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Technical Cooperation on Nuclear Risk Reduction with China

Summary of 2014-2020 Initiatives of the Stanford Center for International Security and Cooperation and Collaborating China Agencies

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December 2023

FSI Stanford Freeman Spogli Institute for International Studies

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Abstract

Between 2014 and 2020 the Center for International Security and Cooperation at Stanford University pursued a program of technical collaborations with nuclear experts in China. The goal was reduction of the dangers associated with the widespread applications of nuclear and radiological technologies. The collaboration built on long bilateral relationships between U.S. and China scientists. Major topics addressed included improved security against terrorist nuclear and radiological threats, responses to growing North Korean nuclear capabilities, and risk reductions in the civilian nuclear power industry. Engagements emphasized the application of systems analysis and scenario-based planning techniques. Diverse contributors have included young professionals and academics to senior technical experts from both countries. The program has addressed emerging nuclear and radiological challenges and has invigorated relationships between nuclear professionals in China and the U.S. Collaborations were paused in early 2020 as a result of the COVID-19 pandemic.

Acknowledgments

The research documented in this report would not have been possible without the enthusiastic participation and creative inputs of many collaborators in the nuclear community in China. Special thanks are due to Dr. Zhu Xuhui (China National Nuclear Corporation – retired) for his ideas and proactive support of the engagements in China. Dr. Wu Jun, Director of the Center for Strategic Studies in the China Academy of Engineering Physics (CAEP/CSS) and Dr. Hu Side (CAEP/CSS – retired), were also critical in supporting the work and offering compelling technical inputs. Many other senior experts and officials in several China nuclear organizations were also critical in enabling the collaboration.

Many professionals working in China's nuclear programs participated in the collaborative workshops. Staff of the CAEP/CSS deserve particular note due to their technical contributions to the exchanges and their continuing support of the project. Others in the China Institute of Nuclear Information & Economics (CINIE) played a growing role as the program progressed.

In addition to the authors, principal U.S. contributors include Dr. Jason Reinhardt (Sandia Laboratories) who provided research and leadership in the areas of systems and risk analysis and adversary modeling and Dr. Leonard Connell (Sandia Laboratories – retired) who provided radiological threat and countermeasures systems and risk analyses. Robert Carlin provided expert background and leadership in the analysis of North Korean nuclear issues. Allison Puccioni, Nick Hansen and Elliott Serbin completed open source analysis work supporting the engagements on North Korea. These and many other U.S. contributors not named here were vital to the success of this program.

This research was supported by grants from the MacArthur Foundation and the Carnegie Corporation of New York. Initial work (2014-2016) in the program was also supported by the Naval Postgraduate School's Project on Advanced Systems and Concepts for Countering Weapons of Mass Destruction (PASCC) via Grant Number N00244-14-1-0032. Open source analysis of North Korean nuclear activities was supported by a grant from the Nuclear Threat Initiative.

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Executive Summary

The Nuclear Risk Reduction Program at the Center for International Security and Cooperation (CISAC) at Stanford University has sought to reduce global nuclear dangers through international technical cooperation. The growing threats of nuclear terrorism and proliferation in Asia made engagement with China a critical aspect of this work. During the period 2014 to 2020, Stanford CISAC worked with nuclear experts in China to develop solutions to a few of the most critical emerging risks associated with nuclear and radiological technologies. These technical engagements have precedents beginning in the 1990's and have built upon the long-term relationships established in the earliest U.S.-China cooperative programs.

The project focused on several major nuclear and radiological problems. The first and most extensive collaborations addressed nuclear security against terrorist threats employing nuclear and radiological materials. The primary research topics in this area were: 1) detection and interdiction of smuggled radiological or nuclear material; 2) radiological ("dirty bomb") threats and countermeasures; and 3) nuclear forensics. A second technical focus on potential responses to North Korean nuclear activities emerged later in the program. Potential strategies and systems to support transparency, verification of agreements, and ultimately nuclear dismantlement were discussed. Finally, an ongoing but lower-level engagement addressing the risks of civilian nuclear power was also pursued.

Approaches that extended traditional technical cooperation processes were utilized in the engagements. One of these was application of the tools of systems and risk analysis to structure the engagements and to perform collaborative analyses. Another was the use of highly interactive approaches such as scenario-based tabletop exercises to engage a wide range of contributors.

An extensive series of planning meetings, workshops, and expert exchanges took place during the program. A diverse set of participants contributed to the exchanges, including subject matter experts, systems analysts, and younger nuclear professionals and students. The discussions uncovered a variety of new technical options for future cooperative work. The many professional relationships created and nurtured through the program are an important legacy for future engagements.

The technical engagements were put on hold with the outbreak of the COVID-19 pandemic in 2020.

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1. Introduction

1.1 International Technical Cooperation to Reduce Nuclear Risks

The risks associated with civilian and military applications of nuclear technologies have grown as these applications have become more widespread. The longstanding concerns over the safety of nuclear energy and the safety and control of nuclear arsenals of major powers continues. More recently the threats of terrorist nuclear or radiological attack and the behaviors of nuclear weapons proliferators have become increasing concerns. These threats have become increasingly global, motivating a wide range of international actions to reduce the dangers. These have included political measures including treaties and regulations on international commerce. An important international activity to mitigate risk has also been technical cooperation. Such cooperation provides the basis for monitoring and enforcing international agreements and provides the technical support to nations seeking to improve their internal management and regulation of nuclear technologies.

Among the options for international technical cooperation, bilateral collaboration between major nuclear powers is particularly important. Such engagements can help align understandings and practices among nations that are most responsible for the future directions of regional and global nuclear security. These engagements are also uniquely suited to consideration of the safety and security of global nuclear weapons arsenals or defense nuclear materials and facilities.

China is an important partner for bilateral technical engagement with the U.S. It plays key roles in nuclear security matters in East Asia and is committed to broader regional and global influence. Its expansive nuclear power industry enables it to influence civilian nuclear security operations worldwide. The degree to which China develops and promulgates a strong nuclear security culture will substantially influence global nuclear risks. In addition, there is a significant historical precedent for bilateral technical cooperation between China and the U.S. While all such engagements are influenced by the shifting national security and economic policies of each country, the technical relationships in the nuclear arena between China and the U.S. have demonstrated an encouraging durability over the last thirty years.

1.2 Precedents for Bilateral Nuclear Cooperation with China

While technical cooperation in nuclear matters has long taken place between the U.S. and its allies, cooperation between adversaries has a shorter history. A notable example is the technical cooperation between the U.S. and Russia following the end of the Cold War under the aegis of the Nunn-Lugar Cooperative Threat Reduction (CTR) program. Concurrent and related activities also took place within the U.S. Department of Energy Lab-to-Lab program. This work was instrumental in mitigating the dangers associated with widely dispersed nuclear weapons, large

stockpiles of poorly secured fissile material, and underemployed nuclear weapons scientists in the Former Soviet Union.[1]

Motivated in part by the successes of the Russian program, the leaders of the U.S. and Chinese nuclear weapons laboratories in 1995 established a Lab-to-Lab program to share technical information that addressed nuclear risks in both countries. Initially, the primary interactions involved workshops in the U.S. to identify technical directions that might support China's efforts to develop a safer and more secure nuclear enterprise. These initial workshops led to a set of concepts for future collaboration as well as increased interaction between the defense nuclear communities in China and the U.S.[2] The first substantive joint project was a demonstration of materials protection, control, and accounting (MPC&A) concepts in a civilian nuclear facility in China.[3] Unfortunately, these Lab-to-Lab engagements came to an untimely end when the Cox Commission alleged that China was using the program as an intelligence tool against the U.S.[4] While the commission's accusations were disputed by independent nuclear experts[5], the ultimate outcome was a suspension by the Chinese defense nuclear community of direct engagements with the U.S. national laboratories.

Technical collaborations with China in nondefense nuclear areas continued, albeit at a reduced level, under the auspices of the 1985 Peaceful Uses of Nuclear Technology (PUNT) agreement. These programs often involved personnel from the U.S. national laboratories. One milestone in this work was the Joint China-U.S. Integrated Nuclear Materials Management Technology Demonstration in October 2005.[6] Another was the bilateral project supporting radiological security at the 2008 Beijing Olympics.[7]

New opportunities for nuclear cooperation opened up following the April 2009 speech in Prague by then-president Obama which highlighted international nuclear risks. A growing awareness of the threat of radiological and nuclear terrorism drove the establishment of new U.S. domestic programs as well as international initiatives. The Nuclear Security Summits held in 2010, 2012, and 2014 provided impetus for technological cooperation, notably in a Chinese commitment to a Center of Excellence for Nuclear Security. Other initiatives included the Global Initiative to Combat Nuclear Terrorism (GICNT) and expanded programs by the International Atomic Energy Agency (IAEA). These international programs received growing technical support through U.S. national laboratory efforts. Non-governmental efforts also expanded, with the U.S. National Academies and the Nuclear Threat Initiative leading significant international programs.

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[1] A very diverse set of technical programs was pursued. A comprehensive treatment of the Russia program is included in Siegfried Hecker, ed., "Doomed to Cooperate," Bathtub Row Press, 2016.
[2] Nancy Prindle, "The U.S.-China Lab-to-Lab Technical Exchange Program," *The Nonproliferation Review*, Spring/Summer 1998, pp111-118.
[3] "Integrated Demonstration of Materials Protection, Control, and Accountability," U.S.-China Lab-to-Lab Technical Exchange Program, published by Los Alamos National Laboratory, LALP-98-65, June 1998.
[4] "Report of the Select Committee on U.S. National Security and Military/Commercial Concerns with the People's Republic of China," U.S. Government Printing Office, 1999.
[5] Michael May (ed.), "The Cox Committee Report: An Assessment," Center for International Security, Stanford University, Dec 1999. (available at: cisac.fsi.stanford.edu/publications/cox_committee_report_the_an_assessment)
[6] The technical features of the Joint China-U.S. Integrated Nuclear Materials Management Technology Demonstration (October 2005) can be accessed at: www.ciae.ac.cn/eng/AnnualReport/english2005/10.doc
[7] Chong, D. et al, "U.S.-China Radiological Security Cooperation in Preparation for the 2008 Beijing Olympic Games," Los Alamos National Laboratory, Conference Paper LAUR-08-3098, July 2008.

1.3 Context of the Stanford-China Collaboration

In 2013 researchers at the Stanford Center for International Security and Cooperation (Stanford CISAC) began discussions with key nuclear experts in China with the goal of defining a technical exchange program that would assist both countries in addressing the emerging risks of global civilian and defense nuclear activities. Stanford CISAC was well positioned to pursue this goal. A number of CISAC researchers and affiliates had played significant roles in the earlier China Lab-to-Lab effort, most notably Dr. Siegfried Hecker who, as director of Los Alamos National Laboratory at the time, championed the relationship with China's nuclear laboratories. Many of the key leaders in China's nuclear programs have also spent time as scholars at Stanford. Stanford CISAC has a long history of cooperative work in East Asia including the Project on Peace and Cooperation in the Asian-Pacific Region led by former Professor John W. Lewis. Finally, Stanford CISAC's strong relationships with the U.S. national laboratories were vital in securing the technical talent needed to execute such a cooperative program.

However, challenges existed as well. First, since many technical nuclear topics touch upon sensitive national security topics in both countries, it was necessary to define joint study areas that were both significant and also available for open discussion. Second, technical exchanges have faced increased scrutiny in the U.S. due the concerns regarding inadvertent transfer of intellectual property. The Stanford-China planning largely bypassed this issue by focusing on the systems aspects of potential security solutions. This includes the definition and modeling of threat scenarios and the requirements tradeoff studies that are the foundation for system design. This approach recognized that China's rapid technical advance has enabled it to implement whatever technical systems it finds essential. Hence the most fruitful cooperative collaborations must address the definition of the threats and requirements on future security systems as well as the role of international operational cooperation.

1.4 Report Overview

The goal of this report is to provide a record of the activities and accomplishments of the Stanford-China technical collaboration program between 2014 and 2020. The major technical issues addressed in the program as well as the innovative approaches and methodologies employed are outlined in Chapter 2. More detail regarding the major phases of the collaboration engagements is included in Chapter 3. Chapter 4 includes a short summary of accomplishments and some thoughts on future opportunities. Finally, the short appendix contains a listing of research products produced as a part of the project.

2. Scope and Approaches

2.1 Engagement Goals

The goals of the technical collaborations envisioned by the early organizers were twofold. The first was to identify areas of collaboration and the appropriate experts and resources that offered the greatest opportunities for reducing nuclear dangers. The second was to seek approaches that would nurture professional relationships among the technical experts of both countries, especially the younger professionals that both the U.S. and China are developing as the problem solvers of the future. The initial selection of technical topics and engagement approaches was based on early project planning discussions. These initial technical choices evolved due to both natural progression of the research as well as the impact of external events. The approaches and methodologies employed in the collaboration also shifted with time as the technical topics, objectives and participants changed.

This evolution of technical topics and engagement approaches resulted in three distinct phases in the project. However, the transitions between phases were not abrupt but rather became apparent in the natural course of the engagements. The technical focus and the engagement approaches in each of the three phases are introduced in the following sections. More detailed descriptions of the workshops that were the principal events are included in the next chapter.

2.2 Primary Technical Areas Addressed

Phase 1 (2014-2016): Analysis of Nuclear Security Measures against Nuclear and Radiological Terrorism

The threat of a terrorist radiological or nuclear attack by terrorists was the initial technical focus of the collaborations. At the time of the initial project discussions, many analysts believed the likelihood of such an attack was high. Scenarios ranged from the dispersal of radiological material (termed a “dirty bomb”) up to and including the detonation of an improvised nuclear device (IND) with kilotons of nuclear yield. The large amount of fissile and other radioactive material worldwide and the possession of nuclear weapons by potentially unstable regimes add to these concerns. The growing capability of terrorist organizations worldwide also supported this as a compelling initial direction for collaborations.

Phase 2 (2016-2017): Scenario Planning and Tabletop Exercises addressing Radiological Terrorism

Phase 2 of the collaborations continued to focus on more specific aspects of the radiological terrorism threat. However, the questions and approaches to the interaction were quite different. Phase 2 sought to address fundamental questions of threat definition and response options through use of highly interactive tools such as scenario-based planning exercises. This permitted a deeper involvement by diverse participants from both countries and focused particularly on the younger, academic and professional contributors.

Phase 3 (2018-2019): North Korea Nuclear Issues

Growing international concerns in the second half of the decade over the nuclear programs of North Korea motivated an increased emphasis on this topic in the third phase of the program. These discussions benefitted from a growing body of related research at Stanford CISAC.

Ongoing: Civilian Nuclear Power Issues

Technical collaboration efforts proceeded in the area of civilian nuclear power risks over the course of the program. These were at a lower level of effort than the primary technical phases of the work introduced above.

2.3 Approaches and Methodologies

Many if not most bilateral exchanges between technical experts involve the presentation of technical talks that reflect the research activities of each presenter. This kind of exchange is much like a small scale version of a larger international professional meeting. The developers of the Stanford-China collaboration established a somewhat different context by adopting a focus on systems and risk analysis as one foundation for the technical exchanges. This was in part due to the match between the capabilities of the Stanford team and the interests and mission of the primary China collaborators, the Center for Strategic Studies of the China Academy of Engineering Physics (CSS/CAEP). However, it was also consistent with China's increasing technical capabilities to implement systems solutions. The engagement approach in Phase 2 emphasized more interactive analysis tools. This was done to enable broader participation and contribution of younger nuclear professionals from China and the U.S.

Application of Systems and Risk Analysis (in Phases 1, 2, and 3)

Within the U.S. national security community, systems analysis and its variants (e.g., risk analysis, decision analysis, scenario planning, systems gaming) are primary tools in systems assessment, operations development, and resource allocation processes. The concepts and tools of strategic decision and risk analysis appear to offer significant benefits for collaborative international projects. More specifically, these tools provide ways to handle several important collaborative analysis problems. One is representation of uncertainties about future events (e.g., capabilities and intent of adversaries, future scenarios, physical and environmental factors). Another is the development of a diverse set of strategic alternatives that can broaden the perspective of the analysis. Finally, explicit value metrics are central to the process, allowing more transparent linkage between national perspectives and the choice of response strategies and collaboration options.

Joint efforts in systems and risk analysis are synergistic with the more focused technical exchanges pursued by other national and multilateral contributors. This is illustrated in Figure 3.1. Many past and current technical exchanges focus on the fundamental technologies and concepts that underlie the design of security systems to reduce nuclear dangers. While this is appropriate for most international engagements, China's strong capabilities in advanced technologies make it very capable of implementing very advanced security systems should it find

them useful. Hence, it is essential to move the bilateral dialogue to a higher level of shared security concerns and away from the details of technical design. This provides the opportunity to address the vital broader issues of threat perception, systems performance, and joint response protocols. Systems analysis is a tool that has long been used to deliberate defensive systems issues in the U.S. Its use as a communication and collaboration tool for international engagements, however, appears to be infrequent.[8]

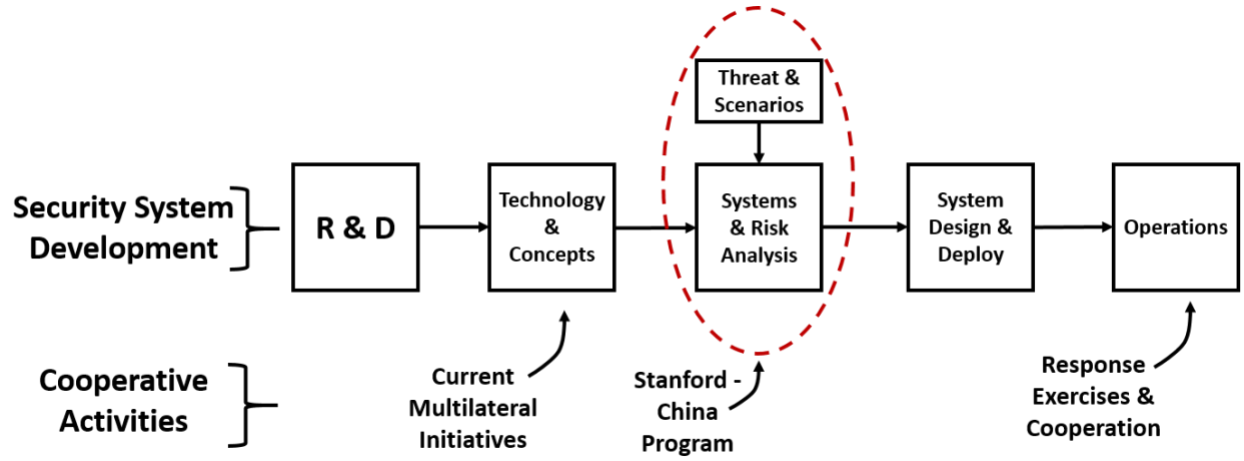

Figure 3.1 Role of Systems Analysis in Cooperative Exchanges with China

The focus on systems and risk analysis methodologies brings with it some very useful tools. These include those drawn from the decision analysis and scenario planning communities. Tools such as decision and influence diagrams, strategy tables, decision trees, and Bayesian networks can greatly assist in the framing, modeling, and communication of system performance and its uncertainties. In addition to the power of the tools, the joint synthesis of a shared model is central to the concept of collaborative analysis. The partners can hopefully agree on the basic structure of the physical systems model, even though their assessments of the input variables and uncertainties may be very different. Making these differences in input variables explicit will enhance shared understanding among international partners in the same fashion that the process builds clarity and understanding within U.S. analysis teams.

Several approaches were adopted to emphasize systems and risk analysis methodologies in the Phase 1 exchanges. First, examples of prior systems analyses performed in both China and the U.S. were invited as a part of the two workshops in this phase. Second, several collaborative studies utilizing systems analysis approaches were performed. Finally, a series of briefings on the role and implementation of systems and risk analysis was included in the workshops and in the 14th and 15th PIIC Beijing Seminars.

[8] While not broadly applied, the idea of joint systems analysis teams is not new. See, for example, Lewis Dunn, "Reshaping Strategic Relationships: Expanding the Arms Control Toolbox," *Arms Control Today*, May 2009, pp. 15-21, www.armscontrol.org.

Interactive Approaches to Scenario and Adversary Analysis (in Phase 2)

A variety of techniques including scenario-based tabletops, wargames, and group planning tools are useful in soliciting insights from a group of contributors who bring diverse backgrounds and experiences into a collaboration. While the use of these approaches in training and operational environments is commonplace, deliberation on more complex technical issues can also be enhanced by these highly interactive techniques. Diverse inputs are particularly important in the initial development of both attack and response scenarios to guide security system development. They help ensure that innovative or unusual factors are not neglected in the requirements generation process. Such approaches are also applicable to higher level collaborations as a way of motivating the need for cooperative action.[9]

Scenario-based approaches were employed in both workshops in Phase 2. In the first workshop, a set of scenarios involving the acquisition of radiological sources and subsequent attack on a fictitious country. In the second workshop, several of these scenarios were employed to evaluate alternative detection architectures that might be used to intervene in the attack. Such workshops require considerable advance planning to set up the context and ground rules that will enable the results generated within the workshop to be useful in subsequent decisions. In the Phase 2 work, this approach achieved the desired result of broad participation by diverse workshop attendees.

Systems analysis and modeling are also very useful in understanding the threat against which a security system must operate. While intelligence activities can uncover essential information about current threats, the development of robust systems must consider the future evolution of adversary capabilities. Characterization of the threat and attack scenarios is one of the most critical elements in the development of requirements for a security system. It is often disagreements in the nature of the threat that leads to differences in favored response strategies. Adversary analysis was an important foundation to collaborations in Phase 2.

[9] One such event involving the China nuclear security community was reported by Page Stoutland, "U.S.-China Cooperative Nuclear Security Table-Top Exercise," 15th PIIC Beijing Seminar on International Security: Strategic Stability and Cooperation, Suzhou, China, November 2, 2016.

3. Summary of Engagements and Collaborative Research

3.1 Timeline and Participants

The Stanford-China cooperative program included a series of planning and coordination meetings, six workshops involving diverse contributors, collaborative and independent studies in primary research areas, expert meetings on specific questions of interest, and conference presentations. Preparation for and execution of the workshops comprised a major fraction of the research effort. Strong support throughout the program was provided by the Center for Strategic Studies (CSS) of the China Academy of Engineering Physics (CAEP). Other organizations in China have also played key roles. These include the Institute for Applied Physics and Computational Mathematics (IAPCM), the China Institute of Nuclear Information & Economics (CINIE), the China Arms Control and Disarmament Association (CACDA), and the China Institute for Atomic Energy (CIAE).

The timing of the six workshops in the collaboration through 2019 is shown in Figure 4.1. The workshops were convened at the Stanford Center at Peking University in Beijing. The objectives and content of each workshop is described below. The three PIIC Beijing Seminars that took place during October 2014 (in Hangzhou), November 2016 (in Suzhou), and October 2019 (in Shenzhen) were also important venues for collaborations.

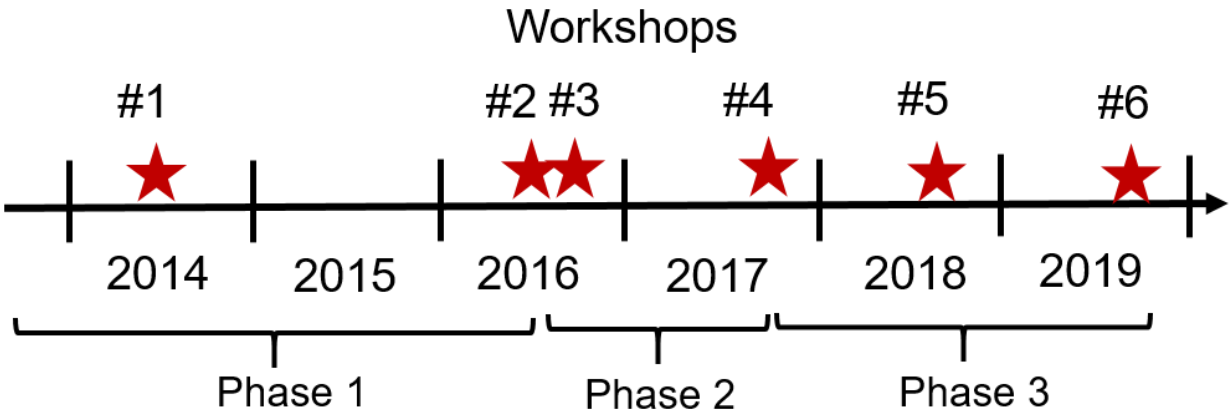

Figure 4.1 Engagement Timeline

3.2 Phase 1 Collaborations: Analysis of Nuclear Security Measures against Radiological and Nuclear Terrorism

Collaborations in Phase 1 focused on research addressing countermeasures to radiological and nuclear terrorism. This phase of the work was initiated through a planning meeting in late 2013 where an initial technical focus on radiological and nuclear terrorism and an emphasis on systems and risk analysis were adopted for collaborations. This set the stage for the sharing of national studies in Workshop #1. This workshop and a subsequent planning meeting set the stage for the work supporting Workshop #2 which was the final Phase 1 collaboration.

Workshop #1 (June 17-18, 2014)

This workshop provided a forum for the review of systems studies performed by China and the U.S. on various aspects of radiological and nuclear terrorism. In addition, U.S. experts contributed briefings on the application of systems and risk analysis in security studies. During deliberations at Workshop #1, nuclear forensics emerged as a topic of interest. This motivated an additional planning meeting in October 2014 where nuclear forensics experts from the U.S. were invited to brief on current capabilities and research efforts. As a result of these engagements, three primary research areas for future collaborative studies were identified. These were:

1. Detection and interdiction of smuggled nuclear materials
2. Response to radiological threats
3. Development of nuclear forensics capabilities

Collaborative Studies (2015 and Early 2016)

As a result of 2014 deliberations, three new studies were pursued under the auspices of the Stanford-China program to address topics of interest in the primary research areas. These collaborative studies were also structured to employ a spectrum of systems and risk analysis approaches. The three studies and their principal investigators were:

1. Port and Transit Detection and Interdiction (Dr. Zhang Songbai, China Institute for Applied Physics and Computational Mathematics)
2. Wide Area Search (Dr. Jason Reinhardt, Stanford University and Sandia National Laboratories)
3. Nuclear Forensics Capability Development (Dr. Larry Brandt, Stanford University)

Workshop #2 (June 6-7, 2016)

This final workshop in Phase 1 shared results in the three primary research areas identified earlier. Both China and U.S. participants presented briefings on current studies and research underway in each country. Results of the three collaborative studies listed above were presented. Finally, additional tutorial briefings on the role of systems and risk analysis in security studies were also included.

Each of the three technical sessions focused on the primary research areas fostered extensive and useful discussions among the experts in attendance. The nuclear forensics session, led by Dr. Sue Clark and Dr. Nathalie Wall (both from Washington State University) provided a comprehensive technical review of that area. However, it was the risk-based radiological analysis work presented by Dr. Len Connell (Sandia National Labs - retired) that offered a compelling direction for later collaborations. The releasable briefings from Workshop #2 were assembled in a Stanford working paper.[10]

[10] Serbin, E. and L. Brandt (ed.), "Summary and Briefings from the Stanford-China Workshop on Reducing Risks of Nuclear Terrorism," Stanford Center for Int'l Security and Cooperation, Sept 2016. (https://cisac.fsi.stanford.edu/publication/summary-and-briefings-stanford-china-workshop-reducing-risks-nuclear-terrorism)

Other Phase 1 Accomplishments

The collaborative and independent studies shared in Phase 1 addressed important countermeasures to radiological and nuclear terrorism. Systems and risk analysis provided a useful framework for sharing perspectives between technical analysts in China and the U.S. The research work also sought to develop criteria and identify a set of prospective future engagement options for China-U.S. cooperation. (These criteria and options are reviewed in in the final Phase 1 report.) The Phase 1 discussions also led to a revised technical focus and new engagement approaches for the subsequent Phase 2 efforts. The Phase 1 program is described in greater detail in a final report written as a deliverable to one of the sponsors, the U.S. Department of Defense Project on Advanced Systems and Concepts for Countering WMD.[11]

3.3 Phase 2 Collaborations: Scenario Planning and Tabletop Exercises addressing Radiological Terrorism

The technical emphasis and engagement approaches in Phase 2 shifted in response feedback from the Phase 1 engagements. The technical focus narrowed somewhat to emphasize the assessments of radiological threats and radiation detection architectures. Engagement approaches were also modified to draw a broader range of contributors into the workshops including younger professionals in the nuclear communities of both countries. As a result, the development of interactive workshop processes that addressed critical technical issues and simultaneously elicited participation from diverse participants became a central objective.

Workshop #3 (August 29-30, 2016)

The first Phase 2 workshop came close on the heels of the final Phase 1 workshop. The risk-based treatment of radiological threats provided by Dr. Len Connell in June 2016 highlighted the opportunity to develop a scenario-based exercise that would inform and engage a diverse set of workshop attendees on the nature of the radiological dispersal ("dirty bomb") threat. For Workshop #3, Dr. Connell expanded his background briefing and introduced a scenario-based exercise to motivate fresh thinking about radiological threats by all attendees. A larger cadre of young nuclear professionals for both countries participated in this workshop. Their assignment was to imagine how terrorist groups with a range of capabilities might acquire, deliver, and disperse radioactive material. The scenarios involved a hypothetical region and target city for which general characteristics (including the availability of radiological sources) was prescribed in the exercise ground rules.

A wide range of scenarios was created by subgroups of the participants. Subsequent discussions of the attributes of each subgroup's options created a very rich space of options for evaluation. The risk attributes of each scenario were evaluated as a concluding analysis activity. The objective of broad participation and engagement was certainly met in this workshop.

[11] Brandt, L., J. Reinhardt and S. Hecker, "Structuring Cooperative Risk Reduction Initiatives with China," Stanford Center for International Security and Cooperation, January 2017. (https://cisac.fsi.stanford.edu/publication/structuring-cooperative-nuclear-risk-reduction-initiatives-china)

Workshop #4 (December 6-7, 2017)

Workshop #4 was another scenario-based tabletop exercise that built on the results of the previous workshop. Broad engagement by a diverse group of young professional contributors was again a primary objective of this workshop. This workshop was developed in conjunction with the International Programs branch of the U.S. Domestic Nuclear Detection Office (DNDO) which provided briefings on its program and supported participation of U.S. national lab young professional contributors at the workshop.

In this workshop participants were asked to extend their consideration of several of the radiological dispersal attack scenarios developed in Workshop #3. They were first asked to fill in more of the operational details of the selected scenarios so specific opportunities for defensive responses to the attack might be considered. They were then offered alternative sets of radiation detection assets that might be applied to thwart the attack. Their challenge was to evaluate the performance of alternative detection architectures in detecting and interdicting the radioactive materials. For continuity, the same hypothetical region and target city were used in this evaluation exercise.

3.4 Phase 3 Collaborations: North Korea Nuclear Issues

During the last half of the 2010-2020 decade, the nuclear weapons and missile programs of North Korea overtook terrorism as the dominant nuclear concern in the United States. Stanford-CISAC had pursued research on North Korean nuclear activities for many years. One notable event in this effort was the 2010 visit to North Korea when Dr. Siegfried Hecker was shown a large uranium centrifuge facility at Yongbyon.[12] As interest in the U.S. increased, Dr. Hecker and other CISAC researchers pursued a variety of research initiatives on North Korean nuclear activities. One was a review of the history of the program and the ways in which it has responded to U.S. policies.[13] Another was an open source and commercial satellite imagery analysis effort to understand activities at the Yongbyon complex as well as broader economic and nuclear issues. By early 2018, these research activities were receiving wide media attention in the U.S.[14]

The Chinese technical experts who participated in the Stanford-China program are also concerned about the North Korean nuclear activities. The Stanford-China nuclear collaborations adapted to these events by focusing on North Korea issues in Phase 3 of the program. A rich set of results was available from Stanford, the U.S. national labs, and relevant Chinese organizations to support Phase 3 workshops and other collaborations. The engagements shared studies and perspective briefings by participating experts, including a number of early-career nuclear

[12] Hecker, S., A Return Trip to North Korea's Yongbyon Nuclear Complex, Nov. 20, 210. https://fsi9-prod.s3.us-west-1.amazonaws.com/s3fs-public/HeckerYongbyon.pdf
Sanger, D., "North Koreans Unveil New Plant for Nuclear Use," New York Times, Nov. 20, 2010. https://www.nytimes.com/2010/11/21/world/asia/21intel.html

[13] Hecker, S., R. Carlin and E. Serbin, "A Comprehensive History of North Korea's Nuclear Program: 2018 Update," Stanford Center for International Security and Cooperation, 2018. (https://cisac.fsi.stanford.edu/content/dprk-history-2018-update)

[14] See, for example: Lai, Broad, and Sanger "North Korea Is Firing Up a Reactor. That Could Upset Trump's Talks with Kim," New York Times, March 27, 2018. https://www.nytimes.com/interactive/2018/03/27/world/asia/north-korea-nuclear.html

professionals. In addition to the two workshops in Phase 3, other exchanges were held with Chinese nuclear agencies and experts.

Workshop #5 (September 25-26, 2018)

This initial workshop of Phase 3 collaborations drew together many senior experts on North Korea from both China and the U.S. The primary objective was to share national perspectives on the North Korean nuclear program and its potential futures. This included discussions on current political and economic forces as well as the prospect for future denuclearization and normalization. The U.S. contributions in this area were based primarily on the Stanford CISAC risk-based assessments and recommendations for a phased denuclearization.[15] Two technical topics were integrated into these higher-level discussions. The first was an assessment of the current status of North Korean missile and nuclear programs drawn from commercial satellite imagery analysis and other open sources. These assessments provided a shared basis for discussion of future scenarios. The second technical topic was an examination of the verification measures that would be needed to confirm North Korea's compliance with possible future denuclearization agreements. A variety of contributors examined precedents from prior arms control verification regimes as well as systems approaches to evaluate future verification options.

Workshop #6 (October 29-30, 2019)

This second workshop in Phase 3 collaborations updated and extended the topics first addressed in Workshop #5. Senior experts provided fresh views of the policy and diplomacy arenas. The status of North Korean missile and nuclear programs was also updated with a new set of open source and satellite imagery results. Several young professional contributors also summarized their recent work on verification challenges and technologies.

Other Exchanges (2018-2019)

As the research at Stanford became widely known among nuclear and North Korea experts in China, opportunities arose for collaborations in other venues. Presentations of the Stanford research at the China Institute for Nuclear Information and Economics (CINIE) followed both Workshop #5 and Workshop #6. The 16th PIIC Beijing Seminar held in October 2019 in Shenzhen was also an important opportunity to share studies on the North Korean program.

3.5 Other Collaborations: Civilian Nuclear Power Risks

Over a period of about five years, we engaged Chinese nuclear experts in exploring the future of global nuclear power. China was transitioning from a nascent nuclear power country to one that would greatly expand it domestically and be prepared to export internationally. Our focus was on how to do so while ensuring nuclear safety and security. Cooperative sessions were organized over the period of several years.

[15] This work continued after the Phase 3 exchanges described in this report. The last available internet update can be found at: https://cisac.fsi.stanford.edu/content/cisac-north-korea

4. Accomplishments and Future Opportunities

4.1 Summary of Accomplishments

The Stanford-China technical collaboration program achieved significant milestones during the 2014-20 period. Important accomplishments of the work include:

- Significant technical exchanges in key nuclear security areas were completed. These collaborations shared technical information and national perspectives on threats and responses to radiological terrorism, nuclear forensics, and the North Korean nuclear program.
- Fresh approaches to international analysis and collaborations have been introduced. These included the use of systems and risk analysis, open source data analysis, and scenario-based exercises.
- Bilateral relationships between the defense nuclear communities in China and the U.S. were strengthened. New professional relationships between early career nuclear experts in the two countries have also been built.

Metrics for evaluating the success of cooperative programs are difficult to apply. This is particularly true for programs seeking to grow professional relationships between technical communities. However, several responses from Chinese colleagues signal a very positive reception of the Stanford-China program. These include strong attendance and continuing support by the workshop participants, broad-based participation by Chinese nuclear organizations, and frequent endorsements supporting continued collaborations. Perhaps most significant, Chinese colleagues have developed new bureaucratic mechanisms that support continuation of the work even when political and bureaucratic policies seemed to block continued progress.

4.2 Looking to the Future

The ideas developed in this research and the renewed relationships among key members of the Chinese and U.S. nuclear communities provide a starting point for deeper technical cooperation on nuclear security matters between the two countries. The Stanford-China program has only scratched the surface of the possibilities for valuable cooperation. Continued efforts to link the two technical communities are essential in coordinating the technical preparations for future nuclear crises. Academic and non-governmental programs such as the one described in this report are particularly important during times of political tension with little governmental cooperation. However, it is also important to encourage efforts through the research agencies of the federal government, especially the national laboratories, to initiate and nurture professional relationships with their counterparts in China. Today's efforts toward this goal can dramatically reduce future global nuclear risks.

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Appendix:
Research Products and Briefings

The principal research products and conference presentations generated during the collaborations are listed below.

Written References

Serbin, E. and L. Brandt (ed.), "Summary and Briefings from the Stanford-China Workshop on Reducing Risks of Nuclear Terrorism," Stanford Center for International Security and Cooperation, September 2016. (https://cisac.fsi.stanford.edu/publication/summary-and-briefings-stanford-china-workshop-reducing-risks-nuclear-terrorism)

Brandt, L., J. Reinhardt and S. Hecker, "Structuring Cooperative Nuclear Risk Reduction Initiatives with China," Stanford Center for International Security and Cooperation, January 2017. (https://cisac.fsi.stanford.edu/publication/structuring-cooperative-nuclear-risk-reduction-initiatives-china)

Conference and Invited Presentations (in chronological order)

Hecker, S., "North Korea's Nuclear Program: A 10 Year Retrospective," 14th PIIC Beijing Seminar on International Security: Strategic Stability and Cooperation, Hangzhou, China, October 21, 2014.

Brandt, L. "China-U.S. Technical Cooperation on Nuclear Risk Reduction: Past Accomplishments and Future Opportunities," 14th PIIC Beijing Seminar on International Security: Strategic Stability and Cooperation, Hangzhou, China, October 20, 2014.

Reinhardt, J., "The Role of Systems and Risk Analysis in Nuclear Matters," 14th PIIC Beijing Seminar on International Security: Strategic Stability and Cooperation, Hangzhou, China, October 20, 2014.

Brandt, L., "Structuring Cooperative Nuclear Risk Reduction Initiatives with China," PASCC Workshop: Countering WMD amidst Global Tensions, Carnegie Endowment for International Peace, September 16, 2016.

Brandt, L., "New Initiatives in China-U.S. Technical Cooperation to Reduce the Risks of Nuclear Terrorism," 15th PIIC Beijing Seminar on International Security: Strategic Stability and Cooperation, Suzhou, China, November 2, 2016.

Reinhardt, J., "Risk Analytic Approaches to Collaborative Nuclear Security," 15th PIIC Beijing Seminar on International Security: Strategic Stability and Cooperation, Suzhou, China, November 2, 2016.

Reinhardt, J., "Modeling Adversaries: A Survey of Methods," 15th PIIC Beijing Seminar on International Security: Strategic Stability and Cooperation, Suzhou, China, November 3, 2016.

Reinhardt, J., "Improving Analytic Methods for Studying Strategic Stability," 16th PIIC Beijing Seminar on International Security: Strategic Stability and Cooperation, Shenzhen, China, October 16, 2019.

Hecker, S., "Denuclearization with normalization of North Korea," 16th PIIC Beijing Seminar on International Security: Strategic Stability and Cooperation, Shenzhen, China, October 17, 2019.

Serbin, E., "North Korea's Yongbyon Nuclear Facilities," 16th PIIC Beijing Seminar on International Security: Strategic Stability and Cooperation, Shenzhen, China, October 17, 2019.

Brandt, L., "The Changing Face of China-U.S. Technical Cooperation in Nuclear Security," 16th PIIC Beijing Seminar on International Security: Strategic Stability and Cooperation, Shenzhen, China, October 17, 2019.

In addition to this summary report and the Stanford references listed above, additional unpublished detailed technical data on a number of the workshops is available from the authors in the following draft report: Brandt, L. and S. Hecker, "Technical Cooperation on Nuclear Risk Reduction with China: Technical Data from 2014-2020 Engagements between Stanford CISAC and Collaborating China Agencies," December 2023.

North Korea Nuclear Program Research References

Extensive work by Dr. Siegfried Hecker and colleagues related to the North Korean nuclear program played a key role in the China nuclear security engagement. This research continued and was the basis for a book published by the Stanford University Press in 2023. Relevant references include:

Hecker, S., R. Carlin and E. Serbin, "A Comprehensive History of North Korea's Nuclear Program: 2018 Update," Stanford Center for International Security and Cooperation, 2018. (https://cisac.fsi.stanford.edu/content/dprk-history-2018-update)

Hecker, S., R. Carlin and E. Serbin, "North Korea's Denuclearization: Status and Prospects," Stanford Center for International Security and Cooperation, April 2019. (access at: https://cisac.fsi.stanford.edu/content/cisac-north-korea)

Hecker, S. with E. Serbin, *Hinge Points: An Inside Look at North Korea's Nuclear Program*, Stanford University Press, 2023.