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Structuring cooperative nuclear risk reduction initiatives with China

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Final Report

Structuring Cooperative Nuclear Risk Reduction Initiatives with China

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January 2017

Abstract

The Stanford Center for International Security and Cooperation engaged several Chinese nuclear organizations in cooperative research that focused on responses to radiological and nuclear terrorism. The objective was to identify joint research initiatives to reduce the global dangers of such threats and to pursue initial technical collaborations in several high priority areas. Initiatives were identified in three primary research areas: 1) detection and interdiction of smuggled nuclear materials; 2) nuclear forensics; and 3) radiological ("dirty bomb") threats and countermeasures. Initial work emphasized the application of systems and risk analysis tools, which proved effective in structuring the collaborations. The extensive engagements between national security nuclear experts in China and the U.S. during the research strengthened professional relationships between these important communities.

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), was also critical in supporting the work and offering compelling technical inputs. Special thanks are due Dr. Zhang Songbai of the Institute for Applied Physics and Computational Mathematics (IAPCM), who was in residence as a Visiting Scholar at Stanford for six months as a part of the Stanford research team. Several of the staff of the CAEP/CSS also made important contributions to the research.

In addition to the authors, principal U.S. contributors include Dr. Sue Clark and Dr. Nathalie Wall of Washington State University, who were essential to the nuclear forensics engagements. The staff at Lawrence Livermore National Laboratory, most notably Ross Williams and Kim Knight, supported the prototype systems framing study in nuclear forensics completed as a part of this research. The radiological threat and countermeasures systems analyses were provided by Dr. Leonard Connell (Pacific Northwest National Labs). All of these U.S. contributors played very important roles in the success of this project.

This research was 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 (awarded by the NAVSUP Fleet Logistics Center – San Diego). Related research at the Stanford Center for International Security and Cooperation supported by the MacArthur Foundation and the Carnegie Corporation of New York also provided important contributions.

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Executive Summary

The Nuclear Risk Reduction program at the Center for International Security and Cooperation (CISAC) at Stanford University seeks to reduce global nuclear dangers through international technical cooperation. The growing threats of nuclear terrorism and proliferation in Asia have made engagement with China a critical aspect of this work. Such engagement can support China's efforts to improve its nuclear security culture and to exercise more effective regional leadership in controlling and responding to radiological and nuclear threats. In addition, collaboration between China and the U.S. will build the technical protocols and relationships that can improve joint response to international nuclear terrorist events.

For several years Stanford CISAC researchers and nuclear experts in China have jointly pursued a project that addresses the threat of radiological and nuclear terrorism. A primary objective of this project was to identify cooperative technical initiatives of mutual interest that could contribute to more effective responses to terrorist actions. Three primary research areas were identified: 1) detection and interdiction of smuggled radiological or nuclear material; 2) nuclear forensics; and 3) radiological ("dirty bomb") threats and countermeasures. Initial collaborative analyses were performed in the first two areas. The tools of systems and risk analysis were emphasized in these initial analyses to test their effectiveness in framing and implementing the engagements. Project studies and related work from both China and the U.S. were shared in a final workshop held in Beijing in June 2016.

The project made substantial progress in several important areas. The technical dialogues and initial analyses identified a rich set of prospective initiatives for future cooperative research to build capabilities and to promote shared understanding and cooperative responses to terrorism. The systems analyses developed significant technical insights into several of the highest priority research issues. These jointly-performed analyses also proved the effectiveness of systems and risk analysis tools for sharing strategic perspectives, fundamental values, and solution options between collaborating researchers. The discussions with Chinese experts also uncovered a variety of new technical options for future work that were not apparent at the beginning of the project. Finally, the extensive series of workshops, meetings, and joint study efforts that took place during the research strengthened professional ties between key national security nuclear communities in China and the U.S.

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1. Introduction

1.1 International Initiatives to Prevent Radiological/Nuclear Terrorism

The threat of a terrorist radiological or nuclear (rad/nuc) attack has been a growing concern in recent years. Many analysts believe that the likelihood of some form of rad/nuc attack in the near future is high. Scenarios for such an attack range 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 material worldwide and the possession of nuclear weapons by potentially unstable regimes add to these concerns.

The radiological and nuclear terrorist threat is becoming increasingly global. Terrorist groups may seek radiological or nuclear materials in whatever country provides them the best opportunity to divert those materials for their use, with a subsequent transport to a fabrication or attack venue in a different country. An effective system to respond to these threats must also be global. Many multilateral organizations and initiatives have countering nuclear terrorism as a part of their mission. Among the most important is the International Atomic Energy Agency (IAEA). However, there are many others, such as the Global Initiative to Combat Nuclear Terrorism (GICNT) and the Nuclear Security Summits (NSS) that have been convened every two years since 2010. These efforts have largely focused on physical security and on material protection, control, and accountability (MPC&A) measures intended to prevent diversion of civilian fissile materials.

Bilateral engagements are also important in international efforts to prevent and respond to nuclear terrorism. Bilateral engagements offer the opportunity to tailor the exchanges to the needs, constraints, and risk reduction opportunities of the cooperating states. They are also uniquely suited to engagements that consider nuclear weapons or defense nuclear materials and facilities. These areas are often best addressed bilaterally due to the need for special attention to information sensitivity and nonproliferation treaty constraints.

Technical collaborations among countries can provide the expertise to craft national nuclear security systems and to coordinate international responses to terrorist actions. The multilateral coordination and training activities of the IAEA have been particularly useful in this regard. Historically, there have also been very important bilateral technical engagements that addressed emerging vulnerabilities. Perhaps the most notable of these were the Nunn-Lugar Cooperative Threat Reduction (CTR) program and the Department of Energy Lab-to-Lab program initiated at the end of the Cold War. Since they are important precedents for this research, these programs will be discussed in greater detail later in this report.

1.2 Bilateral Technical Collaborations with China

China is an important partner for bilateral technical engagement with the U.S. It plays key roles in nuclear security matters in East Asia. Its commitment to broader influence in the region is growing, as evidenced by the Nuclear Security Center of Excellence that was opened in Beijing in March 2016. Its growing 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.

1.3 Research Objectives

The overall objective of the research summarized in this report was to reinvigorate technical collaborations between defense nuclear experts in China and the U.S. with the shared goal of reducing the global dangers of radiological and nuclear terrorism. The project identified technical questions of mutual interest and pursued joint research in these areas. The primary engagements during the research involved nuclear experts with backgrounds in defense nuclear technologies and national security issues from both countries. A new approach to collaboration that emphasizes the methodologies of systems and risk analysis was a central focus of the project.

The research consisted of three overlapping elements. The first element focused on an initial technical review by the Stanford research team[1] that provided a starting point for subsequent interactions. The second involved extensive engagements with Chinese nuclear experts to identify topics of mutual interest, to review related current work in both countries, and to suggest future technical collaboration options. The third included the completion of several prototype systems analyses that provided initial technical insights to questions of mutual interest and demonstrated the utility of the systems and risk analysis methodologies emphasized in this project. The last two elements comprised the bulk of the research effort.

This report describes the engagement process and the primary research areas in Chapter 2. The historical precedents and current context of bilateral nuclear cooperation with China are reviewed in Chapter 3. Future collaboration options and summaries of the joint studies performed as a part of this project are described in Chapter 4. Finally, Chapter 5 includes a short summary of accomplishments, a listing of research products, and a discussion of the path forward.

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[1] The term “Stanford research team” used throughout this report includes the principal investigator, Siegfried Hecker, and the lead researchers, Larry Brandt and Jason Reinhardt. It also includes Dr. Zhang Songbai, who was in residence at Stanford as a Visiting Scholar from October 2015 through March 2016. Also, as noted in the acknowledgments, other U.S. technical experts made important contributions to the research.

2. Scope and Approach

2.1 Elements of the Research

The research completed in this project can be broadly divided into the following three elements:

1. **Initial Review and Framing Studies:** The first element involved an analysis of the precedents and current context for technical cooperation on rad/nuc terrorism risk reduction. This included an examination of the history of nuclear engagements with China, including the early Lab-to-Lab efforts. The successes and pitfalls of earlier programs informed both the current project and the criteria proposed for evaluation of future collaboration options. Another aspect of the first phase was a review of currently available U.S. sources and subject matter expert inputs to develop summaries of the key issues in rad/nuc terrorism response. This included development of an initial set of collaboration options. Together, these initial activities provided a technical starting point for engagements.
2. **Engagements with Chinese Collaborators:** The second element of the research involved extensive engagements with Chinese nuclear experts. The character and objectives of these engagements evolved as the research progressed (discussed in more detail below). In each stage of the engagements, the Stanford research team prepared and presented technical materials that responded to the ideas and concerns that emerged during earlier discussions.
3. **Prototype Studies:** The third element of the project included the completion of initial systems analyses in the highest priority research areas identified in the engagement process. These prototype studies sought to provide significant technical results. They were also structured to illustrate a spectrum of systems analysis applications, ranging from top-level framing studies through more quantitative modeling studies. In addition to the studies completed under the auspices of this project, related work of both Chinese and U.S. origin was shared in the final workshop.

2.3 The Engagement Process

The engagements with Chinese nuclear experts comprised a major fraction of the research effort in this project. These engagements involved an iterative series of meetings, workshops, and joint studies that occurred both in China and at Stanford over the course of over three years. The principal collaborators in China were from the China Academy of Engineering Physics (CAEP). The CAEP Center for Strategic Studies (CSS) was a key contributor. Other organizations, notably the Institute for Applied Physics and Computational Mathematics (IAPCM), were also significant participants. These groups play major roles in China's nuclear national security community. Their participation in direct collaborations with U.S. national security nuclear experts (including direct relationships with the U.S. national laboratories) has been very limited for over fifteen years. (This is discussed in more detail in the next chapter.) One important goal of this project was to contribute to the revitalization of these relationships.

The key events in the collaboration process are shown in the timeline in Figure 2.1. These were milestones in a multi-stage process by which the questions of mutual interest were defined, information was shared in the primary research areas, and prototype joint analyses were completed. The objectives and accomplishments for each stage of the process are outlined below. Note that these stages were sometimes overlapping, with early objectives reappearing for discussion as the research progressed.

* SCPKU = Stanford Center at Peking University
** IAPCM = Institute for Applied Physics and Computational Mathematics (Beijing)

Figure 2.1 Key Events in Engagement Timeline

Stage 1: Top-Level Scoping *(Key Meetings: April 15, 2013 at Stanford University, Palo Alto; November 15, 2013 at the China Institute for International Studies, Beijing)*

These initial discussions identified the top-level topics and proposed methodologies that would be addressed in the collaboration. The overall issue that emerged as the highest priority was the technical response to radiological and nuclear terrorism. The application of systems and risk analysis was proposed as the methodological focus for collaborations in the second of these meetings.

Stage 2: Technical Workshops *(Workshop #1: June 17-18, 2014; Workshop #2: October 24, 2014; Both at Stanford Center at Peking University (SCPKU), Beijing)*

The two-day workshop in June 2014 was particularly important in the review and discussion of technical response challenges associated with nuclear terrorism. U.S. and China briefings described technical approaches of each country. In addition, U.S. briefings on the application of systems and risk analysis to security problems provided a rationale and more specific examples to support a focus on these methodologies in the collaborative work. The workshop confirmed mutual interest in 1) detection and interdiction of smuggled nuclear materials, and 2) response to radiological threats. Interdiction scenarios of interest assumed unauthorized acquisition of foreign radiological or nuclear assets by terrorists, followed by international movement of these materials or devices. The topic of nuclear forensics also emerged as a primary interest of China experts. As a result, the second workshop in October 2014 included a more extensive discussion of the nuclear forensics options that might be pursued within the current collaborations. The overall result of these two workshops was the definition of the three primary research areas that would be the focus of the work for the remainder of the project. These are described in more detail in the next section.

Stage 3: Collaborations on Prototype Studies

The work on prototype systems analyses in the primary research areas occurred at Stanford in 2015 and early 2016. The most intense period of collaboration came with the appointment of Dr. Zhang Songbai, a scientist from China's Institute for Applied Physics and Computational Mathematics (IAPCM), as a Visiting Scholar at Stanford University. The goals of these prototype collaborative studies were:

- To model and assess technical issues of greatest mutual interest
- To define strategies and specific options for future technical cooperation
- To illustrate application of systems analysis tools, including those in the related disciplines of decision analysis, risk analysis, and scenario planning

Three analyses in two of the principal research areas were completed under the auspices of this project. They embodied a range of analysis objectives, from high-level framing studies to more detailed systems modeling and Bayesian analysis formulations. These studies are summarized later in this report.

Stage 4: Related Research and Concluding Workshop

In addition to the three prototype systems analyses introduced above, other related work was included in the final workshop. Perspectives on confidence building and capability development in nuclear forensics were offered by Dr. Sue Clark and Dr. Nathalie Wall (both from Washington State University). An overview of the third primary research area, radiological threats and countermeasures, was provided by a key U.S. expert, Dr. Leonard Connell (Pacific Northwest National Labs). As an outgrowth of Dr. Connell's session in the final June workshop, an additional, multiple sponsor, workshop was held on August 29-30, 2016 (also at SCPKU) to explore adversary capability models and dirty bomb attack scenarios. The releasable briefings from the final June PASCC-sponsored workshop have been assembled in a Stanford report.[2] Excerpts from that report summarizing key workshop briefings are included in Appendix 3.

2.3 Technical Scope and Primary Research Areas

Technical countermeasures to rad/nuc terrorism can be loosely divided into two categories: prevention and response. Prevention focuses on keeping radiological and nuclear materials (and other critical nuclear assets) out of the hands of terrorists or other unauthorized individuals. Response addresses those measures that can disrupt terrorist objectives after the rad/nuc material has been diverted or after an initial attack has been executed. Much previous international effort, including extensive programs at the IAEA as well as the work packages of the Nuclear Security Summits, have emphasized prevention. Hence, the work in this research was targeted at response countermeasures. A top-level architecture for the principal response countermeasures is shown in Figure 2.2. Significant U.S. domestic programs addressing each area have been in place for the last ten to fifteen years, and provide a starting point for defining international needs and responsibilities.

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[2] 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. (http://cisac.fsi.stanford.edu/publication/summary-and-briefings-stanford-china-workshop-reducing-risks-nuclear-terrorism)

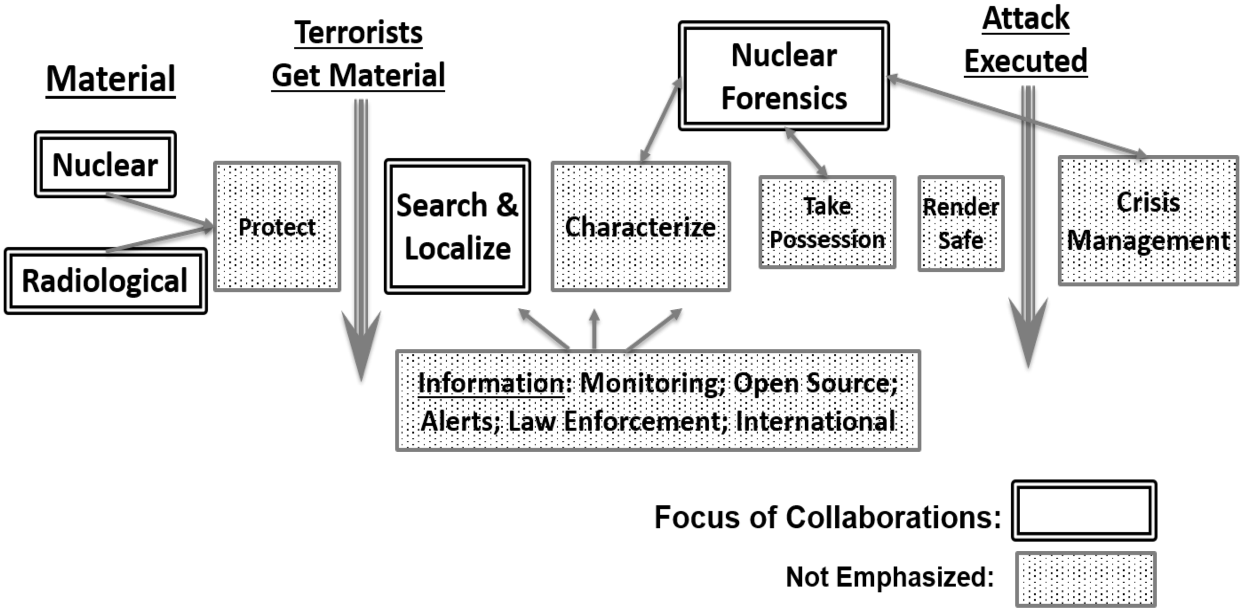

Figure 2.2 Top-level Rad/Nuc Terrorism Response Architecture.

Note that the radiological and nuclear countermeasures in each functional area may be quite different. Radiological sources generally emit much higher levels of penetrating radiation and are thus easier to detect and interdict. The forensics and post-attack recovery steps for dirty bomb attacks are also very different than those for improvised nuclear devices. Overall, this is a rich area for technical research and cooperation.

The early engagements resulted in the definition of the following three primary research areas for subsequent work.

- Research Area #1: Detection and Interdiction of Smuggled Nuclear Materials: When terrorists or other unauthorized individuals illicitly acquire radiological or nuclear materials, they will usually (though not always) choose to move the materials from the acquisition location. Transit to subsequent locations where device fabrication occurs, or to the attack venue, may involve extensive movements through international regions. These moves provide an opportunity for authorities to intercept the materials. The detection, characterization, and interdiction of nuclear and radiological materials that are outside of administrative controls has received growing attention in the U.S. over the last decade. But it is a complex and multi-faceted problem that can best be addressed internationally with shared information and planning.

- Research Area #2: Nuclear Forensics: An effective nuclear forensics capability has been widely recognized as a vital tool in deterring and responding to possible terrorist actions. Current U.S. and multilateral programs supporting improvement of international nuclear forensics capabilities provide a starting point for development of new bilateral efforts with China. Challenges facing China in its development of a robust and internationally recognized nuclear forensics capability were a major topic of discussion in this project.

- Research Area #3: Countermeasures to Radiological Threats: Many experts believe that the dispersal of radioactive material from radiological devices is one of the highest probability terrorist attacks. Irradiators and other devices utilizing intense sources are widely used in commercial applications worldwide. Extensive systems analysis studies to understand the range of possible terrorist radiological attacks and to recommend countermeasures and responses have been completed in the U.S.

2.4 Application of Systems and Risk Analysis Methodologies

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.

A proposal to employ systems and risk analysis methodologies was made to the Chinese collaborators early in the engagement process. There were several reasons for this. First, and most important, was China's growing technical skills in the basic science and engineering expertise that support development of nuclear security and response systems. China is approaching a peer status with the U.S. in many nuclear security technical areas. The joint execution of higher level systems analyses of shared security concerns moves the dialogue away from the details of technical design to the broader issues of threat perception, systems performance, and joint response protocols. Systems analysis is a tool that has long been used to discuss and evaluate defensive systems issues in the U.S. Its use as a communication and collaboration tool for international engagements, however, appears to be infrequent.[3]

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.

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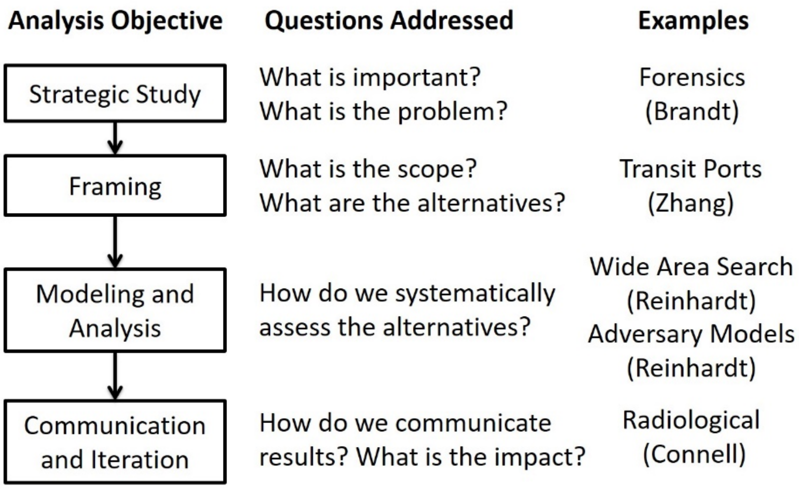
[3] While not broadly applied, the idea of joint analysis teams is not new. See, for example, Lewis Dunn, "Reshaping Strategic Relationships: Expanding the Arms Control Toolbox", *Arms Control Today*, May 2009, pp. 15-21, www.armscontrol.org.

Recognition of the potential importance of systems analysis methodologies, coupled with the analysis skills of the Stanford research team and the strategic analysis mission of CAEP/CSS, resulted in a decision to emphasize systems and risk analysis approaches in the project. As a result, the Stanford team prepared materials throughout the engagement process that discussed the rationale for and the application of systems analysis techniques to international security problems. Several of the workshop and conference briefings that describe the foundation of systems analysis and the methodologies employed are listed in Table 2.1

Date	Event	Presenter	Title
June 17, 2014	Stage 2 Workshop 1	J. Reinhardt	Role of Systems and Risk Analysis in Understanding Technical Needs
Oct. 20, 2014	14th PIIC Beijing Seminar	J. Reinhardt	The Role of Systems and Risk Analysis in Nuclear Matters
Oct. 24, 2014	Stage 2 Workshop 2	L. Brandt	Joint Research Options in Systems and Risk Analysis
"	"	J. Reinhardt	Examples of Nuclear Terrorism Systems Analysis Contributions
Aug. 29, 2016	Radiological Workshop	J. Reinhardt	Modeling the Adversary: A Key Technical Challenge
Nov. 3, 2016	15th PIIC Beijing Seminar	J. Reinhardt	Modeling Adversaries: A Survey of Methods

Table 2.1 Project Briefings on Systems Analysis Methodologies and Practice

The prototype systems analyses performed as a part of this project were designed to illustrate several categories of analysis objectives that are important in the national and international security context. These categories are introduced in Figure 2.3 and include references to the presenter who briefed the exemplary studies in each category at the final project workshop.



Analysis Objective	Questions Addressed	Examples
Strategic Study	What is important? What is the problem?	Forensics (Brandt)
Framing	What is the scope? What are the alternatives?	Transit Ports (Zhang)
Modeling and Analysis	How do we systematically assess the alternatives?	Wide Area Search (Reinhardt) Adversary Models (Reinhardt)
Communication and Iteration	How do we communicate results? What is the impact?	Radiological (Connell)

Figure 2.3 Alternative Systems Analysis Objectives and Final Workshop Examples

2.5 Other Collaboration Insights

In the course of the project engagements, several insights regarding the elements of future successful collaborations emerged. These were discussion points or ideas that seemed to recur frequently during the research and discussions. Three such recurrent ideas are summarized below.

1. Adversary Models and Analysis: Key roles of systems analysis groups in U.S. national security analysis organizations are to understand adversary capabilities and to evaluate how alternative adversary decisions will impact security systems. Modeling and evaluation of adversary capability and options is also a central concern of Chinese technical analysts. Various methodological approaches are available to generate insights in this area. Late in the project, a survey of applicable methodologies was completed and was presented at the follow-up August workshop and in somewhat abbreviated form at the 15th PIIC Beijing seminar.[4] Further work on the analytical basis for adversary assessments is a prospective topic for future collaborations.

2. Technical Exchanges Supporting Crisis Management: One area that needs more attention is the planning for cooperative technical exchanges to reduce tensions and guide actions during international nuclear terrorism events. One such event was played in a tabletop held in Beijing in November 2015 hosted by the Nuclear Threat Initiative.[5] In the discussions surrounding the events postulated by that tabletop, the cooperative forensics analysis of captured fissile materials was recognized as a key need. Other types of technical cooperation will no doubt be important in other terrorism scenarios. A priori planning against a jointly postulated set of international radiological and nuclear terror scenarios could be one starting point for developing technical protocols for such events.

3. Exercises and Tabletops: The use of exercises and tabletops to communicate insights and perspectives among technical experts was reaffirmed during the engagements in this project. While the use of these approaches in training and operational environments is commonplace, engagements on more complex technical architecture issues can also be enhanced by these highly interactive techniques, as opposed to a more traditional technical briefing approach. This was demonstrated in the follow-on radiological workshop held in August 2016 in Beijing.

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

[5] 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. Precedents and Context for Nuclear Cooperation

3.1 Lessons Learned from Post-Cold War Nuclear Cooperation

The end of the Cold War brought on a very active and successful period of bilateral cooperation with former adversaries to reduce nuclear risks. The dangers associated with widely dispersed nuclear weapons, large stockpiles of poorly secured fissile material, and underemployed nuclear weapons scientists motivated the U.S. to partner with Russia and the republics of the Former Soviet Union to address these issues. The Nunn-Lugar Cooperative Threat Reduction (CTR) program was the centerpiece of the U.S. nuclear efforts. Also, in the same time period, the U.S. nuclear laboratories began working with Russian nuclear scientists in the Lab-to-Lab programs. While much of the cooperative work involved rather straightforward consolidation of nuclear assets and improvements in facility security, there was a very significant advanced technology component in the programs. Much of the work dealt directly with the security of defense fissile materials and the safety and security of the weapons in the nuclear stockpile. This depth of interaction was only possible with the bilateral engagement of two nuclear weapons states.[6]

While the cooperative programs with Russia have evolved to reflect changes in both the nature of nuclear dangers and the political climate, the past successes of those programs are strong evidence of the value of direct engagements between nuclear experts in the U.S. and those of competitor nations. The benefits demonstrated in the Russia programs include:

- Successful mitigation of the immediate dangers
- Increased clarity and confidence in the safety and security of the nuclear weapon and fissile material stockpiles of both countries
- Improved relationships between nuclear experts of each country, allowing the evolution of ongoing partnerships to reduce risks

It is notable that some of the same benefits that accrued to post-Cold War cooperation with Russia were also experienced in the much more limited Lab-to-Lab efforts with China.

3.2 The China Lab-to-Lab Program (1995-99)

In 1995, the leaders of the U.S. and Chinese nuclear weapons laboratories established the Lab-to-Lab program to share technical information that could support the reduction in nuclear risks in both countries. The avoidance of nuclear dangers in China and the management of accidents or other nuclear crises globally were motivators for this engagement. The ongoing success of similar efforts in Russia was another supporting factor. 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

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[6] A very diverse set of technical programs was pursued. A comprehensive treatment of the Russia program is included in Siegfried Hecker, *Doomed to Cooperate*, Bathtub Row Press, 2016.

communities in China and the U.S.[7] The first substantive joint project was a demonstration of MPC&A concepts in a civilian nuclear facility in China.[8]

These engagements came to an end when the Cox Commission alleged that China was using the program as an intelligence tool against the U.S.[9] While the commission's accusations were disputed by independent nuclear experts[10] and never corroborated, the ultimate outcome was a decision by the Chinese defense nuclear community to withdraw from future direct engagements with the U.S. government and national laboratories. That isolation remains largely in effect today. In spite of the untimely demise of the program, longer term benefits have continued to accrue from the initial efforts. These include:

- Nuclear security programs with the Chinese civilian nuclear sector: Some of the efforts in the terminated Lab-to-Lab program shifted to relationships with the civilian nuclear sector in China. For example, the MPC&A work continued in this manner, culminating in the Joint China-U.S. Integrated Nuclear Materials Management Technology Demonstration in October 2005.[11]
- Continuing non-governmental nuclear engagements between China and the U.S.: The personal and professional relationships initiated during the Lab-to-Lab era generated a continuing set of engagements with U.S. non-governmental organizations and universities.[12] These relationships have been key to the success of the collaborative research program described in this report.

3.3 New Models for Cooperative Nuclear Engagement

Since the end of the Cold War, the context of international engagements has changed significantly. This has necessitated a rethinking of cooperative paradigms to devise approaches that meet current needs. Two principal drivers of this evolution deserve comment:

1. Changes in Bilateral Relationships: Changes in diplomatic, economic, and technical relationships between two countries will determine the nature of desirable bilateral cooperative engagements. When the initial engagements with Russia and China began in the 1990's, each had a very different relationship with the U.S. than today. In the case of China, their technological infrastructure and their nuclear security enterprise were

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[7] Nancy Prindle, "The U.S.-China Lab-to-Lab Technical Exchange Program", *The Nonproliferation Review*, Spring/Summer 1998, pp111-118.

[8] "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.

[9] "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.

[10] M.M. 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)

[11] The case for cooperative technical programs in MPC&A was made in Busch, N. "China's Fissile Material Protection, Control, and Accounting", *The Nonproliferation Review*, Fall/Winter 2002, pp. 89-106. 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

[12] Ongoing relationships with non-governmental organizations have allowed some cooperative work on defense nuclear issues to continue (e.g., the U.S. National Academies, which has led an ongoing technical engagement effort with China's defense nuclear community. http://sites.nationalacademies.org/PGA/cisac).

relatively less mature. As China advances to become a "near peer" to the U.S. in nuclear technologies, the bilateral cooperative engagements must shift from an educational and assistance focus toward an emphasis on peer-to-peer research and analysis, and on collaborative resolution of international nuclear accidents or security events.

2. Broader Threats and Participation: In the immediate post-Cold War years, the primary threats that drove cooperation were linked to the nuclear weapons, materials, and facilities in the former Soviet Union. However, global terrorist and proliferation threats have broadened, resulting in efforts to expand regional participation in cooperative threat reduction efforts and to institute new multilateral mechanisms to respond to these changes.

In light of these new contextual realities, the nature of the cooperative nuclear activities with Russia and China has undergone major changes. In addition, the U.S. cooperative threat reduction effort has expanded to address a range of weapons of mass destruction threats in other regions.[13] Much of the focus for cooperative technical assistance has shifted from bilateral relationships toward multilateral agencies (particularly to the IAEA for nuclear security) and tailored multilateral efforts (e.g., Nuclear Security Summits, Global Initiative to Counter Nuclear Terrorism, Proliferation Security Initiative).

Analysts concerned with the future of cooperative engagements have addressed new concepts for going forward. A new strategy for moving beyond the focused nuclear security tasks of the original cooperative threat reduction program towards a greater emphasis on a broader set of engagements, often emphasizing peer relationships, was proposed in a National Academies analysis of future directions for U.S. threat reduction programs.[14] The envisioned future concept was termed "CTR 2.0". Others have identified important features of an evolving cooperative engagement effort, including a move toward peer partnerships rather than U.S.-driven investment and education programs.[15] As these changes have been implemented, the important question of criteria to measure program success has become increasingly important. This question is addressed in the next section.

The research documented in this report seeks to contribute to these new perspectives on international technical engagements to reduce global nuclear risks. The focus on cooperative systems and risk analysis begins with the assumption that participants are equal partners in the framing and modeling of the security issues, and that the differing inputs from each partner to the analyses are recognized and preserved as a key aspect of the final study outputs. Further implementation of these analytical methodologies in peer-to-peer collaborations is an important next step in the practice of global engagement.

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[13] Some of these changes can be accomplished largely by internal U.S. programmatic decisions, others depend on the willingness of partner nations to participate. See, for example: Woolf, Amy, "The Evolution of CTR – Issues for Congress", Congressional Research Service, 2014.

[14] National Academy of Sciences, "Global Security Engagement: A New Model for Cooperative Threat Reduction", Committee on Strengthening and Expanding the Department of Defense Cooperative Threat Program, National Academies Press, 2009, www.nap.edu.

[15] See, for example: 1.) Kane, C., "From Donor to Partner: The Evolution of U.S. Cooperative Threat Reduction into Global Security Engagement, 2011, www.nti.org/analysis/articles/; 2.) Jenkins, B., "Adapting to the Times: Evolution of the U.S. Threat Reduction Programs", *Arms Control Today*, Jan/Feb 2011, www.armscontrol.org.

3.4 Evaluation Criteria and Performance Metrics

An explicit set of selection and evaluation criteria along with performance metrics that communicate the benefits of the work are essential tools for the development and management of a cooperative international program. Performance metrics for early CTR efforts were concrete and convincing. The "Nunn-Lugar Scorecard" included quantitative criteria (such as the number of missiles or delivery platforms destroyed) that had clear ties to reductions in nuclear dangers.[16] However, for many later CTR tasks, such easily quantified measures were not possible. Research addressing this problem has identified important principles and best practices, but is hampered by the broader and less tangible elements of the evolving CTR program.[17] One of the tasks of this research project was to propose a set of criteria for the evaluation of technical collaboration options. This was done by starting with a set of first principles and knowledge of the successes and pitfalls of earlier cooperative programs. A list of criteria was then proposed.

Two of the most important roles that evaluation criteria and performance metrics can play in a cooperative program are:

1. Guidance for design an effective and balanced program: Candidate options for cooperative projects offer different potential risks and benefits (both technical and political). Furthermore, a wide spectrum of cooperative opportunities exist. Various factors will need to be considered as the projects are defined. This might include national intent, assumptions about scenarios, information sharing constraints, and operational limitations. Clarity regarding these risks and benefits is important for the selection of an effective portfolio.
2. Compelling assessments of the project achievements: A clear description and evaluation of in-process and completed projects will need to be communicated to decision makers in both China and the U.S. to provide for continuing support of the programs.

The literature review and discussion with subject matter experts identified several specific concerns that should be considered in the evaluation of candidate cooperative projects. These concerns give rise to a very diverse set of criteria that are difficult to implement using quantitative measures. However, they remain important to resource allocation decisions. Some of the most important of these concerns include:

- Portfolio Balancing: A wide spectrum of cooperative activities can be pursued to reduce the risks of nuclear terrorism. Projects can be defined from the early stages of R&D and system development, through system deployment and operations. Each phase of this cooperative spectrum involves different kinds of risks and rewards, depending on the specific structure of the project. Consideration of options across this spectrum is vital in crafting a valued and robust cooperative program. Several categories of cooperative efforts are illustrated in Figure 3.1. For example, the research documented in this report has focused attention on the second category – architecture analysis, particularly using the tools of systems and risk analysis.

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[16] For historical scorecards, see http://www.dtra.mil/Missions/Partnering/Nunn-Lugar-CTR-Scorecards/

[17] National Academy of Sciences, "Improving Metrics for the Department of Defense Cooperative Threat Reduction Program", National Academies Press, 2012, www.nap.edu.

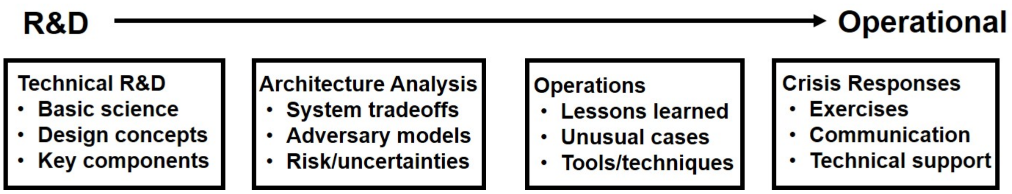

Figure 3.1 Categories of Technical Cooperation

- Assurance of Other Nations: Global expectations for safe and secure nuclear operations (both civilian and military) are increasing.[18] These expectations are particularly intense for nuclear weapon states due to the risks associated with nuclear stockpiles, defense fissile materials, and defense nuclear facilities. Cooperative programs that can assure other nations of responsible handling of civilian and defense nuclear assets and facilities are particularly valuable.

- Risks of Collaboration: It is important to recognize that collaborative activity also brings risks. Loss of sensitive national security information and the potential loss of intellectual property are also possible for collaborations close to the R&D end of the spectrum in Figure 3.1.

The application of systems analysis and modeling approaches offers a new approach to the establishment of joint metrics regarding system performance and the value of cooperative projects. Establishing a common model allows alternative outcomes to be clearly defined. Changes in technical system performance can then be traced to specific differences in threat perceptions or other input variables. This offers a more transparent approach to evaluating projects (including international collaborations) that promise capability improvements.[19]

A final listing of the proposed evaluation criteria list developed in this project is included in Appendix 1. This list was reviewed with Chinese collaborators as a part of the final workshop. However, no effort was made at that time to formally apply the criteria to formally rank either the work areas in the current project or the more complete list of future collaboration options included in Appendix 2.

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[18] Some examination of this issue has occurred in conjunction with the Nuclear Security Summit process. See, for example Global Dialogue on Nuclear Security Priorities, "Non-paper 2: Practical Proposals for Providing International Assurances", Nuclear Threat Initiative, 2012, www.nti.org. More research is needed in this area.

[19] These ideas are developed more fully in: National Research Council, "Performance Metrics for the Global Nuclear Detection Architecture", National Academies Press, 2013, www.nap.edu.

4. Summary of Engagements and Collaborative Research

4.1 Future Collaborative Options

One objective of this project was the development of promising options for future technical collaborations between China and U.S. nuclear experts. Initial ideas by the Stanford research team were included in the informational briefings that framed the discussions at the collaborative workshops. These informational briefings sought to characterize technical issues in systems for response to rad/nuc terrorism, and to introduce possible cooperative paths forward to address these issues. The synthesis of the initial ideas relied on two sources:

1. Subject Matter Experts: U.S. participants in the project included individuals with extensive R&D experience in the three primary research areas. Additional background came from discussions with U.S. national laboratories experts.
2. Technical Cooperation Literature: A significant literature exists proposing technical directions for more robust nuclear engagements with China.[20] A review of this literature was useful, although many of the projects proposed there addressed broader questions than the terrorism response questions addressed in this project.

The subsequent exchanges during the collaboration process expanded and focused these initial options. The final list included ideas that emerged from both China and U.S. experts during the analyses or discussions. A final version of this list is included in Appendix 2.

4.2 Area #1 Research – Detection and Interdiction of Smuggled Materials

The technologies and architectures associated with this research area were the predominant focus of the Stanford research team. Two classes of scenarios, one in which the smuggled material passes through a choke point (e.g., port of entry, transit terminal, secure area portal), and another in which the material is hidden or transiting within a much larger search area, were each addressed by separate systems analyses. The detection systems and operations used to interdict threats for these two classes of scenarios are very different. A variety of systems, risk, and decision analysis tools was used in the framing and modeling tasks in these studies. A more complete description of each study is included below. The briefing charts that summarized these analyses at the final workshop are included in the workshop summary report.[21]

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[20] Some of the more notable references in this literature include: 1) Pregenzer, A., "Technical Cooperation on Nuclear Security between the United States and China: Review of the Past and Opportunities for the Future", SAND2011-9267, Dec 2011; 2) Tobey, W., "Cooperative Actions by the United States and China to Meet Nuclear Security and Proliferation Challenges", in L.A. Dunn, "Building Toward a Stable and Cooperative Long-Term U.S.-China Strategic Relationship", Science Applications Incorporated, Dec 31, 2012; 3) Hui Zhang and Tuosheng Zhang, "Securing China's Nuclear Future", Belfer Center for Science and International Security, Harvard Kennedy School, March 2014.

[21] Elliot Serbin 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. (http://cisac.fsi.stanford.edu/publication/summary-and-briefings-stanford-china-workshop-reducing-risks-nuclear-terrorism).

Port and Transit Detection and Interdiction[22]

This study was led by Dr. Zhang Songbai of the China Institute for Applied Physics and Computational Mathematics during his tenure as a Visiting Scholar at Stanford. The goal of the work was to frame the port and transit detection problem using the tools of decision analysis, and to postulate strategies for both improvement of system performance and for collaborative initiatives that might significantly improve those capabilities. This study was the most collaborative of the analyses done as a part of this project, with Dr. Zhang consulting on a frequent basis with the other members of the Stanford research team. The study begins with a review of the challenges of counter-nuclear terrorism in general and the particular demands on port and transit facility detection systems. Importantly, Dr. Zhang then contrasts the strategies and systems used by the U.S. and China, and includes a qualitative performance assessment of each based on currently available research. He then takes initial steps in the framing and development of a quantitative assessment model. Figure 4.1 shows the decision diagram used to structure his initial probabilistic model of detection system performance.

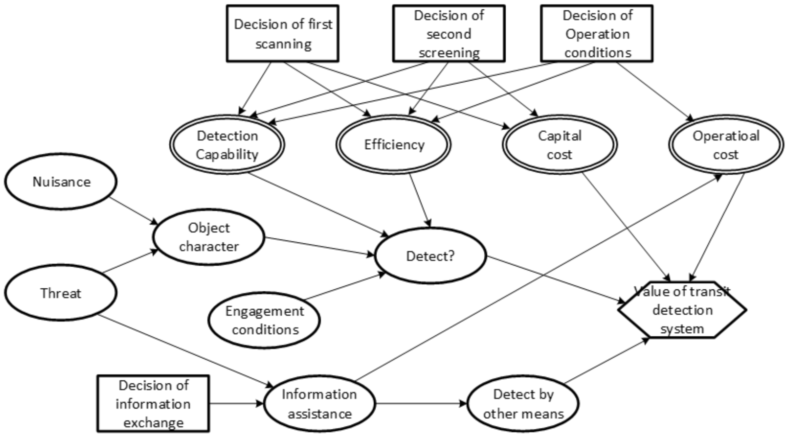

Figure 4.1 Top-level Decision Diagram for Port and Transit Node Study

The study concludes with the development of two strategy tables, one addressing alternative measures to improve detection system cost effectiveness, and a second examining candidate strategies for international collaboration to support these improvements. Briefing slides used to communicate these results in the final workshop are included in the workshop summary report.

Wide-Area Search[23]

Wide-area search for radiological or nuclear materials that are out of regulatory control has long been recognized as one of the most challenging problems for nuclear detection architectures. Jason Reinhardt undertook a study in this area both to review critical technical and architecture issues and to illustrate the power of decision analysis tools, including Bayesian network models

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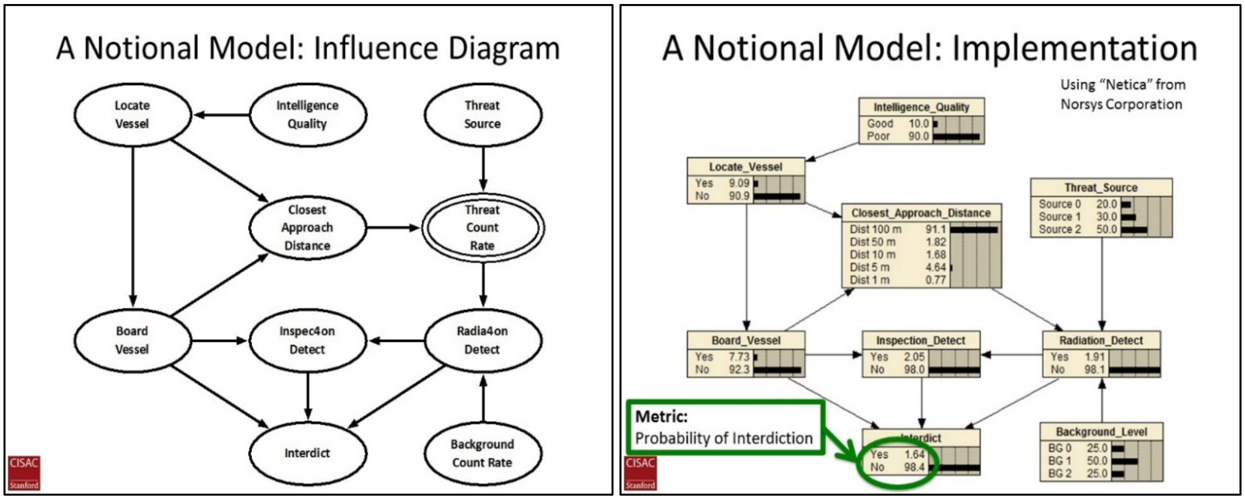
[22] Zhang Songbai, “Application of System and Decision Analysis for Port and Transit Radiation Detection”, presented at the Stanford-China Workshop on Reducing Risks of Nuclear Terrorism, Stanford Center at Peking University, June 6, 2016.

[23] Reinhardt, Jason, “Wide-Area Search: A Central Challenge in Countering Nuclear Terrorism”, presented at the Stanford-China Workshop on Reducing Risks of Nuclear Terrorism, Stanford Center at Peking University, June 6, 2016.

and performance sensitivity studies. A maritime search example provides the specific context for the analysis. The study begins with a tutorial on the basis for difficulties in maritime search followed by an introduction of various architectural options for detection systems. The first step in the analysis is definition of an influence diagram to define the probabilistic linkages for a first-order, notional model. This is then converted to a Bayesian network model using the modeling tool Netica (Norsys Corporation). Assignment of an initial, reasonable, conditional probability distribution to each node in the notional model provides a baseline for sensitivity studies. The influence diagram and the graphical output of the Bayesian system model are illustrated in Figure 4.2. The study then postulates various alternatives to improve system performance, including detector enhancements (e.g., detector background suppression, increased detector spectral resolution) or information quality enhancements (e.g., improved monitoring and localization of maritime vessels, information sharing to improve intelligence on maritime traffic). Assignment of revised probability distributions to the nodes that are directly affected by these enhancements permits the model to estimate system performance sensitivities. For the reasonable assigned distributions, results indicate that information quality upgrades are the most effective of the postulated enhancements in improving system performance. Briefing slides used to communicate these results in the final workshop are included in the workshop summary report.



A Notional Model: Influence Diagram

A Notional Model: Implementation

Using "Netica" from Norsys Corporation

Figure 4.2 Influence Diagram and Bayesian Model Outputs – Wide-Area Search Model

4.3 Area #2 Research – Nuclear Forensics

In its leadership roles as a global supplier of civilian nuclear technologies and as a principal contributor to regional nuclear security, China has recognized the importance of nuclear forensics capabilities. Participation in the multilateral programs of the IAEA and the International Technical Working Group (ITWG) is one mechanism that China is employing to build forensics capabilities. These programs are particularly useful in development of credible laboratory measurement protocols which are a foundation for forensic analysis. However, other activities that are essential to the creation of a robust nuclear forensics capability are largely absent from these multilateral efforts.

A critical feature of any national nuclear forensics program is the development of comparative signatures and their inclusion in accessible databases. Nuclear forensics analysis is an iterative process by which sample measurements are compared to known reference data to draw inferences about the source and prospective applications of the sample material. The development of a comprehensive set of signatures can involve sensitive data and reference samples which are not readily available through multilateral organizations. Hence, each nation must build its own signature database to address key prospective forensic analysis cases.

As a part of the collaborative engagements in this project, there was particular interest in the role that analysis and modeling might contribute to forensics capability development. In response to this question, an initial framing study that examined analytic elements of signature and database development was pursued.[24] The critical signature database needed to successfully identify unknown samples of nuclear materials can be developed in two ways. The most common is the collection of comparison samples from diverse sources. In forensics investigations involving high-risk fissile materials (e.g., plutonium and highly enriched uranium) only a few centers worldwide have assembled the requisite signature database to perform successful analyses. There is little precedent for sharing of sensitive reference samples and signatures internationally.

As China seeks to create comprehensive signature databases, particularly for high-risk materials, modeling and analysis experts could play a very significant role. At the top level, analysts can create a strategy for database development and analyze the types of signatures that might be most important in crisis situations. Models can also play a role in the development of signatures themselves through the analysis of production processes responsible for the creation of various high-risk materials in the civilian and military nuclear materials cycles. Finally, the analysis community can lead efforts to plan for international exchanges in situations in which the sharing of signatures or laboratory analysis results might be in the best interests of China and its international partners. These results provided the basis for several future collaboration options between analysts in China and the U.S. Briefing slides used to communicate these results in the final workshop are included in the workshop summary report.

4.4 Area #3 Research – Radiological Threats and Countermeasures

Collaborative interest in the technical aspects associated with radiological threats and countermeasures grew throughout the course of the project. No new analyses in this area were done under the auspices of this project. However, one of the U.S. leaders in the systems and risk analysis of radiological threat (Dr. Leonard Connell, Pacific Northwest National Labs) joined the Stanford research team to provide summaries of past U.S. work in this area at the final workshop.[25] Dr. Connell's past studies provided an excellent match with both the Chinese interest in radiological security and response issues and the focus on systems and risk analysis adopted for this project. Briefing slides used to communicate these results in the final workshop are included in the workshop summary report.

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[24] Brandt, L., "Development of Nuclear Forensics Capabilities: An Initial Systems Framing Study", Center for International Security and Cooperation, Stanford University, presented at the Stanford-China Workshop on Reducing Risks of Nuclear Terrorism, Stanford Center at Peking University, June 6, 2016.

[25] Connell, L., "Radiological Terrorism: Risk-Based Systems Studies", Pacific Northwest National Laboratories, PNLL-SA-118342, presented at the Stanford-China Workshop on Reducing Risks of Nuclear Terrorism, Stanford Center at Peking University, June 7, 2016.

5. Accomplishments and Conclusions

5.1 Summary of Accomplishments

This research has explored the application of new technical collaboration methodologies to several research areas with the goal of reducing the risks of radiological and nuclear terrorism. Important accomplishments of the work include:

- The application of jointly-performed systems and risk analysis provided a useful framework for sharing perspectives and security solutions between technical analysts in China and the U.S. The exemplary systems analyses pursued in this research have addressed strategic alternatives and preferences in a way that can allow each partner's technical community to have a clearer understanding of the other's fundamental values and perspectives.
- A set of future collaboration options in three primary research areas related to radiological and nuclear terrorism have been identified. The prototype systems analyses developed significant technical insights and have also addressed future pathways for cooperative research.
- The engagements with Chinese collaborators have revealed several promising new directions for future technical collaborations. These include exchanges on adversary modeling methodologies, a priori planning for technical exchanges as a part of the incident management of terrorist nuclear crises, and greater use of exercise and tabletop approaches to improve technical interactions.
- Progress in re-establishing bilateral relationships between the defense nuclear communities in China and the U.S. has been made. These relationships have atrophied in the aftermath of the Cox commission report. This research has opened new pathways for the nurturing of these important professional ties.

In addition to this report and the many briefings developed for project meetings and workshops by both U.S. and China researchers, the following research products have been completed:

Final Workshop Report

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. (http://cisac.fsi.stanford.edu/publication/summary-and-briefings-stanford-china-workshop-reducing-risks-nuclear-terrorism)

Conference Presentations

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.

5.2 Next Steps

The ideas developed in this research and the renewed relationships among key members of the Chinese and U.S. nuclear communities provides a starting point for deeper technical cooperation on nuclear terrorism response between the two countries. We will endeavor to expand the participation by the U.S. national laboratories in this research to support a more substantial analysis and technical project portfolio in the future. A partnership between the U.S. national laboratories and selected U.S. non-governmental organizations and universities could be a very effective mechanism for moving forward on the ideas proposed in this research.

Appendix 1 – Prospective Evaluation Criteria

The following criteria summarize the research and deliberations of the Stanford research team regarding evaluation of cooperative technical projects.

Proposed Criteria

Maximize Joint Positive Impacts: This criterion assesses how well the proposed work is expected to improve technical systems in a manner that reduces nuclear risks for both the U.S. and China. This can occur when the joint projects address significant needs and interests of both partners. High evaluations on this criterion might occur where:

- The project improves shared understanding of goals, constraints, and threat priorities.
- The project addresses key technical problems in countering threats of mutual concern.
- Synergies based on the unique capabilities of research groups in China and the U.S. can result in productive teaming.
- Sharable data, analyses, design concepts, or prototypes may exist in one country that could reduce R&D costs and risks for the other.

Minimize Risks of Cooperation: This criterion assesses the possible negative outcomes that might result from technical engagements. The technical cooperation process itself may be subject to unexpected, disruptive, and perhaps inaccurate outside criticisms. Options that insure that these risks are small and controllable would rank highest in this criterion. Possible considerations include:

- Perceived loss of sensitive or proprietary data or intellectual property
- Political criticism of the value or intent of the program
- Ability of the program to continue through periods of political tension

Prepare for Future Crises: This criterion assesses the ability to build relationships, plans and technical tools that could help China and the U.S. in their cooperative response to future international terrorist events. Successful preparations for such scenarios, and putting into place effective information transfer and joint technical responses, might control the progression of such events and reduce possible negative outcomes.

Promote Positive External Impacts: This criterion assesses ways in which the cooperative work might influence other countries and non-state individuals or groups. These might include:

- Some threats might be deterred if substantial information sharing and cooperation on defensive systems were apparent.
- Other regional states with either civil nuclear energy or defense nuclear assets might be influenced to recognize the threat and increase their efforts in prevention and response.
- Other global states might be reassured that two of the key nuclear powers are working together to implement advanced technical systems to reduce risks of nuclear terrorism.

Appendix 2 – Final Collaborative Options List

Introduction

This list summarizes the final set of research ideas for future technical collaborations in the primary research areas designated in this project. This list is the result of several iterations and incorporates inputs from Chinese collaborators offered during the project workshops and collaborative research. Initial examination of several of the topics listed here were a part of the collaborative analyses completed in this research project. No attempt was made to prioritize which of these areas are most promising for future research collaborations. That selection will depend on the composition and interests of future collaborative research teams.

Nuclear Smuggling - Detection and Interdiction Options

1. ***Detection Architecture Evaluation***: The framework and criteria used to evaluate a detection architecture is a key determinant of system requirements and design. A shared understanding and adoption of common approaches between China and the U.S. would improve cooperative responses to terrorist actions. Some useful collaborative analysis activities include:
    - Review alternative tools, approaches, and frameworks for architecture evaluation
    - Conduct a joint scenario-based exercise to identify the similarities and differences between China and U.S. perspectives on architecture performance assessment
    - Identify analytical insights and propose best practices for evaluation methodologies and criteria that can be promulgated more widely in outreach activities

2. ***Situation Assessment and Adaptive Detection Architectures***: Effectiveness of detection systems could be enhanced by the integration of disparate external information. Effective detection architectures will need to respond to these important but likely incomplete clues. Activities in a cooperative examination of this area might include:
    - Identify the most likely types of information that might be available to improve detection architecture performance and guide interdiction activities
    - Postulate flexible, deployable, detection architectures that could respond to external information on the status of compromised nuclear materials and assets
    - Consider the design and evaluation of data fusion systems to support the operation of these architectures
    - Generate ideas on ways in which China and the U.S. could cooperate to improve broader situational awareness including increased information sharing, specialized search and screening systems, and increases in international border security

3. ***Active Detection Systems***: Illumination of suspicious articles by nuclear particles, particularly neutrons, might provide a very useful approach to detection of low signature, shielded fissile materials. Useful cooperative topics might include:
    - Identify potential application scenarios and risk/benefit tradeoffs from both the Chinese and U.S. perspectives
    - Jointly conduct tests of prototype systems in both China and the U.S.

4. ***Measurement and Modeling of Backgrounds***: One factor that limits the effectiveness of area search operations using technical detection systems is background radiation. A baseline of backgrounds in urban areas might be useful in later search operations in the same areas. However, variability due to weather, transient sources (e.g., medical patients), and other factors make use of baselines difficult. Possible research areas include:
    - Review past efforts and equipment used in collection of urban backgrounds
    - Review and improve algorithms for reducing noise in background measurements to improve search for radioactive sources
    - Assess limits of noise reduction and change detection methodologies

5. ***Management of Nuisance Alarms***: Radiation detector alarms caused by naturally-occurring radioactive materials complicate the operation of a radiation detection-based interdiction architecture. Projects that share insights regarding the management of these so-called nuisance alarms could increase the likelihood that real threats can be detected. This could increase the deterrent effect of detection architectures. Some specific activities might include:
    - Evaluate possible joint acquisition and sharing of nuisance alarm data
    - Share technical and operational experience in addressing nuisance alarms
    - Seek to extend currently available options
    - Analyze the effects of radioactive masking sources in terrorist scenarios

6. ***Special Event Protection***: An early cooperative effort between the China and the U.S. focused on the protection of the 2008 Olympics in Beijing from radiological and nuclear threats. Cooperative work to build on these initial efforts might be useful. Topics could include:
    - Review approaches to pre-event screening of special event venues
    - Identify prospective improvements in portal screening detection systems
    - Evaluate advanced systems (e.g., multiple phenomenology fusion, active illumination, radiography) to examine suspicious objects or vehicles encountered during the event

Nuclear Forensics Options

1. ***Guidance for Nuclear Forensics Signature and Database Development***: Development of nuclear forensics signatures and databases that contain signature data are essential to a national nuclear forensics program. Modeling and analysis experts can play a large role in understanding the role of predictive signatures, definition of database structures, and statistical analysis tools. Possible collaboration topics in this area could include:
    - Develop and prioritize scenarios of greatest forensics importance. Establish an approach to understanding the requirements (e.g., timelines, confidence levels, international participation) for forensics evaluations in the highest priority scenarios
    - Evaluate the role of predictive versus comparative signatures. Recommend modeling strategies for areas in which predictive signatures are most applicable
    - Engage national and international stakeholders to develop strategies to collect inputs for the forensics database in the most important areas

2. ***Technical Engagements to Prepare for International Cooperation during Nuclear Crises***: Databases and communication protocols that could support joint forensics activities in the event of international crises could offer major benefits to both China and the U.S. Analysis and contingency planning is essential in preparing for timely and technically useful engagements in crisis situations. Cooperative studies in this area could include:
   - Develop forensics scenarios in which international cooperation is very important. Consider alternatives for information sharing that could improve the likelihood of an effective international response
   - Identify specific technical capabilities or contingency plans that could make crisis cooperation in nuclear forensics easier
   - Develop exercises and tabletops that can illustrate the benefits of data sharing and other cooperative technical activities

Radiological Threat and Countermeasures Options

1. ***Development of a General Adversary Framework for Assessing Relative Risk of RDD Scenarios***: An essential element for risk-based systems analysis of radiological terrorism is the rank ordering of threat scenarios based on relative risk. This requires the building of an adversary capability framework – one that stratifies the key attributes which define adversary capability into 3 or 4 Adversary Capability Levels (ACLs). Scenarios are then assessed for likelihood by using subject matter experts to map scenarios to the ACLs. It would be useful to collaborate on a general ACL framework for assessing various radiological source acquisition scenarios. Possible collaboration topics in this area would include:
   - U.S. and Chinese collaborators independently develop a notional list of possible scenarios for the malevolent acquisition of radiological materials. The scenarios should include the following specifics: (a) what radionuclide (and device type) is selected for acquisition? (b) What is the source activity and IAEA Category? (c) From what region of the world is the source acquired? (d) What mode of illicit acquisition is selected (covert with insider, overt attack/sabotage, theft of portable vs. facility theft, etc.)?
   - Using the overall initial list of scenarios, collaborators identify the important attributes and capabilities needed to execute these illicit acquisition scenarios? From this, develop a 3-tiered Adversary Capability Level structure for the acquisition of radiological sources.
   - U.S. and Chinese analysts independently assess adversary capabilities required for each of their scenarios. Compare and contrast U.S./Chinese assessments.

2. ***Development of Specific RDD Response/Cleanup Plans for Area Denial RDDs***: Some RDDs could pose significant area denial consequences and the current response plans lack the specificity needed for these contingencies. Cooperative studies in this area could include:
   - Reviewing past accidents involving powdered sources to develop specific response recommendations for both the emergency, intermediate and late phases of response
   - Compare and contrast emergency response plans currently in place for the U.S. and China. Identify differences in needs due to societal and bureaucratic constraints.
   - R&D on new cleanup technologies for area denial RDDs

3. ***Response Plans for High Risk Portable Sources***: High activity portable radiation sources pose special risks due to their portability and frequent transport. Developing collaborative efforts to better protect these sources and to conduct rapid search and recover operations when lost or stolen would help reduce RDD risk. Possible areas of collaboration include:
   - Review of national and international regulations applicable to portable sources
   - Studies on the feasibility of tagging and tracking portable sources
   - Studies on best practices for securing portable sources during transport and use

4. ***Alternative Technology Options for High Risk Radiation Sources***: The 2008 U.S. National Academy Study on Radiation Source Use and Replacement recommended the phase out of high activity CsCl sources. The committee recommended replacement of CsCl with X-ray machines or with less dispersible forms of Cs-137. Implementation of these recommendations in the U.S. has been slow. Cooperative studies on replacing high risk radiation sources with alternative technologies could be useful. Possible areas of collaboration include:
   - Modeling, experiment and testing on radiation sources designed to be highly resistant to explosive dispersal
   - Comparison of the relative attractiveness of alternative sources to China and the U.S. Identify commercial, regulatory, and societal factors that might make the preferred risk reduction strategies different.

Appendix 3 – Summary of Final Workshop Briefings

This appendix includes brief summaries of briefings presented at the final project workshop. One session of the final workshop was devoted to each of the primary research areas explored during the project. Several briefings were not made available for release, and are hence not referenced here. The presentation slides for the released briefings are included in the summary report.[26]

Session 1: Interdiction of Smuggled Radiological and Nuclear Materials

Briefing 1: "Application of System and Decision Analysis for Port and Transit Radiation Detection", ZHANG Songbai (Institute for Applied Physics and Computational Mathematics)

> This study applies the tools of decision and risk analysis to frame key issues surrounding the use of technical systems, particularly those that use radiation detectors, in the discovery of illicit nuclear or radiological materials passing through ports or other transit facilities. The work first characterizes the challenges facing these detection architectures. It then outlines China and U.S. deployments and provides a qualitative assessment of their effectiveness based on reference to existing studies. The analytic focus of the work is the framing of detection system elements and uncertainties using a decision diagram format, followed by use of Bayesian network tools to begin further analysis. Possible strategies for technical collaborations are also developed.

Briefing 2: "Wide-Area Search: A Central Challenge in Countering Nuclear Terrorism", Jason Reinhardt (Stanford University and Sandia National Laboratories)

> This work addresses the particularly difficult problem of the search for nuclear materials when their location is not well known within a large area. It begins with a taxonomy of search scenarios followed by a discussion of the physics and operational challenges associated with the mission. The many variants of wide-area detection architectures are summarized. A maritime search example then provides a more specific context for the analysis. A decision diagram characterization and a notional Bayesian network model were developed for this exemplary case. Reasonable probability assessments were made to illustrate the relative quantitative value of several types of detection system enhancements. These included increased detector performance, more effective vehicle inspection operations, and improvements in vessel locating capability through surveillance and information sharing. The importance of vessel location knowledge was highlighted by these results.

Briefing 3: "Two Possible Algorithms for Radioactive Source Locating by Radiation Detection", ZHU Jianyu (China Academy of Engineering Physics – Center for Strategic Studies)

> This briefing reviews development of two algorithms for localization of a radioactive source within a fixed area – one algorithm for passive detection and the other for active detection. The performance of the algorithms is assessed by simulation against a variety of sources. Quantitative measures of location uncertainties provide estimates of the relative performance of the two algorithms under various conditions. Sensitivities of algorithm performance to background levels and to source strength and shielding are also assessed.

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[26] 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. (http://cisac.fsi.stanford.edu/publication/summary-and-briefings-stanford-china-workshop-reducing-risks-nuclear-terrorism).

Session 2: Nuclear Forensics

Briefing 1: "Tabletop Exercise Nuclear Incident Scenario – Technical Insight", ZHANG Jiaqi (China Institute of Nuclear Information and Economics)

> This briefing summarizes a recent tabletop exercise attended by several Chinese government organizations that analyzed a scenario involving the capture of illicit highly enriched uranium (HEU). The scenario hypothesized the discovery of HEU by the U.S. in the crash of an aircraft from Central Asia that had last landed in China. The scenario also involved a later discovery of HEU by China on a similar transport aircraft forced to make an emergency landing in Southern China. This tabletop explored China's emergency response and technical forensics options. The role of international cooperation and responses to U.S. queries were also topics of discussion in the tabletop.

Briefing 2: "Confidence Building Activities to Support a Robust Nuclear Forensics Capability", Sue Clark (Washington State University)

> This briefing describes several essential elements in the development of a robust nuclear forensics capability. It begins by introducing the overall response to a nuclear event as outlined in the model action plan. Technical forensics are a key part of this plan. Confidence in forensics measurements depend on both good laboratory practices and good management practices. The use of IAEA reference samples in the validation of processes for Pu isotopic analysis was cited as one example of the discipline required in the development of high confidence processes. Tradeoffs among accuracy, precision, and speed depend on the nature of the nuclear event and are a critical consideration in the design of measurement processes. International exchanges can provide very useful support to the development of technical nuclear forensics expertise.

Briefing 3: "Human Capital Development for Nuclear Forensics", Nathalie Wall (Washington State University)

> This briefing begins by examining in greater detail the role of technical nuclear forensics capabilities in all aspects of the model action plan for nuclear events. The U.S. programs designed to develop and maintain the human capital needed to realize these capabilities are then reviewed. The undergraduate Nuclear Forensics Summer School at Washington State University is one example of an efficient approach to the development of technical nuclear forensics expertise.

Briefing 4: "Numerical Simulation Work on Nuclear Spent Fuel for Nuclear Forensics", SU Jiahang (Center for Strategic Studies, China Academy of Engineering Physics)

> This briefing describes initial studies that utilize models of reactor fuel isotopics to develop signatures that can be used in the forensics analysis of spent fuels. Initial modeling focused on a 5MWe air-cooled reactor and included isotopic sensitivities to burn-up range and cooling time. Subsequent work applied factor analysis to the characterization of known spent fuel samples to confirm the ability of the methodology to determine reactor type, fuel composition, and burn-up. Application of factor analysis techniques increases the discrimination of sample analyses over what would be possible using just one or two characteristic isotopes.

Briefing 5: "Development of Nuclear Forensics Capabilities – A Systems Framing Study", Larry Brandt (Stanford University)

This briefing summarized an initial systems framing study that identified ways in which modeling and analysis might support development of more effective nuclear forensics capabilities. The work highlights the importance of signature development and its database and analytic components. Differences between predictive signatures that utilize process knowledge and models as opposed to comparative signatures that require reference samples was reviewed. (The use of models as a basis for signature development is illustrated in Briefing 4 of this workshop session.) Modeling and analysis can fill in the gaps in national forensics databases that cannot be covered by sample collection or international data. The structure and processes for international information sharing following a nuclear event is another area in which analytical efforts would be useful.

Session 3: Countermeasures to Radiological ("Dirty Bomb") Threats

Briefing 1: "Review of Nanjing Source Recovery Incident", ZHANG Zhigang (Nuclear Radiation Safety Center)

A diverted Iridium-192 source was successfully recovered by Chinese authorities in 2014. This event demonstrated the capabilities of China's radiological and nuclear emergency response capabilities. (An English version of this briefing was not available for inclusion in the workshop summary.)

Briefing 2: "Radiological Terrorism Risk-Based Systems Studies", Leonard Connell (Pacific Northwest National Laboratory)

This briefing summarized a broad range of technical information regarding the risk analysis of radiological sources and their use in radiological dispersal devices (RDDs). The foundations of risk analysis as applied to radiological attacks are reviewed. The characteristics of radiological sources and attributes that make some more dangerous than others are then outlined. Results from the 2008 National Academies study that highlighted the unique risks of cesium chloride (CsCl) sources are then summarized. Subsequent studies to further understand radiological source risks and the more specific physical and economic consequences of a radiological dispersal attack are referenced. Significant programs have been instituted in the U.S. to reduce the vulnerability of deployed CsCl irradiators.

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