction among scientists and sale of equipment related to nuclear safety."[120]

Weak institutional and personal bonds between scientists on both sides restricted the space for discussing PALs and ESDs. Pakistani officials aimed to limit the discussion on PALs with the U.S. to basic concepts. According to Feroz Khan, a director in Pakistan's Strategic Plans Division from 1993-2003, "U.S. officials demanded from Pakistan that they needed to know the broader designs of nuclear weapons, in order to customize the PAL. The Pakistanis, in turn, just

[117] Albright, "Securing Pakistan's Nuclear Weapons Complex"; Sanger and Shanker, "A Nuclear Headache"; Sanger and Broad, "U.S. Secretly Aids Pakistan in Guarding Nuclear Arms"; Caldwell, "Permissive Action Links," 236.
[118] Author interview with Neil Joeck, phone, November 2021.
[119] U.S. Embassy Pakistan. "'Ambassador's Talk with General Zia,' Embassy Islamabad Cable to State Department." Cable, September 5, 1978. Mandatory Declassification Review request. Obtained and contributed by William Burr and included in NPIHP Research Update #3. History and Public Policy Program Digital Archive. https://digitalarchive.wilsoncenter.org/document/112839.
[120] Subrahmanyam, K. "Dialogue With Pakistan: India Must Take the Initiative." *The Times of India,* 2000, 21.

wanted to know the general concept."[121] The lack of lab-to-lab connections meant that U.S. and Pakistani engineers had not built up a reservoir of trust on the basis of smaller projects. Without this type of genuine partnership, the two sides were unable to navigate the sensitivities of cooperating on complex nuclear safety and security technologies.[122]

Alternative factors

Possibly, the U.S.'s reluctance to share complex nuclear safety and security technologies in this case can be explained by Pakistan's nuclear posture. For example, U.S. experts believed that Pakistan's warheads were de-mated from delivery vehicles. If the U.S. thought that this meant Pakistan's command and control system was more likely to "fail-safe" than "fail deadly," then the case for nuclear assistance would be weakened. This line of thinking does not hold up. On the whole, U.S. decision-makers recognized that, during times of crises, Pakistan would predelegate nuclear use capability to the military, increasing the risk that these systems would fail-deadly.[123]

The presence of legal barriers is another potential explanation for why the U.S. did not transfer certain techniques to Pakistan.[124] State Department lawyers were concerned that sharing devices such as PALs with Pakistan would violate Article I of the NPT, which forbids signatories from aiding non-nuclear weapon states to "manufacture or otherwise acquire nuclear weapons."[125]

[121] Author interview with former director of Pakistan's Strategic Plans Division Feroz Khan, phone, February 2022.
[122] Bunn, Matthew. "Cooperation to Secure Nuclear Stockpiles: A Case of Constrained Innovation." *Innovations: Technology, Governance, Globalization* 1, no. 1 (2006): 115–37.
[123] Arceneaux, Giles David. "Beyond the Rubicon: Command and Control in Regional Nuclear Powers." PhD Thesis, Syracuse University, 2019.
[124] Hersh, "Watching the Warheads"; Sanger, *The Inheritance*.
[125] McDermott, "PALs for Pals." Pakistan is considered a non-nuclear weapon state under the NPT, since the treaty defines these states as those that conducted a nuclear test before 1967.

Yet, the role of the NPT was not decisive for U.S. nuclear assistance to Pakistan. To make the case that transferring safety and security technologies to Pakistan violates Article I, one would have to construe this type of assistance as encouraging Pakistan to combine nuclear weapons components into deliverable bombs. Even this argument would be about "violating the spirit" as opposed to "the letter of the NPT."[126] Indeed, according to scholars familiar with these debates at the time, within the confines of the NPT, there was room for U.S. officials to maneuver.[127] *The New York Times* reported in 2001 that a senior U.S. official stated that the NPT would not be an impediment to improving the safety and security of the Pakistani arsenal.[128]

D. U.S.-Russia Warhead Safety and Security Exchange (1994-2007)

With the collapse of the Soviet Union in the early 1990s, Soviet and American leaders confronted the serious risk that nuclear weapons could fall into the wrong hands. In response, American and Russian scientists began cooperating on the safe and secure transport of nuclear weapons from former Soviet republics to Russia for dismantlement. The groundbreaking 1991 Nunn-Lugar legislation is widely recognized for its role in reducing the risks of nuclear accidents and theft of nuclear weapons by hostile actors. Former President Obama called it "one of the most important investments we could have made to protect ourselves from catastrophe."[129]

U.S.-Russian nuclear cooperation involved the transfer of different types of technologies. The Nunn-Lugar program provided essential aid in the form of Kevlar blankets to protect warheads and secure railcars for warhead shipments, it was limited to "external-protection

[126] Giles, "Safeguarding the Undeclared Nuclear Arsenals."
[127] Author interview with Scott Sagan, November 2021; author interview with Michael Krepon, November 2021.
[128] Sanger and Shanker, "A Nuclear Headache."
[129] Obama, Barack. *The Audacity of Hope: Thoughts on Reclaiming the American Dream*. Crown, 2006, 311.

equipment" that were not integrated in nuclear weapon systems.[130] In contrast, the Warhead Safety and Security Exchange (WSSX) agreement, signed in December 1994, provided a channel for the transfer of more complex nuclear safety and security technologies, including tamper-indicating devices and access-control technologies. For instance, within the WSSX framework, U.S. and Russian nuclear labs cooperated on the TOBOS[131] project, an automated monitoring and inventory system that monitored the security of warhead containers across their life cycle. In describing the difference between TOBOS and other forms of nuclear cooperation, experts noted, "Although individual and/or one-off upgrades to facilities, trucks, railcars, and nuclear warhead containers are important in certain instances, they are not as effective as a standardized system-wide solution."[132]

To evaluate my theory, this case analysis focuses on how WSSX was shaped by previous opportunities for technical cooperation. I do not review the balance-of-motivations approach in this case, as it is well established that risks related to the former Soviet Union's loosely controlled nuclear weapons overwhelmed any downsides to nuclear assistance.[133] Rather, the evidence should show that WSSX participants had to overcome an additional hurdle: sharing tacit knowledge on safety and security techniques that were integrated with warheads while not divulging classified or sensitive information. Unlike the U.S.-China and U.S.-Pakistan cases, the case evidence should validate that the strength of technical ties between U.S. and Russian scientists facilitated the transfer of more complex nuclear safety and security technologies.

---

[130] Smirnov, German A., and Andrey S. Sviridov. "Collaboration under WSSX: A VNIIA Perspective." In *Doomed to Cooperate*, edited by Siegfried S. Hecker. Bathtub Row Press, 2016, 225.
[131] Tekhnologii obespecheniya bezopasnosti opasnykh sistem, or Technologies for Securing the Safety of Dangerous Systems.
[132] Mann, Greg, Andrey S. Sviridov, and Konstantin Zimovets. TOBOS: A Nuclear Warhead Container Security System." In *Doomed to Cooperate*, edited by Siegfried S. Hecker. Bathtub Row Press, 2016, 239.
[133] Bernstein, Paul I., and Jason D. Wood. *The Origins of Nunn-Lugar and Cooperative Threat Reduction*. Edited by Jeffrey A. Larsen and Erin R. Mahan. National Defense University Press, 2010.

Complexity, technical cooperation, and U.S.-Russian nuclear assistance

As was the case with U.S.-China and U.S.-Pakistan nuclear assistance, WSSX encountered resistance from U.S. and Russian officials concerned about exposing sensitive information. Initially, the Russian military resisted revealing that there were any vulnerabilities in their control of nuclear weapons.[134] WSSX activities were subject to oversight by a steering committee composed of representatives from the U.S.'s Department of Energy and Department of Defense as well as Russia's Ministry for Atomic Energy and Ministry of Defense.[135]

Nevertheless, scientists developed workarounds that allowed for both sides to trust that sensitive information would be protected in the process of sharing information about warhead safety and security. For instance, discussions about tamper-indicating devices touched on concepts related to advanced PALs. Specifically, discussions related to PAL features that disabled the weapon after too many wrong inputs were too sensitive. In these cases, U.S. scientists and Russian counterparts would "almost play a game of negative guidance."[136] This is similar to the "negative guidance" or "20 questions" approach that the U.S. adopted in nuclear safety and security exchanges with the French, which had occurred three decades earlier, under which U.S. officials would indicate whether or not the French were on the right track in their development of certain systems, without providing direct advice.[137]

The aforementioned TOBOS project best captures how U.S. and Russian scientists were able to walk the line between conveying critical know-how and ensuring the protection of sensitive information. Since TOBOS was so integrated into the Russian warhead monitoring and

---

[134] Mann, Sviridov, and Zimovets, "TOBOS," 240; Smirnov and Sviridov, "Collaboration under WSSX," 225.
[135] White, Paul C., and K. David Nokes. "Nuclear Warhead Safety and Security: An Overview." In *Doomed to Cooperate*, edited by Siegfried S. Hecker. Bathtub Row Press, 2016, 184.
[136] Author interview with former acting laboratory director for national security at Los Alamos Paul White, Zoom, February 2022.
[137] Ullman, "The covert French connection."

accounting system — it was designed to provide real-time location reporting and security monitoring for a large inventory of warheads — the Russians could not risk accepting off-the-shelf U.S. solutions: “When a general opened the munitions vault door to a 12th GUMO storage facility it would not go over well to see a Sandia Lab logo on a Russian container control unit.”[138]

Instead, the U.S. needed to help Russia build its own TOBOS system, without exchanging classified or sensitive information. While U.S. engineers did not share specific code and software from its warhead monitoring and technology project, they did help build test sites and trouble-shoot technical problems. In one reflection on the TOBOS project co-authored by key U.S. and Russian participants, they recall, “For example, on mutual site visits the teams would be briefed on the concept for security operations, visit storage facilities to examine equipment configurations, and even test each other’s components. Although, when it came to specific system performance data, codes, and limitations, such discussions were sensitive and respectfully averted.”[139]

These transfers of complex nuclear safety and security technologies depended on the trusting relationships that had developed between U.S. and Russian weapons experts.[140] The TOBOS project involved people who had previously worked together on nuclear accident response procedures and efforts to improve physical security at nuclear research reactors.[141] WSSX built previous technical exchanges, including the Joint Verification Experiment of 1988, Geneva Testing Talks, and surety technology symposia. As Paul White reflects, “Personal

[138] Mann, Sviridov, and Zimovets, TOBOS, 242. The 12th GUMO refers to the Russian Ministry of Defense’s 12th Main Directorate.
[139] Mann, Sviridov, and Zimovets, TOBOS, 245.
[140] For similar dynamics in U.S. assistance to Russia’s nuclear navy, see Bunn, “Cooperation to Secure Nuclear Stockpiles.”
[141] Mann, Sviridov, and Zimovets, TOBOS, 240.

relationships grew and continued to the present day. One should not underestimate the importance of the continuity of these relationships. Trust grew out of repeated encounters and enabled the continued development of forward-leaning programs like WSSX."[142]

Alternative Factors

One could argue that the unique circumstances of the Soviet Union's breakup could account for the U.S.'s willingness to share information on advanced warhead monitoring technologies and access control techniques. Certainly, for the U.S., this historic event ushered in a dramatic shift from regarding the Soviet Union as its foremost geopolitical rival to assisting nuclear safety and security challenges linked to the Soviet collapse. Despite this impetus, the U.S. still encountered obstacles familiar to those involved in nuclear assistance to China and Pakistan. Russia would distrust the U.S.'s provision of integrated systems, and U.S. interagency groups maintained a cautious approach to disclosing information about U.S. nuclear weapons to the new Russian Federation.

In marked contrast with the previous two cases, sustained interactions between American scientists and their Soviet colleagues made it more feasible for the U.S. to share complex nuclear safety and security technologies with Russia. "The U.S. technical community has over 30 years experience in developing, deploying, and maintaining verification and monitoring regimes for bilateral treaties with Russia, as compared to a limited engagement of China's technical community in the last decade," Prindle wrote in 1998.[143] WSSX's extensive scope owed much to technical cooperation spanning decades that had generated "a sort of professional sympatico" between U.S. and Russian weapons scientists.[144]

---

[142] Roundtable discussion in *Doomed to Cooperate* (p. 205).
[143] Prindle, "The U.S.-China Lab-to-Lab Technical Exchange Program," 118fn1.
[144] White and Nokes, "Nuclear Warhead Safety and Security," 192.

IV. Conclusion

By highlighting how specific technological features shape the process of sharing nuclear safety and security technologies, this article has introduced a novel theory for the determinants of nuclear cooperation. The tacit and sensitive knowledge involved in the transfer of complex nuclear safety and security technologies imposes elevated demands for technical cooperation. Absent sustained interactions necessary to build up a repository of trust between technical communities, transferring more complex safety and security technologies will be infeasible.

One contribution of my argument is to scholarship on nuclear safety and security assistance. It is difficult to comprehend why states do not help each other reduce the risks of accidental and unauthorized nuclear explosions. Existing explanations that flesh out the motivations of the transferring state provide a useful starting point, but they do not explain cases when the balance of incentives leans toward sharing but no transfer occurs. By highlighting technical cooperation as a key factor, my approach fills this gap by differentiating between different types of nuclear safety and security technologies and focusing on the process by which nuclear assistance occurs.

Other international relations scholarship, including work on the role of international technology transfer in both China's rise and nuclear proliferation, has also emphasized the importance of scientific networks in sharing complex technologies.[145] In one sense, my paper shows that this insight from scholarship on preventing the *unwanted* diffusion of key technologies extends to the *wanted* diffusion of nuclear safety and security technologies. This highlights a difficult conundrum for researchers and policymakers seeking to manage the risks of

[145] Gilli and Gilli, "Why China Has Not Caught Up Yet"; Kroenig, *Exporting the Bomb*; Montgomery, "Ringing in Proliferation."

powerful technologies: the very networks that facilitate the unwanted diffusion of technological capabilities are also critical to spreading safety and security technologies.

My findings also speak to scholars and policymakers engaged in international nuclear policy. States more experienced with developing and implementing nuclear safety and security technologies may need to open up channels for technical cooperation with other states *before* a precipitating crisis or collapse exposes vulnerabilities to unauthorized or accidental nuclear use.[146] At present, such technical ties are limited between U.S. nuclear labs and both Chinese and Russian nuclear labs.[147] Still, one should not take these conclusions too far. While more intricate safety and security devices may be more effective at limiting the risks of inadvertent and unauthorized nuclear use, the introduction of more complexity into nuclear systems could also create the conditions for "normal accidents."[148] Nor are technological fixes the end-all solution to issues of nuclear security and safety. Organizational culture may be just as – if not more – important.[149]

More broadly, my argument has implications for cooperation on safety and security technologies in non-nuclear domains. Drawing on the historical template of the U.S.-Soviet Union nuclear cooperation, U.S. policymakers have stressed the need to find the "Permissive Action Link for AI."[150] A more comprehensive historical analysis reveals that the feasibility of nuclear assistance differed based on the features of safety and security technologies. This points

[146] Talmadge, Caitlin. "Striking a Balance." *The Nonproliferation Review* 12, no. 1 (March 1, 2005): 1–35, 26-27.
[147] Hecker, "Adventures in scientific nuclear diplomacy"; "Why Is China Modernizing its Nuclear Arsenal?" event transcript, Carnegie Endowment for International Peace, March 24, 2015, 12, <http://carnegieendowment.org/files/12-chinanucleararsenal240315wintro-formatted.pdf>; White and Nokes, "Nuclear Warhead Safety and Security."
[148] Regarding the most advanced PALs, Stein and Feaver write, "It is currently believed that even someone who gained possession of such a weapon, had a set of drawings, and enjoyed the technical capability of one of the national laboratories would be unable to successfully cause a detonation without knowing the code" (Stein and Feaver, "Assuring control of nuclear weapons," 58); Perrow 1984; Sagan 1993.
[149] Bunn, Matthew, and Scott D. Sagan. "A Worst Practices Guide to Insider Threats: Lessons from Past Mistakes." American Academy of Arts and Sciences Cambridge, MA, 2014.
[150] Smith, "Marshaling AI Cooperation."

toward the need to find the match between the various types of PALs for AI and the requisite level of technical cooperation to manage information risks involved with the transfer process. Future research should explore the limitations and opportunities to translating insights from nuclear assistance to safety and security issues in other emerging technologies such as synthetic biology, nanotechnology, cyber, and space. In a landscape where most analysis on the international politics of emerging technologies focuses on destructive capabilities such as new weapons systems, my hope is that this paper opens up space for more scholarship on technologies that guard against destruction.