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

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Abstract

Even during the Cold War, the U.S. and the Soviet Union cooperated on nuclear safety and security. Since accidental or unauthorized nuclear detonations anywhere 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? While existing explanations focus on the political costs and proliferation risks faced by the transferring state, 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 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) and Pakistan (1998-2003); and U.S. sharing of complex nuclear safety and security technologies with Russia (1994-2007). My findings suggest the need to examine not only the motivations behind nuclear assistance but also the process by which it occurs and the features of the technologies involved, with implications for how states cooperate to manage the global risks of emerging technologies.

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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)*. For example, environmental sensing devices (ESDs) that 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 unintended escalation. States should also be invested in other states' nuclear security, including that of hostile rivals, to reduce the likelihood of an unintentional nuclear war. Regarding 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" (Sanger and Broad 2007).

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 techniques from China and Pakistan (Caldwell 1987; Feaver 1992; Ullman 1989). 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” (Morse 1971).

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 (Caldwell 1987; Feaver 1992; Feaver and Niou 1996; Giles 1993; Miller 1993).

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.[1] 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 (Ding and Dafoe 2023; Ding 2024).

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.

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 (Collins 1974; Kerr 2008; Polanyi 1958).

[1] 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. assistance to France on nuclear safety does not qualify as sensitive nuclear assistance (Kroenig 2010, 201-202).

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.[2] Sharing PAL designs with other states, for instance, could give them information for devising countermeasures against the transferring state's own nuclear systems (Caldwell 1987, 236). 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 (1990-1999) 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

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[2] Contrary to the orientation of existing studies, concerns may be enhanced on the recipient side. According to interviewees knowledgeable about U.S. decision-making on nuclear assistance, potential recipients feared that accepting U.S. help would expose them to backdoors (co-founder of the Stimson Center Michael Krepon, Interview 2021; former member of the U.S. State Department's Policy Planning Staff Neil Joeck, Interview, 2021; former chief of the State Department's China Division Thomas Fingar, Interview, 2021).

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.[3] While the existing literature's focus on the balance of benefits and costs weighed by transferring states is helpful, it neglects crucial considerations about the feasibility of assistance, especially related to the recipient state's trust that the process will not expose weaknesses in its nuclear weapons capability (Miller 1993).

Second, this article complements the burgeoning literature on sensitive nuclear assistance and civilian nuclear assistance, which has greatly improved our understanding of how international aid in weapons-critical and dual-use technologies affects the spread of nuclear weapons to non-nuclear states (Brown and Kaplow 2014; Fuhrmann 2012; Gibbons 2020;

[3] This also bears on broader debates over international cooperation on technological safety, which examines accidents in civilian industries (McLean and Whang 2020).

Kroenig 2010; Montgomery 2005; Rabinowitz and Sarkar 2018). By highlighting the transfer of safety and security technologies to states that have already acquired nuclear weapons, this article highlights a different set of motivations, trade-offs, and constraints faced by transferring and recipient states. In doing so, it highlights a relatively understudied type of nuclear assistance, which is arguably just as, if not more important, for international security.

Third, unlocking how states share nuclear safety and security technologies also bears on current discussions about risks associated artificial intelligence (AI) and other emerging technologies. 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” (Smith 2020). 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 (NSCAI 2021). Notably, the reference for this recommendation highlights the historical case of PALs (NSCAI 2021, 106). 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.

The 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. 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 these 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 (Caldwell and Zimmerman 1989; Renic 2023).

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. 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 (Dunn 1982; Giles 1993). 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?" (Feaver 1992, 184).

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 (Peltzman 1975). Nuclear assistance to other states may encourage them to adopt risker nuclear postures, such as by mating warheads and delivery systems (Lewis 2007). 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" (Broad 1991).

Second, transferring states must also contend with domestic political costs. They may refrain from sharing safety and security technologies to avoid public controversy.[4] Again, even with U.S. nuclear cooperation with allies, this was a salient consideration. Morse, the DoD official who initiated U.S.-France nuclear safety talks, once noted that news media and public representatives would oppose any engagement in this area (Morse 1971). Historically, U.S. nuclear assistance has encountered Congressional and military opposition.

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, 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

[4] The recipient state may also seek to avoid domestic costs, such as the perception that their nuclear systems were not independently developed.

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 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 (Sagan 1993). In 1981, two decades after the first PAL was invented, mechanical locks still protected around half of the U.S. nuclear weapons in Europe (Stein and Feaver 1987, 55). 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 (Bleck and Souder 1984). 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 (Cotter 1987).

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 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 (MacKenzie and Spinardi 1995). In fact, this aligns with findings that highlight 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 access to experts and tacit knowledge in states with deep experience in nuclear weapons production (Montgomery 2005; Montgomery 2013).

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 (Feaver 1992b, 14). 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 (Rogers 1971).

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 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 (Bunn 2006; Evangelista 1999; Talmadge 2005). On the tacit knowledge condition, repeated social interactions allow communities to share uncodified and personally embodied knowledge (Collins 1974; Kerr 2008; Polanyi 1958). In these settings, scientists interact as “members of the same or similar technical cultures,” which allows them to “‘repair’ the insufficiency of explicit instructions” (MacKenzie and Spinardi 1995, 66).

As for protecting sensitive information, consistent interactions between technical experts in the transferring state and recipient state provide the maneuvering room for sharing information about safeguards connected to nuclear weapons capability (Giles 1993, 182). Such 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 (Miller 1993). These contentions draw on the robust science and technology studies literature on social networks, trust, and technology transfer, which has uncovered similar dynamics in other settings, such as the impact of prior collaboration experience on the ability of university-industry partnerships to carefully handle sensitive company knowledge (Collins 2001; de Wit-de Vries 2019).

The balance between sharing tacit knowledge and guarding sensitive knowledge 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. He reflects, “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 technical specialists” (Voznyuk 2016, 47). When this basis for technical cooperation is weak or nonexistent, transferring more complex safety and security technologies will be infeasible.

Alternative factors

Before turning to the empirical analysis, it is 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 (Miller 1993). 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 (Feaver 1992a, 181-187).

Legal issues also influence the share-withhold decision. In transferring nuclear safety and security technologies, the Nonproliferation Treaty (NPT) presents a potential constraint because it forbids signatories from assisting non-nuclear states to “manufacture or otherwise acquire nuclear weapons.” In debates over whether the U.S. should share PALs with Pakistan, State Department lawyers argued that nuclear safety and security assistance violated this clause of the NPT because it could induce Pakistan to build more nuclear weapons (Sanger and Broad 2007). In 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 (Miller 1993). 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 Warhead Safety and Security Exchange (1994-2007).[5] 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 and security assistance in the U.S. context, which is considerably more open on this subject than other potential transferring states.[6]

Table 1. Case Selection for Empirical Analysis

		Basis of technical cooperation	
Complexity level of safety and security technologies		Weak	Strong
	Low → lessened demands for technical cooperation	**Share:** U.S.-Soviet Union (1961-1963)	**Share:** U.S.-Russia, via Nunn-Lugar Program (1991-2012)*
	High → elevated demands for technical cooperation	**Withhold**: U.S.-China (1990-1999); U.S.-Pakistan (1998-2003)	**Share:** U.S.-Russia Warhead Safety and Security Exchange (1994-2007)

*Cases with low complexity and strong technical cooperation are not as helpful for testing my theory because they do not test whether regular technical exchanges are necessary for sharing safety and security technologies. The Nunn-Lugar program is discussed in the Warhead Safety and Security Exchange case.

[5] I am grateful to an anonymous reviewer for suggestions that made this table more intuitive and fit-for-purpose.

[6] When nuclear safety and security assistance is covert, our understanding of this process is limited. Still, with the aid of evidence from declassified materials and elite interviews, it is possible to achieve a reasonable degree of certainty about key details.

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. 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 (Stein and Feaver 1987, 55-56; Bleck and Sounder 1984). No longer just a coded switch that linked detonators and a battery, this security technology is deeply integrated with the weapon system (Lewis 2007).

These cases also provide variation in the outcome, both between and within cases. During the Warhead Safety and Security Exchange (WSSX), 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 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. Except for Pakistan, all recipients were acknowledged nuclear weapon states, which limits the purchase of legal explanations centered on the NPT.

On this thread, it is important to note that broader bilateral relationships between transferring and recipient states also shape patterns of nuclear safety and security assistance.[7] If overall ties between two states become more distrustful and competitive, then relations between their respective technical communities would be negatively impacted. The selected cases do weigh changes in the general geopolitical landscape; however, they also show that broader ties do not determine technical ones. In the WSSX case, for instance, strong connections between scientists enabled them to collaborate on warhead monitoring technologies, despite the significant degree of mistrust between Russian and U.S. political leaders on such topics.[8]

To reconstruct debates over transferring nuclear safety and security technologies, I draw on a wealth of elite interviews and archival materials. I benefited from documents 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. I also conducted 20 interviews with experts and key officials familiar with U.S. decision-making on nuclear safety and security assistance.[9] These interviewees came from communities connected to the nuclear labs, U.S. government agencies, think tanks, and academia.

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[7] I thank an anonymous reviewer for raising this point.
[8] Related work has established that technical exchanges can outpace the readiness of political leaders, reframe national security interests, and broaden cooperation beyond the original scope (Talmadge 2005; White and Nokes 2016).
[9] The end of the article provides a list of interviews.

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 (Bennett 1991; Stein and Feaver 1987, 83). In addition, McNaughton also passed along information on PALs to Soviet officials in a 1963 Chicago meeting.[10] By the end of the 1960s, it was believed that the Soviets adopted PALs on their nuclear weapons (Bennett 1991, 5; Meyer 1987, 521). 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 (Meyer 1985).

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

Balance-of-motivations

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

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 (Haworth 1962). In 1961, the *Saturday Evening Post* published an article on PALs, with the Pentagon's permission and active assistance (Wyden 1961).

Since horizontal proliferation risks were less relevant given the Soviet Union's status as an established nuclear power, motivations against sharing centered primarily on vertical proliferation risks and domestic political costs. 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 (Bennett 1991). 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" (Klein and Littell 1969, 8). In addition, key decision-makers in the Kennedy Administration acknowledged the possible domestic backlash to sharing nuclear safety and security technologies (Bennett 1991).

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" (Stein and Feaver 1987, 83). This quote indicated that several people in the Office of Secretary of Defense confirmed this calculus (Feaver, Interview, 2021). 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 (Klein and Littell 1969). These concerns traced back, in part, to a key point of contention among senior U.S. officials during the crisis over whether a Soviet retaliatory response would be decided by officers in Cuba or leaders in Moscow (Trachtenberg 1985, 154).

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 (Bennett 1991, 180; Miller 1993, 104). On sharing early versions of PALs, Thomas Schelling commented, "Once you have the concept, a 12-year-old could comprehend the mechanics within minutes" (Klein and Littell 1969, 47). While Schelling exaggerates the simplicity of early PALs — technical personnel had made numerous reliability upgrades — his overall point accurately diagnoses how technological specifics conditioned the ease of sharing (Luedecke 1963).

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 (Dunn 1982, 10). 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 (Hecker 2011). 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 (Hecker 2011).

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 officials from China's nuclear weapons program to visit U.S. nuclear weapons labs in 1994 (Coll 2001; Coll and Ottaway 1995; Stober and Hoffman 2001).[11] On each of these exchanges, Chinese nuclear weapons specialists requested U.S. assistance with nuclear safety and security, especially PAL technologies (Coll 2001; Coll and Ottaway 1995). 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.

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 (Tang et al. 2002). However, the U.S. did not attempt to transfer PALs, ESDs, and other complex safety and security technologies.

[11] I thank Sig Hecker, former director of the Los Alamos National Laboratory, for confirming some of these accounts in the U.S.-China lab-to-lab cooperation case. Hecker, Interview, 2021; Hecker, Interview, 2022.

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 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 (Caldwell and Zimmerman 1989).[12] 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 (Caldwell 1987, 232).

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 (Holt and Nikitin 2015). The Clinton administration "feared the backlash of seeming to sell another piece of critical technology to Beijing" (Sanger 2009, 226). Nancy Hayden (née Prindle), who managed technical

[12] During the 1969 Sino-Soviet border dispute, a Chinese military leader bypassed approval protocols and ordered China's Second Artillery to move to highest alert for launch of nuclear-armed missiles (Cunningham 2019, 13).

dialogues between U.S. and Chinese nuclear scientists during this period, recalls, "Every time we met with the Chinese, we had to go in front of interagency, and you had journalists following every meeting…It's the perception – why are we working with the Chinese? They're bad" (Hayden, Interview, 2022).

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 that high-ranking officials from China's nuclear weapons program had visited U.S. labs (Coll and Ottaway 1995). 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 (Hecker, Interview, 2021). 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.[13]

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."[14] 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

[13] Proliferation concerns linked to Chinese assistance to Pakistan and Iran's nuclear weapons programs raised the political costs of nuclear assistance. Holt and Nikitin 2015.
[14] 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.

and China, U.S. nuclear assistance is “more the norm than the exception” (Miller 1993, 122). One formal model 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” (Feaver and Niou 1996, 230).[15]

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]” (Coll and Ottaway 1995, A16; Coll 2001). 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 (Hecker 2011; Johnston et al. 1999). The window for nuclear assistance had closed. In fact, to this day, it is still unclear whether Chinese nuclear weapons are equipped with PALs.[16]

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 (Sanger and Broad 2007; Stober and Hoffman 2001). 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” (Coll and Ottaway 1995, A16).

On the flip side, Chinese officials were also reluctant to accept American-made devices, especially those more connected to weapons systems (Caldwell, Interview, 2021). China

[15] Feaver and Niou (1996) argue that providing nuclear security assistance to an enemy great power will not hurt the nonproliferation regime.
[16] For differing views on whether China has implemented PALs, see interview of Harold Agnew by Stuart Leslie on 2006 May 22, Niels Bohr Library & Archives, American Institute of Physics; Lewis 2007, 38.

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" (Riqiang 2016, 235). 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" (Fingar, Interview, 2021).

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, Hayden wrote, "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" (Prindle 1998). 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.[17] In fact, the Clinton administration viewed this emerging backchannel as a way to "advance the U.S.'s quiet nuclear engagement with China" (Coll and Ottaway 1995).

[17] 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 integrity sensors were used on PALs. Letter from Robert Duff to Gerald Johnson, box 25, folder 7, Gerald Johnson Papers, MSS 0206, Special Collections and Archives, UC San Diego.

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 (Prindle 1998, 113; Hayden, Interview, 2022). 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 (Layne, Interview, 2022). As of 1998, an English-Chinese glossary of material protection control and accounting terminology was still being reviewed by Chinese scientists (Prindle 1998, 117).

Alternative Factors

In terms of legal factors that could have shaped this case's outcome, domestic laws are more relevant than the NPT, since China is a recognized nuclear weapons state. In particular, the Atomic Energy Act (AEA) constrains the U.S.'s ability to share data related to nuclear weapons design. In the context of this case, most discussions about the AEA and U.S. nuclear assistance to China centered on civil nuclear cooperation, which ultimately resulted in a Congressionally approved agreement between the two countries on this topic (Holt and Nikitin 2015). Moreover, as demonstrated by the U.S.'s covert assistance to France on PALs in the 1970s, the U.S. could have still adhered to the AEA by disclosing information about complex nuclear safety and security technologies without providing actual designs or equipment (Ullman 1989).

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 (Stein and Feaver 1987, 88). In 1990, at the Second Beijing Arms Control Seminar, 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" (Norris et al. 1990).

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 (Hersh 2001; Khan 2000). In U.S.-Pakistan Track II backchannel dialogues during this period, participants discussed cooperation on nuclear safety and security.[18] 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 (Sechser 1999; Subcommittee on Asia and the Pacific 1999). 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 (Sanger 2009, 223; Joeck, Interview, 2022; Khan, Interview, 2022).

Balance-of-motivations

What explains this outcome? 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 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 (Giles 1993, 183). 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 (Caldwell 1987,

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[18] Scholars from Stanford University's Center for International Security and Cooperation participated in these dialogues from 1998 to 2001 (Professor Scott Sagan, Interview, 2021).

236; Feaver 1992a). 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 (Ganguly, Interview, 2022).

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 (Feinstein 2002). 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.

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 (Sanger 2009, 216). 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 (Hathaway 2000).

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

(Krepon, Interview, 2021). 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 (Sanger 2009, 217). Lastly, the risk that nuclear safety and security devices would encourage elevated risk postures was mitigated by the recognition that in times of crises —when nuclear risks were highest — Pakistan's nuclear weapons would likely be assembled quickly anyways (Cotta-Ramusino and Martellini 2002).

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 regarding PALs, fears that U.S. assistance "would teach Pakistan too much about American weaponry" presented a barrier to sharing (Sagner and Broad 2007).

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 (Krepon, Interview, 2021). 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 (Durrani 2004, 41).

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 (Sanger and Broad 2007). 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 would divulge too much information about its nuclear arsenal (Sanger and Shanker 2003; Sanger and Broad 2007). As Neil Joeck, who covered 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" (Joeck, Interview, 2021).

Transferring tacit knowledge about ESDs and PALs while protecting sensitive information was impossible without enduring collaborations between U.S. and Pakistani scientists. The U.S. was reluctant to open technical channels with Pakistan on nuclear safety and security measures (Subrahmanyam 2000, 21). Any lab-to-lab cooperation in the late 1990s and early 2000s was also 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.[19]

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 wanted to know the general concept" (Khan, Interview, 2022). The lack of lab-to-lab connections meant that U.S. and Pakistani engineers had not built up a reservoir of trust based on 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 (Bunn 2006).

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 safely" than "fail deadly," then the case for nuclear assistance would be weakened. This line of thinking does not hold up. 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 (Arceneaux 2019).

[19] U.S. Embassy Pakistan. "'Ambassador's Talk with General Zia,' Embassy Islamabad Cable to State Department." Cable, September 5, 1978. Obtained and contributed by William Burr, History and Public Policy Program Digital Archive.

The presence of legal barriers is another potential explanation for why the U.S. did not transfer certain techniques to Pakistan (Hersh 2001; Sanger 2009). One issue that decision-makers grappled with is whether assistance to Pakistan on PALs violated the AEA's limitations on sharing restricted data, and there is some evidence that this was a major hurdle for the Bush administration (Sanger 2009, 225). Still, undeterred by the AEA, the U.S. provided substantial nuclear safety and security assistance to Pakistan, which included aid for radiation-detection devices, in a $100 million package that was not fully disclosed until six years later. It should also be noted that the U.S. helped Russia develop complex nuclear safety and security technologies under WSSX, even though the two sides had not signed an agreement required by the AEA for substantial nuclear cooperation to take place (Hecker 2016, 221).

As for international legal constraints, U.S. officials expressed concerns 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. Under the NPT, Pakistan is considered a non-nuclear weapon state, since the treaty defines nuclear-weapon 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" (Giles 1993). Indeed, according to scholars familiar with these debates at the time, within the confines of the NPT, there was room for U.S. policymakers to maneuver (Krepon, Interview, 2021; Sagan, Interview, 2021). In a 2001 report by *The New York Times*, one senior U.S. official stated that the NPT would not be an impediment to improving the safety and security of the Pakistani arsenal (Sanger and Shanker 2003).

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" (Obama 2006, 311).

Across different avenues of U.S.-Russian nuclear cooperation, technological content differed. While 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 equipment" that was not integrated in nuclear weapon systems (Smirnov and Sviridov 2016, 225). In contrast, the Warhead Safety and Security Exchange (WSSX) agreement, signed in December 1994, provided a channel for transferring more complex nuclear safety and security technologies, including tamper-indicating devices and access-control technologies. For instance, under WSSX, U.S. and Russian nuclear labs cooperated on the TOBOS project,[20] an automated 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

[20] Tekhnologii obespecheniya bezopasnosti opasnykh sistem, or Technologies for Securing the Safety of Dangerous Systems.

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" (Mann et al. 2016, 239).

In line with the balance-of-motivations approach, after the collapse of the Soviet Union, U.S. decision-makers calculated that the risks of loosely controlled nuclear weapons overwhelmed any drawbacks to nuclear safety and security assistance, opening the window for the Nunn-Lugar and WSSX initiatives.[21] Yet, the balance-of-motivations approach struggles to decipher why the U.S. was able to share *different types* of nuclear safety and security technologies. Thus, the following case analysis focuses on the WSSX channel because participants had to overcome a challenge not faced by the more well-known Nunn-Lugar program: sharing tacit knowledge on safety and security techniques that were integrated with warheads without divulging sensitive information. If my theory holds, the strong basis of technical cooperation between U.S. and Russian scientists should have facilitated the transfer of more complex nuclear safety and security technologies.

Complexity, technical cooperation, and U.S.-Russian 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 (Mann et al. 2016, 240; Smirnov and Sviridov 2016, 225). 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 (White and Nokes 2016, 184).

[21] Proliferation risks were muted, but there were some political costs, as some argued that cooperative threat reduction programs allowed Russia to divert funds toward military modernization (Woolf 2003).

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, as former laboratory director for national security at Los Alamos Paul White relates, U.S. scientists and Russian counterparts would "almost play a game of negative guidance" (White, Interview, 2022). 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 (Ullman 1989).

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 very integrated into the Russian warhead monitoring and 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" (Mann et al. 2016, 242).[22]

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

[22] The 12th GUMO refers to the Russian Ministry of Defense's 12th Main Directorate, which holds prime responsibility over managing nuclear warheads.

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” (Mann et al. 2016, 245).

These transfers of complex nuclear safety and security technologies depended on trusting relationships that had developed between U.S. and Russian experts. The basis for many of these relationships was the 1988 Joint Verification Experiment (JVE), in which Soviet and American nuclear weapons scientists visited each other's labs to test verification techniques for the Threshold Nuclear Test Ban Treaty. The JVE paved the way for a series of other lab-to-lab scientific collaborations that preceded WSSX, including the 1993-1994 surety technology symposia, which brought together hundreds of American and Russian nuclear weapons specialists to discuss safety and security issues (White and Nokes 2016). As Paul White reflects, “Personal 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” (Hecker 2016, 205).

Indeed, many of the key participants in WSSX were alumni of the JVE and earlier lab-to-lab cooperative programs. 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 (Mann et al. 2016, 240). Most prominently, Viktor N. Mikhailov, who led the Soviet technical delegation to the JVE, later signed the WSSX agreement as Russia's Minister of Atomic Energy.[23] When these scientists confronted the challenges of cooperating on complex safety and security technologies at WSSX, they could draw on a shared history of working through sensitive issues.

Alternative Factors

One could argue that the unique circumstances of the Soviet Union's breakup accounts 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 managing 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. The new Russian Federation distrusted 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 (White, Interview, 2022; Mann et al. 2016).

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. WSSX's extensive scope owed much to earlier technical engagements that had generated "a sort of professional sympatico" between U.S. and Russian weapons scientists (White and Nokes 2016, 192). These professional and personal friendships, strengthened by lab-to-lab exchanges undertaken in the previous decade, enabled the two sides to share information on complex warhead monitoring technologies.

[23] In his memoir, Mikhailov (1996) wrote that the main impact of the JVE was "not the development of procedures and extent of nuclear test monitoring of the joint development of technical verification means, but the chance for interpersonal communications with the American nuclear physicists."

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 sensitive nuclear assistance as well as China's efforts to imitate advanced weapon systems, has also emphasized the importance of scientific networks in the transfer of complex technologies (Gilli and Gilli 2019; Kroenig 2010; Montgomery 2005). 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 powerful technologies: the very networks that could facilitate leakage of sensitive technologies 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 (Talmadge 2005, 26-27). At present, such technical ties are limited between U.S. nuclear labs and both Chinese and Russian nuclear labs (White and Nokes 2016). Still, one should not take these conclusions too far. While intricate safety and security devices may be more effective at limiting the risks of inadvertent and unauthorized nuclear use, the introduction of complexity into nuclear systems could also create the conditions for "normal accidents" (Sagan 1993). 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.

More broadly, my argument has implications for cooperation on safety and security technologies in non-nuclear domains. Drawing on the historical template of U.S.-Soviet Union nuclear cooperation, U.S. policymakers have stressed the need to find the "Permissive Action Link for AI" (Smith 2020). My historical analysis points toward matching the various types of PALs for AI with requisite levels of technical cooperation to manage information risks involved with the transfer process. Future research should explore the limitations and opportunities to translating insights from the nuclear domain to safety and security issues in other emerging technology domains such as synthetic biology, cyber, and space. In a landscape where most analysis on the international politics of emerging technologies centers on their destructive potential, my hope is that this paper opens space for more scholarship on technologies that guard against destruction.

List of Interviews

List of interviews

1. Dan Caldwell, phone, 27 September 2021.
2. Dan Caldwell, phone, 8 November 2021.
3. Michael Krepon, phone, 10 November 2021.
4. Neil Joeck, phone, 18 November 2021.
5. Scott Sagan, Stanford, 17 November 2021.
6. Fiona Cunningham, phone, 18 November 2021.
7. Peter Feaver, phone, 24 November 2021.
8. Thomas Fingar, Stanford, 9 December 2021.
9. Dan Caldwell, Stanford, 9 December 2021.
10. Sig Hecker, Zoom, 13 December 2021.
11. Sumit Ganguly, phone, 13 December 2021.
12. Herb Lin, Stanford, 2 February 2022.
13. Rose Gottemoeller, Stanford, 8 February 2022.
14. Feroz Khan, phone, 10 February 2022.
15. James Timbie, Stanford, 10 February 2022.
16. Paul White, Zoom, 21 February 2022.
17. Sig Hecker, Zoom, 3 March 2022.
18. Nancy Hayden, Zoom, 4 April 2022.
19. Clyde Layne, Zoom, 13 April 2022.
20. Marvin Weinbaum, phone, 10 October 2022.

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