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Controlling Threats To Nuclear Security

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CONTROLLING THREATS TO NUCLEAR SECURITY:
A Holistic Model

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James L. Ford and
C. Richard Schuller

A Study by the Center for Counterproliferation Research

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FOREWORD

The collapse of the Soviet Union, although providing a host of welcome opportunities for people of that nation, also exacerbated a number of transnational concerns just as serious as those that emanated from the bipolar hostility of the previous 50 years. Among these challenges is the marked increase in the theft of and illegal trafficking in nuclear materials, often referred to as nuclear smuggling.

Prior to the early 1990s, nuclear smuggling generally involved small quantities of bogus materials or, at most, nuclear-associated materials that posed no serious danger to security. Recently, however, several disturbing incidents involving kilogram quantities of sensitive nuclear materials suitable for constructing bombs have occurred. No one doubts that hostile groups could conceivably bring weapons-usable nuclear material into the United States. Moreover, nuclear smuggling represents a possible shortcut for states such as Iran seeking plutonium or highly enriched uranium for their weapons program. The consequences of such states succeeding would be profound.

The U.S. Government takes the threat of nuclear smuggling seriously. Congress has provided funds and the Executive Branch has devised numerous successful programs targeted to reduce this danger at its source—but much remains to be done. This book will contribute to filling that gap by providing a new tool, the nuclear smuggling pathway model, for addressing the nuclear smuggling phenomenon in a holistic way. This model is based on a general systems model and designed specifically as an analytical tool to assist national security personnel at all levels to understand, analyze, and prevent instances of illicit trafficking in nuclear materials. By offering a comprehensive approach usable by many different national and international agencies, the model may help counter a growing national security threat.

ERVIN J. ROKKE
Lieutenant General, U.S. Air Force
President, National Defense University

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Although the idea for the paper was the authors, they would not have pursued it without the encouragement from a number of colleagues in the national security community, representing the many agencies concerned about the illegal transfer of nuclear materials worldwide: the Department of Energy and its national laboratories; the Department of Defense, to include the Defense Nuclear Agency and the Defense Technical Security Administration; the Central Intelligence Agency, particularly the Non-Proliferation Center; the Federal Bureau of Investigation; the United States Customs Service; and the National Security Council's Nonproliferation and Export Control Office.

The authors also wish to acknowledge the strong support and encouragement from John Sopko, former Deputy Chief Counsel to the Minority (and to Senator Sam Nunn, Ranking Minority Member), Permanent Subcommittee on Investigations, Committee on Governmental Affairs, U.S. Senate.

A number of academic and other nongovernmental institutions were very supportive of this work. William Potter, Director of the

information sharing. In managing or analyzing a nuclear event, information may be incoming from various agencies, individuals or other sources. Unless the information can be meaningfully structured and organized, its usefulness is reduced.

- Knowledge of parts of a system can help determine the rest of the system. With a knowledge of some of the components of a theft or smuggling event and their interrelationships, critical information (such as a unique, traceable signature) may become evident and can direct the identification of the rest of the components.

Using a general systems model as a framework and the premise that nuclear theft is a category of complex (that is, sophisticated, akin to "white collar" embezzlement) crime, we analyze the inputs, processes, outputs and context of the theft of nuclear materials to develop a systems model of nuclear theft. We apply systems techniques, such as system decomposition (a top-down breakout of system components into ever increasing detail), to support any level of analysis—broad, national or international policy level of analysis or highly detailed, site-specific level of analysis. Characteristics of nuclear theft, including the properties of nuclear materials, nuclear facilities, and the weapons development cycle, contribute distinctive elements and detail to formulating the NSPM. Finally, we illustrate the model's utility by analyzing two different types of theft scenarios.

We conclude that the strengths of the NSPM are:

- Usefulness in structuring and organizing large amounts of disparate information at any level of detail
- Broad application to evaluate both supply and demand side theft scenarios
- Understandable format that facilitates the integration of information from multiple sources
- Ability to simplify and handle complex situations
- Scalability for use at a national or international level (for setting policy) or at a site level (for pre- and post-incident analyses).

Its potential applications are extensive:

- Postincident investigations
- Risk assessment
- Development of countermeasures, and integration of multisource information
- Event or emergency management

- Training of staff in risk assessment, postincident investigations, and event mitigation.
- Resource allocation planning at national and site levels.

In February 1997, we conducted a workshop to test and evaluate the nuclear smuggling pathway model, with the objective of sharpening its applicability and ease of use. A report of this effort is included as appendix E. Our goal is to bring the model into mainstream use by the analytical and policy agencies of the national security community in order to provide the first comprehensive or holistic approach to nuclear materials theft.

CONTROLLING THREATS TO NUCLEAR SECURITY:

A Holistic Model

1.

NUCLEAR SECURITY THREAT

The Problem

Trafficking in illicit nuclear materials is not a new threat to the security of nations, but the scope of the threat and its potential for affecting international security and relationships have expanded. Whereas early trafficking attempts frequently were scams that involved small amounts of nuclear-associated materials, the dissolution of the former Soviet Union (FSU) made larger quantities of weapons-usable materials susceptible to theft or diversion while the security of at-risk facilities was diminished. Special nuclear material facilities and activities in the FSU no longer receive the same level of protection, control, and monitoring from the KGB, the Red Army or other control organs. Absent is an accurate and complete inventory of FSU special nuclear materials.[1]

In a Senate Hearing in August 1995, Senator Sam Nunn described the nuclear threat emerging from the fall of the Soviet Union as

> creat[ing] scenarios that, even if anticipated, are unfathomable in their scope. Never before in history has an empire disintegrated while in possession of some 30,000 nuclear weapons, at least 40,000 tons of chemical weapons, significant biological weaponry capability, and thousands of weapons scientists and technicians unsure how long they will receive salaries with which to feed their families. Let loose was a vast potential supermarket for nuclear weapons, weapons-grade uranium and plutonium, and equally deadly chemical and biological weapons.[2]

Senator Nunn's concerns are echoed in findings from investigations of the nuclear black market conducted at Harvard[3] and at the Center for Strategic and International Studies, Washington, DC.[4]

The threat is multifaceted. It can appear in many guises and be sustained by a multitude of motivations. While the supply of attractive nuclear materials resides in a handful of nations, the demand is more widespread. Increasing amounts of nuclear material in the FSU are now more susceptible to both protracted theft (e.g., concealed, drawn out over time, or involving planning and organization) and abrupt theft (e.g., executed quickly or involving terrorist action). Meanwhile, political and social turmoil increase the attractiveness of protracted and abrupt theft of nuclear material as a means to amassing power, exerting influence or seeking retribution.

Although policymakers and analysts are not in complete agreement about the severity of the nuclear smuggling threat, there does appear to be general consensus in the national security community that current patterns of nuclear theft and smuggling may be a prelude to more serious episodes, including major covert exports of fissile material, weapon components and even intact nuclear weapons. The current level of nuclear smuggling opens new criminal trade channels and increases potential opportunities for proliferation of weapons of mass destruction.[5]

Approaches to Nuclear Smuggling

The U.S. national security community traditionally has tended to approach nuclear security problems in a compartmentalized and fragmented way. This tendency appears to be a consequence of nonoverlapping areas of responsibility among agencies. For example, law enforcement, intelligence, or nuclear-related agencies generally focus on issues and areas that are within their purview (e.g., the physical security of the facilities that house nuclear materials) and do not integrate other susceptibility factors (e.g., insider or international political events) into their analyses. Issues related to the actual theft of nuclear material are addressed by the Department of Energy (DOE) Material Protection, Control and Accounting (MPC&A) Program. Issues concerning the movement of stolen nuclear material across international borders are handled by the U. S. Customs Service. Issues related to the criminal elements of nuclear materials theft are under the purview of the FBI.[6]

A more complete and useful approach to the theft of nuclear materials would view nuclear security threats in their entirety and include multiple perspectives, the interdependence of the critical elements of each perspective, and the context or situation in which a particular nuclear security problem is embedded. Such a complete approach would be holistic, integrating the multiple perspectives, elements, and context in a framework that would improve understanding, analysis and prevention of the theft of nuclear materials. Even the highly regarded DOE/MPC&A Program, which includes participants representing DOE and the Nuclear Regulatory Commission (NRC), still treats nuclear security analysis and countermeasures as site-bound, pertaining to a specific facility or site. With the exception of the MPC&A Program, most current approaches are response measures taken after nuclear security has been breached.[7]

A Holistic Framework

The alternative framework proposed is based on a general systems model. Two attributes of a general systems model make it especially attractive as the basis for an alternative approach to the analysis and management of the nuclear security threat problem. First, by definition, a system involves multiple interrelated components. Second, the depiction of a system and system processes facilitates an awareness and understanding of the interrelationships among the system components. The likelihood of successful interactions with or interventions into a system is improved with accurate knowledge of the components of the system and of how the components work independently and interdependently.

Any system can be defined as a set or structure of interrelated components. In its simplest form (figure 1), a general systems model depicts the process by which inputs (the raw materials or resources that feed a system) are transformed (processed in some way) into an outcome or output (the end product or result of the processing). A thermostat is an example of such a system. A thermostat is a control system whose components (e.g., sensors) respond to changes in the ambient temperature of a room to regulate heating or cooling. A room thermostat takes in inputs (e.g., information about air temperature), transforms them (e.g., checks against a standard, desired temperature;

engages or disengages a heating or cooling system) into a desired product or outcome (e.g., maintenance of room temperature within a limited range). A beneficial feature of the general systems model approach is that knowledge of parts of a system can help determine the rest of the system. For example, awareness of a desire by many people to regulate and maintain room temperature (the desired outputs) helped link thermometers (tools for providing input) to control devices for heating and cooling systems (transformation processes).

Figure 1. ***An example of a simple, closed (no feedback from environment) system***

System Inputs ---> Transformation Processes ---> System Outputs

The objective of this paper is to describe a framework or systems model that can be applied to understanding and analysis of, and intervention (used in a broad sense to include possible political, legal, law enforcement, and even military actions) in various types of nuclear threat. Our application of systems concepts will be broad rather than narrow. Because the scope of nuclear threat is extensive, our focus will be limited to a particular kind of nuclear threat—the threat of protracted theft in a fixed facility; however, the model represents a basic tool that can be applied to any nuclear threat situation. The model we will construct can be used to analyze the theft and transfer of the nuclear material to another location (smuggling) or to another person, organization, or nation (sale to a customer). It can also provide the basis for the development of effective countermeasures—measures either to stop the theft and smuggling before they occur or change the process or process management of the theft and smuggling to increase the difficulty of execution (e.g., through prophylactic measures). The model is also applicable to law enforcement and intelligence officials for risk assessment and postincident investigations of thefts of nuclear materials.

A systems model approach takes advantage of the previously discussed features of systems constructs and systems model analysis to understand and analyze better a protracted theft of nuclear materials and to design more effective mechanisms to protect nuclear materials. For example, the inputs of such a model might include people, motives, and resources. The transformation processes might include: linking people who have needed resources with people who have necessary skills; planning and coordinating activities; and integrating information from various sources into system outputs. The outputs might include the successful theft and selling of nuclear materials or terrorist activities involving nuclear weapons or materials. The framework provided by the model presented in this paper can help nuclear security experts construct potential theft scenarios for at-risk facilities or reconstruct (in a postincident investigation) the resources, activities, and their interrelationships required for a theft to occur. In both instances, knowledge of parts of the system processes of a nuclear theft scenario can help identify critical components or interrelationships—i.e., a unique, traceable signature that can direct identification of the rest of the system components and their interrelationships.

In the following chapters, the process associated with protracted nuclear theft will be discussed and a holistic, multiple perspective approach to the nuclear theft process will be developed. Our argument begins with the realization that nuclear theft is not unlike other types of complex crime. From this premise, we will explore the elements of protracted theft in general, and nuclear theft in particular, to develop a systems model. In so doing, we will highlight details of some of the most significant recent nuclear smuggling cases to illustrate the model's applicability and utility to this type of crime. There are some characteristics of nuclear theft, i.e., the properties of materials, the facilities, and the weapons development cycle, that contribute distinctive elements to the formulation of the nuclear smuggling pathway model. The model's utility will be illustrated by analyzing a supply-side and a demand-side case. The conclusions we draw from our analysis suggest ways in which we can be better prepared to counter the threat of illicit transactions in nuclear materials and suggest avenues for further study.

Notes

1. Graham T. Allison, Owen R. Cote, Jr., Richard A. Falkenrath, and Steven E. Miller, *Avoiding Nuclear Anarchy; Containing the Threat of Loose Russian Nuclear Weapons and Fissile Material* (Cambridge, MA: The MIT Press, 1966).

2. Statement of Senator Sam Nunn, Hearings on Global Proliferation and Weapons of Mass Destruction, Permanent Subcommittee on Investigations, of the Senate Committee on Government Affairs, March 13, 1996.

3. Allison, et al.

4. *The Nuclear Black Market*, Global Organized Crime Project; Center for Strategic and International Studies, Task Force Report. CSIS, Washington, DC, 1996.

5. Rennsselaer Lee, "Recent Trends in Nuclear Smuggling," speech for the Center for Strategic Leadership, U.S. Army War College, Carlisle Barracks, PA, June 25, 1996.

6. To illustrate this point, the authors call attention to a Department of Energy publication, "Executive Branch Arms Control and Nonproliferation Directory," dated April 1995. This very useful document includes 38 pages of organization charts and mission statements of the 18 Executive Branch departments, agencies and other elements that are engaged in nonproliferation work in some way. There are another 30 pages of telephone numbers and a glossery of terms. In a manner of speaking, one needs a federal directory to get started and to understand who is doing what in this critical area of concern.

7. On May 15, 1996, Nikolai D. Bohdarev, Director of Security at the Kurchatov Institute in Moscow, expressed his concern to the authors that a more comprehensive approach was needed in the DOE Lab-to-Lab Program, to insure that maximum security improvements were obtained from available resources.

2.

THE PROTRACTED NUCLEAR THEFT PROCESS

Systems can be defined and depicted at any level of detail required. The inherent tradeoff in the level of detail is between simplicity and usefulness. Although broadly defined systems are easily understood because of their simplicity, they have limited usefulness. Highly detailed system descriptions provide much more information but can be difficult to understand. We have already described the essential components of any system as consisting of inputs, transformation processes, and outputs. In this section we shall begin to add detail to these components as they apply to protracted nuclear theft by using the concepts of system decomposition and task analysis. Our aim is to provide sufficient detail to illustrate the usefulness of applying a systems perspective to nuclear threat scenarios without creating information overload. We begin with a description of one variant of the protracted nuclear theft process.

The Theft Process

Stealing nuclear materials is theft. All thefts share several basic characteristics and entail at least minimal consideration of requirements related to personnel, access, data and information, management and organization, communication, and equipment associated with the theft. For example, the theft of a small, portable object may require no more than a single individual. Access may not be problematic if the item is unsecured. Data and information may be limited to knowledge that the desired object is available and not protected by a sophisticated security system. Selecting a time when the theft is unlikely to be observed and reviewing the plan mentally or with an accomplice may suffice for the management and organization requirement. Communication or a signaling system may be necessary if an accomplice is recruited, and a few simple tools may constitute the required equipment. As the value, size, or uniqueness of the object to be stolen increases, and as protective safeguards become more elaborate, the complexity of the theft requirements necessarily increase to overcome the greater difficulty involved in stealing the object.

Every thief may have individual motives for stealing an object. Overall, however, motives for a theft can be classified under two general categories: for personal reward in having or using the object, and for the instrumental value associated with having the object. In the former instance, the successful execution of the theft would provide immediate reward, although inexperience with or lack of knowledge of how to use the object may delay gratification. In the latter instance, the stolen object is merely a means to the attainment of the actual object of desire (e.g., money, status, power, or control). Nuclear theft could fall within either category depending on whether the theft is initiated by someone inside a nuclear facility who intends to sell the material for profit, or by a state that intends to use it to attain some objective. Transforming the stolen object into the desired outcome may require two additional types of participants: brokers and buyers, and two additional activities: smuggling (i.e., illicit or covert movement of materials) and selling stolen goods. The addition of more types of participants and activities further increases the complexity of the requirements to accomplish the theft. This, in turn, increases the difficulty of creating and analyzing theft scenarios to develop countermeasures or of reconstructing a theft in a postincident investigation. Thus the protracted theft of nuclear materials could be classified as a theft with complex requirements that will necessitate additional participants and activities (i.e., smuggling and selling stolen goods). In systems terms, the inputs required to accomplish the theft of nuclear materials would require: (1) one or more participants with the appropriate knowledge and skills, and types of participants (thieves, brokers, customers); (2) data and information appropriate for the theft and its brokering and sales requirements, if any; and (3) the appropriate equipment to complete the theft, brokering, and sale. The transformation processes could consist of activities related to: (1) organizing and managing all aspects of the theft, brokering, and sales; (2) access to facilities, equipment, and people needed to accomplish the theft, brokering, and sale; and (3) effective communication among all the participants involved. The outputs are the result of the input and transformation process requirements. An unsuccessful nuclear theft attempt would be a result of not having met all of the input and transformation process requirements for a successful theft. A useful framework for guiding the analysis of potential thefts or the investigation of actual thefts and smuggling of nuclear materials should incorporate the complexity surrounding the theft of nuclear materials.

Systems can be dynamic in at least two ways:

- There is a sequential process flow underlying the system
- If the system is open, it can make adjustments based on new information (i.e., the system acts upon feedback from its environment).

These two aspects of system dynamism provide an additional means of understanding and analyzing nuclear theft. The sequential order inherent in any system stipulates that inputs are required before transformation processes can be engaged and that transformation processes must precede outputs. In a nuclear theft and smuggling scenario, the sale and exchange of nuclear material usually do not occur before the theft (and smuggling) of the material from a facility; also brokering will be difficult if only the promise of nuclear materials exists, because many brokers want a sample of the material before they will make a deal.

Although the order of the processes involved in nuclear theft and smuggling is sequential and relatively fixed, the stimulus for the onset of the nuclear theft and smuggling process can be initiated by relevant participants associated with any point in the process. For example, nuclear theft and smuggling may be initiated by would-be thieves who intend to steal the materials for their own purposes or to sell to others. In this supply-side scenario (figure 2), analysis, intervention, or investigation of a nuclear theft would be guided by the flow of activities related first to the execution of the theft, then to the brokering, and finally, to the sale of the material. Intelligence information that would lead to classification of a potential theft as a supply-side scenario would focus its analysis and intervention on the prevention of the theft and the identification of likely participants (in this instance, the possible thieves).

Figure 2. ***Supply-side process order in nuclear theft and smuggling***

Protracted Theft of Nuclear Material ---> Brokering --->Sale to Customer

Nuclear theft and smuggling may also be initiated by a potential customer who desires the material but has neither the skills nor desire to execute the theft. Although bona-fide customers are rare today, it is generally believed that there are a few states and terrorist groups that desire such material. In a demand-side scenario (figure 3), analysis of a potential nuclear theft and smuggling scenario would be directed from the customer/sale end of the process and would move toward the theft and brokering activities. The analysis might first identify the likely customers of nuclear materials or the political events that would create a desire for nuclear materials and the likely activities that would logically follow. Investigation and intervention in a demand-side situation/ scenario would then focus on the activities, resources and additional participants (in this instance, the brokers and thieves) needed to secure the materials.

Figure 3. ***Demand-side process order in nuclear theft and smuggling***

Desire for Nuclear Materials ---> Brokering ---> Theft
or
Desire of Nuclear Materials ---> Theft----> Brokering to Others

Although they have received little attention from the U.S. nuclear security community, brokers can also be the potential initiators of nuclear theft and smuggling activities. Like an entrepreneur, a broker can create a brokered-supply and/or a brokered-demand for nuclear materials where none exists. Intelligence information identifying successful brokers of illicit materials (nuclear or other, e.g., narcotics, or munitions) can direct the focus of investigations to the activities and contacts of known brokers that would engage the appropriate individuals and organizations needed for the theft and exchange/sale of nuclear materials. Figure 4 depicts the potential process order when a broker initiates the process leading to nuclear theft and smuggling.

Figure 4. ***Potential process order for nuclear theft and smuggling initiated by broker***

Broker---> Instigates Need for Nuclear Materials (Customer)
and
Broker---> Proposes Theft to Potential Thieves

Complexity

As discussed earlier, the characteristics surrounding a theft affect the complexity of the requirements for accomplishing the theft. As the characteristics become more complex, the complexity of the requirements increase. Usually, the more valuable, protected, or unique the object to be stolen, the more difficult it will be to steal and sell. In a nuclear theft and smuggling scenario, the corresponding characteristics likely to have the greatest effect on requirement complexity include:

- Type of the nuclear materials (weapons-grade or nonweapons-grade)
- Location of the materials
- Sophistication of security systems at the material's location
- Amount of material desired or needed.

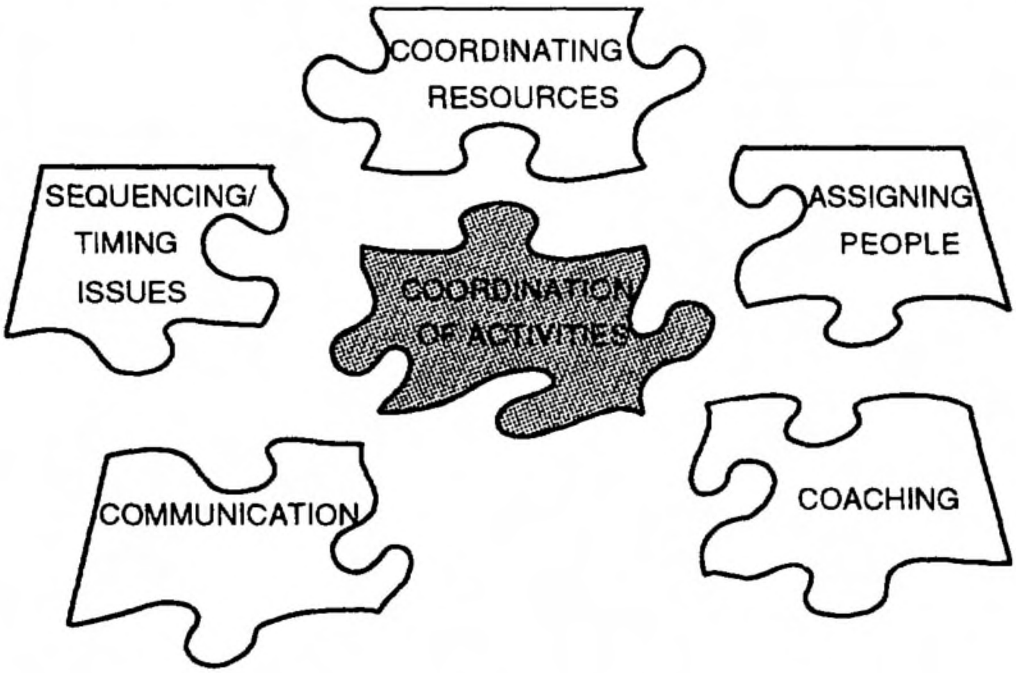
For example, the theft of a small amount of nonweapons-grade nuclear materials from a research laboratory may be an easier task than the theft of large amount of weapons-grade nuclear materials from a facility in the Russian weapons complex; the latter obviously requires a longer period or perhaps more individuals to execute. There are several examples of this in Russia, including several significant nuclear smuggling cases involving more than kilogram quantities of weapons-grade nuclear materials. For example, at the Luch Scientific Production Association, it was possible for one insider with access and intimate knowledge of accounting procedures to steal 1.5 kg. of highly enriched uranium (HEU) by making 20 to 25 small diversions over a 5-month period (May-September 1992). In another case (November

1993), it required a team of three to break into the fuel storage area at the Sevmorput Shipyard near Murmansk, break open a padlock on the door, locate the containers of submarine fuel, break off three parts of a fuel assembly containing 4.5 kg. HEU, place them in a bag, and remove them from the facility.[1]

As the complexity of a theft increases, the complexity and importance of organization and management requirements increase more than do the complexity and importance of any of the other requirements. This relative difference in complexity and importance for organization and management requirements is a result of the greater need for coordination of people, activities, and resources.[2] Coordination of people includes consideration of the number, skills, and characteristics of the people involved. Unless the individuals involved are already part of an intact group or organization, there will be recruitment and selection issues. Recruitment and selection must reflect the technical knowledge and skills required for specific tasks. Depending on the human resources available to recruit from, some training of team members may be necessary, and with it, the need to determine whether the training material was successfully learned. However, it may also be critical to consider the ability of the people recruited to work together as a team—trust, loyalty, and commitment of "team" members may mean the difference between a successful or unsuccessful operation. For example, the recovery by Prague police of 2.7 kgs. of stolen HEU (December, 1994) was made possible through an anonymous tip. Although the theft of the nuclear material had been successful, a breach of trust may have precipitated the capture.

The coordination of activities required to complete complex thefts (figure 5) will involve sequencing and timing of operations, assignment of tasks, and a communications network to match operations requirements. The appropriate sequencing and timing of the operations will depend on accurate and timely data and information, which may need to be communicated to relevant team members by others. The overall success of the theft and smuggling is also heavily dependent on the match between capabilities and task requirements. Less than perfect matches may have to be dealt with as the operations unfold; a situation may require a good "coach" who understands the talent and temperament of the other members of the team. Finally, resources that need to be coordinated will involve equipment (e.g., obtaining the right equipment, ensuring that it is where it needs to be at the right time, etc.) and overall logistics.

Figure 5. ***Activities requiring coordination to complete complex thefts***



The Russian case in Andreeva Guba provides a clear illustration of lack of coordination in several of the above areas, including coordinating resources, communication, and coaching. In July 1993, two Russian naval officers and two seamen allegedly stole nuclear material from a naval fuel base of the Northern Fleet. The Russian investigation of this incident revealed that the two officers actually stole two fuel rods, took them to an abandoned building, and extracted a core containing 1.8 kg. of HEU. With the aid of one of the seamen, the officers carried the core into the nearby hills and buried it while the second seaman stood watch. The remainder of the material was left in the abandoned building over which one of the seaman had control. Three days later, this seaman decided to carry the rest of the material to the secret hiding place in the hills, but abandoned it outside the facility. The theft was detected the same day. The two seamen immediately came under suspicion, but denied any involvement. Alone and scared, they hatched a scheme to go mushroom picking in the hills, where they "discovered" the missing material. Although this aroused suspicions, the seamen remained free until one of them was sent to the brig for some infringement unconnected with the theft. Meanwhile, a search was launched for the remainder of the missing material. The remaining free seaman joined a search team and, finding nothing in his designated search area, broke away from the group, went directly to the secret burial place, moved several stones aside, and "discovered" the missing material. The seaman was arrested and charged with the theft. Initially he denied everything, then changed his story, and finally confessed. The second seaman also confessed. The officers admitted nothing.[3]

The above discussion points to the criticality of organization and management in determining the success or failure of an attempt at protracted nuclear theft and smuggling. Regardless of the attention to detail to ensure the right personnel and equipment have been identified and secured, that access to the desired material is identified, that accurate data and information are obtained, and that communications are established, if the organization and management requirements are not adequately met, the attempt has a higher probability of failure than of success. Awareness of the importance of coordination among the characteristic requirements for a theft and application of this knowledge to analysis and intervention of the theft and smuggling of nuclear materials is the basis for the nuclear smuggling pathway model described in later sections.

Special Characteristics

In addition to sharing similar characteristics with all thefts, protracted nuclear theft and smuggling appear to share characteristics common to highly sophisticated "white collar" crimes such as fraud, embezzlement, and counterfeiting. Like protracted nuclear theft and smuggling, these crimes are inherently complex and require considerable organization and talent to execute successfully. The Andreeva Guba case underscores this point well.

Sophisticated crimes have four general characteristics which appear to be very important in potential nuclear theft and smuggling activities as well.[4] They are as follows:

- The crime is concealed as long as possible.
- Insiders are generally involved.
- Critical skills, organization, and good logistics are necessary to succeed.
- A support system of specialized personnel exists.

Concealment is essential when crimes take time to plan and execute and for undetected escape. When concealment is broken, either unintentionally or intentionally, the thief is exposed to greater risk of detection. For example, in the Sevmorput Shipyard case (November 1993), one of the thieves who sought help from a fellow worker in disposing of material that had been stolen some 6 months earlier was apprehended.[5] Concealment simply may be stealth or may require a complex set of actions (e.g., changing records, assuring documentation is in proper order, preventing suspicions from being aroused, and in general making it appear that everything is "normal") to minimize the probability of dectection.

In the case of nuclear theft and smuggling, the theft is only one segment of the complete process. Detection of the theft after the fact, but before the sale, may provide law enforcement personnel an opportunity to intercept the stolen material before it is delivered to a customer. In fact, theft of nuclear material in all of the cases discussed thus far was successful, yet none of it was ever delivered to an end-user.

Insider involvement is also important to the timeliness and success of sophisticated crimes. The amount of time and resources necessary and the probability of premature detection are increased considerably without the participation of individuals who have access to the material (or inventory records, custody documents, and transfer instruments) as part of their normal duties. In all the nuclear theft cases mentioned above, there was at least one insider involved, someone with access and knowledge of the facility and its procedures who could facilitate the theft.

In addition to extensive organization and management, successful execution of a complex crime may require specialized skills, equipment, and information. In protracted nuclear theft and smuggling, individuals will not be capable of carrying out the complex requirements by themselves. Therefore, organization and management requirements will extend beyond resources, activities, and people and include management of the interrelationships among the people involved, that is, team management. The extent of organization, management, and resources necessary to accomplish complex crimes, including protracted nuclear theft and smuggling, requires an organization, new or existing, capable of meeting the requisite needs.

This need for extensive organization and management is perhaps best demonstrated by viewing a recent significant nuclear smuggling case orginating in Russia and terminating in Germany. In spite of a successful theft of nuclear material, the perpetrators obviously lacked the organization and management necessary to execute the brokering and sale phases of their plans. As a consequence, on August 10, 1994, German police at the Munich airport terminated a nuclear smuggling plan through a sting operation and seized the largest quantity of weapons-usable material recovered in the West to date. This case highlights the existence of an international nuclear supply network, albeit an inadequate one in this instance.[6]

Decomposition of Complex Processes

This section describes an approach for analyzing complex systems in an incremental, top-down manner. Decomposition is a term used to describe this activity; it refers to the successive breakdown of layer after layer of information into increasing detail.

Rationale

The general systems model we propose for understanding and investigating protracted nuclear theft and smuggling is based on a general systems approach. The fact that systems are defined by their interrelated multiple components and that systems models graphically represent the component relationships and process flow is the foundation for the proposed framework. Crimes in general, and thefts in particular, usually have clear, definable process pathways from inception to completion. A systems approach enables the sorting out of functions and activity patterns in a complex interrelated structure.

As discussed earlier, systems models are characterized by:

- A logical ordering of events that occur during system functioning (i.e., temporal sequencing of system events) and the use of graphical representations to express the interrelated structure and functioning

- Inputs, transformation processes, outputs and, in open systems, feedback as the fundamental structural components.

Systems models are also generally constructed using a "top-down" approach. That is, the systems model begins with the most general level of specification and moves to the most detailed specification through incremental steps; rules for specification are strictly applied at each level. This top-down procedure insures that the structure and organization of the model are consistent and ordered, but also allow for easier recognition of patterns within the system structure. The highest level of generality describes the overall functioning of the entire system. Identified subsystems are arranged under the higher level structures. The resultant, overall structure is comprehensible and consistent and can be analytically decomposed.

Before presenting the model as a formal systems diagram, we shall discuss the substantive components. Our approach is to model the system beginning at the most general level and proceeding to increasingly finer levels of detail.

Specific Activities

At the most general level (Level 1) of a systems model of one type of protracted supply-side nuclear theft and smuggling, we can identify at least three major activities:

- Theft of materials
- Brokering
- Sale of materials to customer.

The first major activity, theft of materials, includes all the process activities required to plan the theft, remove material from storage or other location, conceal the theft, and escape undetected. Brokering is the fencing part of the process connecting thieves with an end-user or final customer. This activity involves several intermediary functions, including the sale and transfer of material from the thieves to the customer. The customer may or may not have a pre-existing relationship with brokers or the thieves. Sale and delivery to the customer are the final parts of the process.

Each of the major activities in the theft and smuggling of nuclear materials will be decomposed into more specific and detailed activities and processes. As the activity specification becomes more detailed, it is possible to make a more precise assessment of the problems likely to be encountered in completing them. For a protracted nuclear theft and smuggling scenario, countermeasures can be identified and designed to frustrate potential thieves.

In order to make better judgments about how events in a protracted nuclear theft and smuggling scenario might unfold, it is necessary to specify the components of major tasks with enough precision to understand what activities are or are not physically possible. For example, in an insider theft scenario, it would be necessary to describe what the insider would actually have to do to remove a specific item from a specific room or building. Details of just how thieves went about stealing various types of nuclear material from the Luch, Sevmorput Shipyard, and Andreeva Guba facilities are known and are very instructive for this effort.[7]

Task Analysis

Task analysis provides a mechanism for defining what human actions must occur at each step of the process depicted in a systems model.[8] Its utility lies in both the design of systems and in the analysis of the prerequisites for the successful completion of a series of tasks. This latter application is relevant to the development of the nuclear smuggling pathway model. Two components of a task analysis are pertinent here:

- The task descriptions themselves
- The task requirements or resources necessary to carry out the task.

The concepts underlying task analysis can also be applied to specifying detail of the inputs to a process.

Task Descriptions

Task descriptions are statements of specific efforts that must be taken to accomplish a particular task. Taken together, they specify sets of tasks which must be accomplished for a process to proceed logically through its system. Task descriptions at Levels 1 and 2 are shown in the example above.

Table 1. ***Task descriptions***

Level 1		
Theft of Materials	Brokering	Sale to customer
Level 2	**Level 2**	**Level 2**
Identify object of theft	Identify a broker/ buyer	Identify customer
Plan the operation deal	Negotiate the sale/ object	Customer verifies
Remove object	Provide a sample object	Receive payment for
Pack for transport	Remove object from storage	Transfer object
Conceal theft	Transport object	
Escape undetected	Arrange for sale/deal	
Store material (temporary)		

Task statements, like systems models, are developed "top-down" beginning with the highest level of task definition.[9] Then, the next levels of logically complete tasks are specified. In the example below, the Level 2 description, "Plan operation," is decomposed into two additional levels of component elements. The major components of the "Plan" are defined at Level 3, while the major components of "defeating security sensors" are defined at Level 4. Both sets of components are illustrative and not intended to be exhaustive.

The detail of how to carry out a specific activity, such as defeat the security sensors, is shown in the items in Level 4: disrupting the power supply to the detector and damaging the detector before the theft. These are examples of the progressive degree of detail that can be specified under each of the task descriptions and which become job and/or site specific. The levels of refinement can continue until there is no additional level of detail to be specified.[10]

Task descriptions provide the pattern of action that would be followed by a potential participant (thief, broker, customer). By themselves, task descriptions are insufficient to define the requirements for a successful theft or smuggling operation. For each task set, there are also specific support requirements to be met, or the task cannot be completed. For example, the task of "picking a lock" cannot be completed without special tools (e.g., lock picks). Finding an object in a building requires advance knowledge of the object's location. For a thorough task analysis, it is not enough to specify what must be done, it is also necessary to be specific about what is needed to carry out the task.

Table 2. ***Task descriptions decomposed***

Level 1	Level 2	Level 3	Level 4
Protracted Theft			
	Plan operation		
		Entry into building	
		Avoid alarms	
		Open locks	
		Access route	
		Egress route	
		Transport goods	
		Defeat security sensors	
			Disrupt power supplies to detector
			Damage detector before theft
			Turn off sensors

Task Requirements

Task requirements are the resources needed to carry out various tasks. The six major categories of task requirements described earlier that apply to theft (personnel, access, data and information, management and organization, communi-cations, and equipment) are logistics, information, and support requirements that must be met to complete a given undertaking. All these are ultimately dependent on financial resources used for payments of bribes and the purchase of services and equipment. Personnel requirements include the number of individuals and their technical and nontechnical skills needed to carry out a specific activity. Both insufficiency and excess of personnel can lead to failure. More importantly, personnel capabilities (skill sets) must be matched with the task activity skill requirements.

Access is a requirement especially pertinent to theft of highly valuable objects, such as weapons-grade nuclear materials. Access is important not only in locating and removing the objects to be stolen but also in covering up the crime to avoid detection. Data and information requirements pertain to critical data thieves must have about the material, facility, security system, and security forces (among other things) in order to carry out a successful theft. Thieves must also know how to access records, how to avoid other workers, and when inventories may be taken.

Management and organization requirements refer to the planning, staffing, organizing and directing of the theft operation. This is analogous to the management and coordination activities performed in any organization and is especially critical with highly complex thefts. Communication requirements are essential to ensuring coordination and are important in every phase of a theft. Equipment requirements refer to the material and logistical support that must exist for specific tasks to be completed. For example, if the object to be stolen is a fuel assembly weighing over 200 kg, the thieves must have a hoist to lift the assembly, shielding for the assembly, and an appropriately modified (e.g., shielded) vehicle for transport.

Requirements can be specified at all levels in the functional decomposition of an activity. At each successive level of refinement, the information necessary to complete the analysis becomes more application-specific, and eventually becomes site-specific. At the site-specific level of detail, activity or profile patterns may become evident and may constitute a unique, traceable signature. The signature may be similar to a mode of operation that identifies a specific individual or group as the likely participants (e.g., those having the requisite skills, motivation or needs, or usually operating in the identified pattern, etc.).

At Level 2, a systems analyst can begin to define the general type of problems that thieves may face when trying to steal materials of specific types. This is valuable information that permits general assessments of the threats posed by various theft scenarios. For more detailed analysis of the risks or problems apparent at different facilities, it is necessary to work at lower, more detailed levels. At Level 4, the scenarios will deal with thefts that can be building-specific. From these, an assessment can be made of the current risks that exist and of countermeasures that are, or might be, applied.

An application of this approach to a specific case is presented in the following example that sets forth the basic requirements for stealing nuclear material from a Russian naval fuel storage facility. Information for the model has been taken from the Sevmorput Shipyard case of November 27, 1993. In each cell of the matrix shown, general requirements are specified for those activities and behaviors needed to successfully remove three parts of a submarine fuel assembly from the fuel storage area. To carry out the requirements for this particular theft, personnel included one individual with the proper knowledge of the facility, plus two accomplices. Only simple tools were required to facilitate entry. Because the facility was unguarded at the time of the theft, requirements for concealment were minimized. Following the actual theft, temporary storage of the material was necessary to insure that the theft was properly concealed.[11]

In this scenario, all these requirements were met for thieves to remove the nuclear material successfully and exit the site undetected. Had the thieves not met all of the prescribed tasks and requirements, the theft would probably have failed. A partial illustration of this event is presented in table 3 to aid understanding the utility of the general systems model.

As theft scenarios become more elaborate, or involve more closely guarded materials, the number of requirements and the complexity of the operation increase significantly. For example, theft of a larger amount of nuclear material from a weapons production laboratory brings more people into the operation and creates significantly more problems in both executing the theft and maintaining cover. Concomitantly, the decomposition of the theft process using task analysis becomes a more complex, lengthy, and formidable undertaking.

A Systems Approach

In this chapter, the application of general systems methods to the process of nuclear materials theft has been set forth. This systems perspective shows that protracted theft of nuclear materials is a process from inception, through a series of clearly definable steps, to the sale and delivery to a customer. Systems methodology permits defining all of the intermediate steps in the process which then facilitates organizing a large amount of information into an understandable, interrelated structure. The system process is built from the top-down, that is, from the most general to the most specific activities. Each specific activity can be more carefully analyzed using a methodology known as task analysis, which is the detailed specification of all behaviors needed to carry out a specific, defined action in a protracted theft process. Tasks are also defined from the top-down, with task definition ranging from general to specific.

Table 3. ***Level of Detail: Requirements and Task Descriptions***

Level 1	**Level 2**	**Level 3**	**Level 4**
Task	Task	Task	Task
Theft	Entry to	Climb thru hole in fence to fuel storage area 3-30	Open door to fuel storage building
↓	↓	↓	↓
Requirements	Requirements	Requirements	Requirements
Personnel	Personnel = 3	Personnel = 1 (who knows where holes in fence are)	Personnel = 1(w/lock skill)
	Access = to	Access = to storage bldg.	Access = to padlock on door; to metal bar to break open lock
	Data = site security	Data = holes in fence; no guards	Data = location of holes in fence; entry to storage shed
	M&O = coordinate entry	M&O = none	
	Communications between	Communications =	
	Equipment = entry	Equipment = special tools bypass lock	Equipment = saw for padlock; bar to pry open storage shed door

Task requirements, also defined from the most general level to the most specific, are identified to successfully complete each task. Although all task requirement characteristics are important for success in the planning and execution of an activity, organization and management become more important as activities become more complex. Knowledge of the tasks to be completed, and the requirements to complete each task are essential to understanding the threats posed in different theft scenarios. This knowledge is also of considerable utility in defining countermeasures which can be applied to frustrate adversaries and may provide signatures of impending activities.

Notes

1. Statement of Dr. William C. Potter, Director of the Center for Russian and Eurasian Studies, Monterey Institute of Intenational Studies, during Hearings on Global Proliferation and Weapons of Mass Destruction, held by the Permanent Subcommittee on Investigations, Senate Committee on Government Affairs, March 13, 1996.

2. E. Schein, *Organizational Psychology*, 3rd ed. (Englewood Cliffs, NJ: Prentice-Hall, 1980). See also: J.A. Wagner and J. R. Hollenbeck, *Management of Organizational* Behavior, Englewood Cliffs, NJ: Prentice-Hall, 1992.

3. *Yaderny Kontrol No 1, Digest of the Russian Nonproliferation Journal*, Center for Policy Studies in Russia, PIR Center (Spring 1996): 16-19.

4. Herbert Edelhertz and Marilyn Walsh, *The White Collar Challenge to Nuclear Safeguards* (Lexington, MA: Lexington Books, 1979).

5. Ibid.; Potter testimony.

6. Ibid. The confiscated material consisted of 560 grams of mixed oxide (MOX) fuel in powder form, 363 grams of which was 87 percent pure plutonium. The material was hidden in luggage aboard a Lufthansa flight from Moscow. Authorities speculate that it had been stolen some time earlier from the Institute of Power Engineering Problems in Obninsk, one of Russia's premier nuclear research institutes.

7. Ibid.

8. Rob B. Summers, Michael S. Carey, and Jane S. Astley, "Task Analysis," in *Evaluation of Human Work: A Practical Ergonomics Methodology*, eds. John R. Wilson and Nigel Corlett (London: Taylor and Francis, 1990), chapter 6.

9. Mark D. Phillips, et al., "A Task Analytic Approach to Dialogue Design," in *Handbook of Human-Computer Interaction*, ed. M. Halander (Amsterdam: Elsevier Science Publishers, B. V. North-Holland, 1988), chapter 88.

10. Tom DeMarco, *Structured Analysis and System Specification* (Englewood Cliffs, NJ: Yourdan Press: Prentice-Hall, 1979).

11. Ibid.; Potter testimony.

3.

A HOLISTIC MODEL

Setting the Stage

Our discussion up to this point has identified several concepts and perspectives that are the building blocks for an alternative approach to countering the increased nuclear security threat facing all nations. The concept of systems and the ensuing systems analysis methodology are the essential underpinnings of the holistic model we propose. Representation of threat and activities within an interrelated structure of inputs, transformation processes, and outputs encourages a holistic approach to the identification of relevant participants, activities, and environment comprising potential nuclear theft and smuggling threats. Examining protracted nuclear theft and smuggling as one variant of the more general category of sophisticated, complex crimes provides the substantive basis for populating the structure of our framework. Finally, systems analysis methodology and tools enable the logical system decomposition of protracted nuclear theft and smuggling system elements into detailed, specific activities (tasks) that can be applied to the analysis of at-risk facilities and to postincident investigations. Improved vulnerability analysis and postincident investigations resulting from the application of the nuclear smuggling pathways model will enhance the development of effective countermeasures and interdiction of attempted thefts and smuggling. In this chapter, we integrate these multiple perspectives, concepts, and environments into a nuclear smuggling pathways model.

Description

In our earlier description of systems, we noted that system components included inputs, transformation processes, and outputs and that their overall interrelationship could be depicted as a sequential process flow of:

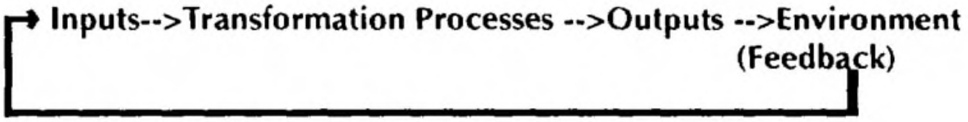
System Inputs ---> Transformation Processes ---> System Outputs

Before we apply this basic structure to a system decomposition of nuclear theft and smuggling within the nuclear smuggling pathway model, we need to reintroduce two more components mentioned previously: system context or environment and feedback.

All systems exist in a definable context or environment that will affect system functioning and effectiveness. In the broadest sense, the relevant environment for all living things is the earth; in a more narrow sense, it may be the specific country or local geographic area. For a nuclear facility, the relevant environment includes the global market composed of other civil and military nuclear research, manufacturing and production facilities and potential customers (broad) and the national complex of nuclear facilities and potential customers (narrower). The environment provides an additional source of information that can be used by the system to make adjustments in appropriate components to ensure system viability. For example, people will begin to dress more warmly when the outside temperature drops below a comfort or survival level; some nuclear weapons production facilities will likely shift their emphasis from the production of nuclear weapons to other lines of work, such as environmental cleanup or non-nuclear high technologies, as a result of the end of the Cold War.

Systems that use environmental or contextual information as feedback regarding system effectiveness are known as open systems; systems that ignore (or have no mechanism for retrieving and interpreting) the available feedback are known as closed systems. We propose that an effective general systems approach to the nuclear theft and smuggling threat must be based on an open systems model that includes attention to and use of feedback from the relevant environment for both system maintenance and improvement. An open system is shown in figure 6.

Figure 6. ***Example of an open system***

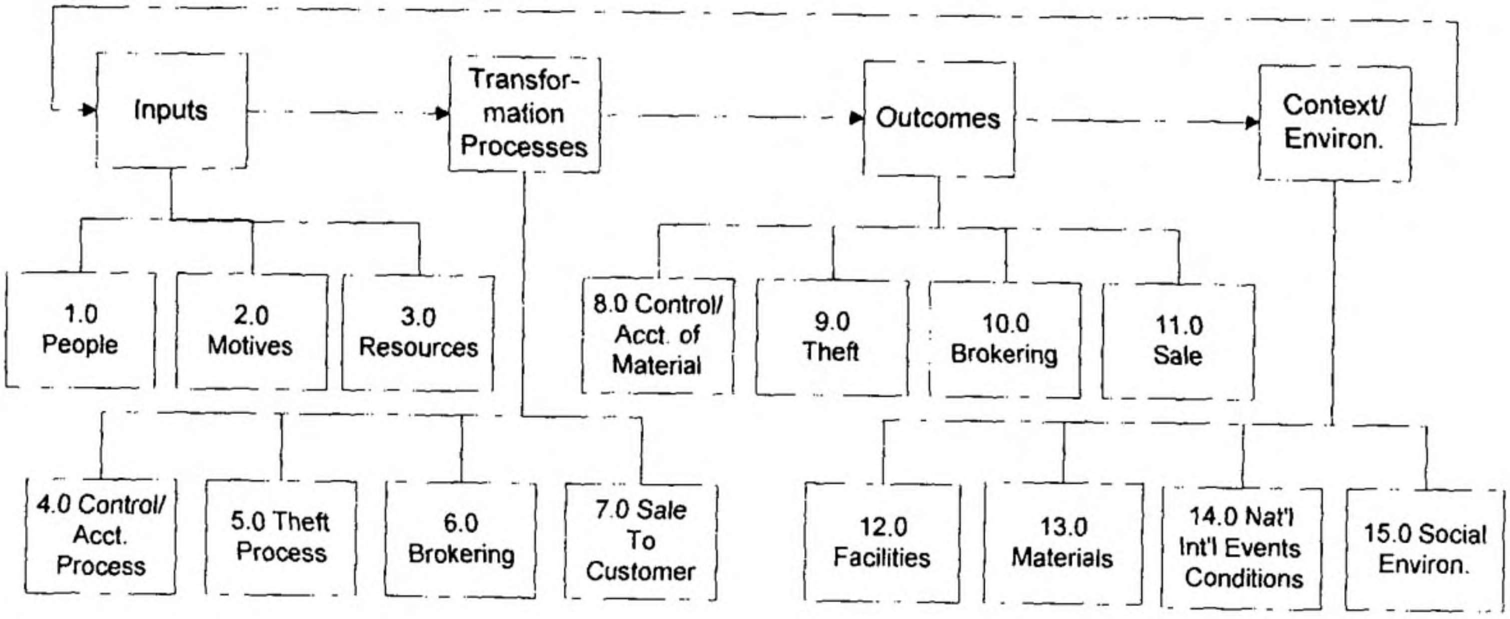


To understand protracted nuclear theft and smuggling from a systems approach, all the critical elements and system components must be identified. Figure 7 uses systems concepts to represent the relevant system components in the nuclear smuggling pathway model at the first, high-level system decomposition. The framework is top-down, beginning with general NSPM system components and moving toward increasingly greater detail. Because the size of the structure can quickly become unwieldy, only the first step in the system decomposition is shown here. The remaining steps are presented in appendix D.

General Framework

This first level of system decomposition identifies people, motives, and resources as general categories that encompass the relevant system *inputs*. In addition to including the theft, brokering, and sale activities that might comprise a protracted nuclear theft, the *transformation processes* in the system also contain material control and accounting processes. Inclusion of countermeasures in the system decomposition guards against overlooking weaknesses or gaps in security that may have allowed theft to occur (e.g., an insider aiding others). Similarly, intentional inclusion of countermeasure *outputs* in the analysis helps protect against prematurely ruling out the probability of an insider threat. Although listed as the apparent last component in the system description, the *context or environment* may be an important starting place for analysis of a protracted nuclear theft. Information about the context and environment in which a theft has or may occur can provide valuable insights that aid in decomposing other system elements (e.g., people or motives).

Figure 7. *System components ---> level 1 system elements*



Inputs ------>	**Transformation Processes ---->**	**Outputs ---------- >**	**Context/Environment --->**
People	Control/Accounting Process	Control/Accting	Facilities
Motives	Theft Process	Theft	Materials
Resources	Brokering Process	Brokering	Nat'l/Int'l Events & Conditions
	Sale Process	Sale	Social Environments

As system decomposition proceeds, an analyst will eventually place all the available information about a part of the system in the model; gaps in the information may then emerge. An analyst, using known and accepted standards (such as those in appendix A) or the particulars of a case, may determine that some information is more important than other information. The NSPM model directly addresses dealing with gaps in information through the characteristic of systems that enables parts of a system to be determined through knowledge of other parts of the system. This characteristic of systems and system decomposition becomes the basis for a valuable strategy for:

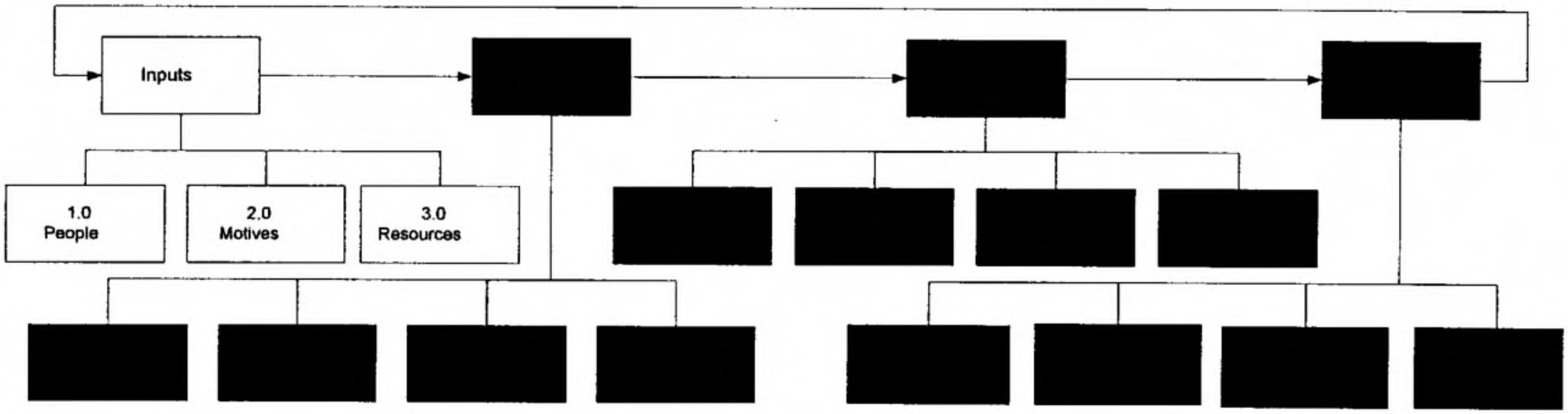
- Integrating existing information about a nuclear security threat event or analysis
- Suggesting where additional information should be gathered
- Creating opportunities for insights to be gained and important inferences to be made from existing information.

Specifically, when all the information about a specific system element (e.g., brokering processes) is expended through system decomposition, additional insight can be gained about that element by looking to and decomposing other parts of the system (e.g., context/environment, inputs, or outputs).

For situations in which some information is deemed more important than other information, the most important or critical information can be flagged. What specific information is actually flagged will be situation specific (e.g., the information critical to a field investigator doing a postincident analysis on a theft at a fabrication plant may be different from the information considered critical by an analyst conducting a risk assessment at a research laboratory). Some information, however, will be critical regardless of the specific situation (e.g., such as a large quantity of weapons-grade material). The examples below illustrate how decomposition would proceed for the "people" element of *inputs* and for the "materials" element of *context/environment*. Each example highlights how the model can be used in the absence of information or to mark critical information.

In figure 8, system decomposition proceeds until Level 5 for "criminal record," when the information available suggests that no prior criminal record exists for an individual. System decomposition can continue, however, by looking to and decomposing other parts of the system. In this example, a logical area to move is to another

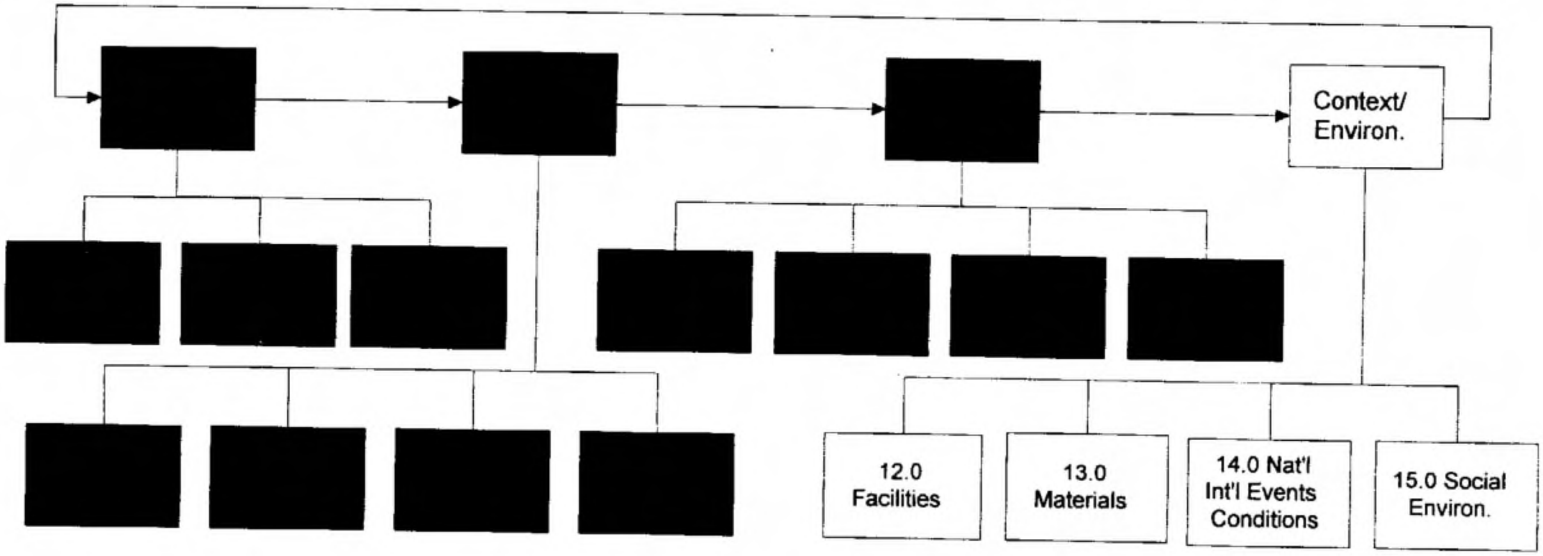
Figure 8. *Example of system decomposition for the system input element "people"*



People (Level 1 System Input)			
Level 2	**Level 3**	**Level 4**	**Level 5**
Individuals	Specialized skills/knowledge	Technical	Nuclear weapons Reactor technology
		Nontechnical	Inventory accounting Heavy equipment
	Insider/outsider	Insider	Access (information, etc.)
		Outsider	Relationship with insider
	Criminal record	Yes	Burglary Drug trafficking
		No	*
	Nationality	Middle East	*
		FSU	*
		SE Asia	*
		UK	*
	Associates	Known criminals	* #
		Known terrorists	* #
		No criminal or ?	*
		No terrorist or ?	*
Ad hoc groups	" "	" "	" "
Established groups	" "	" "	" "

* Go to another component (i.e., inputs, processes, outputs, context/environment) # Obtain information from other sources

Figure 9. *Example of system decomposition for the system context/environment element "Materials"*



Materials (Level 1 Context/Environment)				
Level 2	Level 3	Level 4	Level 5	Level 6
U235	Amount	< 1 Kg		*, #
		> 1 Kg	////////	*, #
	% Enriched	0-50%		*, #
		51-92%		
		> 92%	////////	////////, *, #
Pu239	" "	" "	" "	
UF6	" "	" "	" "	

* Go to another component (i.e., inputs, processes, outputs, context/environment

\# Obtain information from other sources; //////// Red flag marking information as critical element of *inputs* (i.e., decompose information about the individual's associates). In other cases, the appropriate information to continue decomposition may be found under another system component or element. This situation occurs for Level 5 for "nationality." Further insight on the people element of inputs for individuals involved in this scenario could be gained through the decomposition of *environment and context* component (specifically, *national and international events and conditions* and *social environment* related to the FSU).

System decomposition of a component that stops because of gaps in information also occurs for "criminal record," when the information may not be accessible when needed or easily attainable. Here again, decomposition can continue by moving to another part of the system, such as to "associates."

In figure 9, the amount of nuclear material involved and percent enrichment are key pieces of information which, alone or in combination, may signal a higher state of emergency and need for action. In all cases, additional information would contribute to what is known about the materials stolen. Flagging both the amount and enrichment of material may be cause for immediate increased interdiction efforts or development of countermeasures to protect other vulnerable material.

Application of the NSPM to a nuclear situation or potential situation involves selecting the appropriate input, transformation process, output, and context elements and then adapting the rest of the model through appropriate specification of the task definitions and requirements. Using this pathway framework, it is possible to work through various kinds of theft and smuggling scenarios that apply to specific facilities and specific materials, whether they be nuclear or other types. The systems representation of nuclear theft and smuggling arrays all the critical elements to be considered in adequately understanding and analyzing nuclear theft and smuggling situations. Task analysis is incorporated into the description of system process inputs. These are the most general level of task description associated with each of the system processes defined: theft, brokering, and sale. Once all of the system components and elements are fully arrayed, a user of the pathway model can select the elements that match the characteristics and attributes of a specific nuclear theft and smuggling situation. Task analysis can then proceed with a decomposition of the selected elements, whether they are participants, tasks or activities, or contexts.

The resulting interrelated structure will be a fully expanded version of figure 6 and provide essential information necessary for effective vulnerability analysis, countermeasure development, postincident investigations, and identification of susceptibility. Before illustrating specific applications of this pathway model in supply-side and demand-side examples, we will briefly discuss the general applications for which the nuclear smuggling pathway model is useful.

General Example of The Protracted Theft Process

In table 4, a general example is presented using generic task descriptions applied to a protracted nuclear theft and smuggling scenario. This example illustrates how the analysis of a nuclear theft scenario becomes increasingly detailed with additional levels of task descriptions and requirements that are specific to a particular facility or nuclear material. As the detail emerges, it may be possible to identify unique signatures, not unlike genetic signatures expressed in living organisms, that can help pinpoint vulnerabilities (in facilities, security systems, and people), individuals with special networks and specialized skills, and national and international events that might create a demand for nuclear materials. The task descriptions listed here are for illustration only and would be modified to fit specific facilities and situations.

General Example of The Brokering Process

Brokering is the part of the theft and smuggling process that currently poses the greatest obstacles or contains the greatest pitfalls, based on our analysis of recent nuclear smuggling cases. It covers that myriad of activities between the actual theft of the material and its delivery to the customer or end-user. Brokering is essentially the "fencing" part of the process where thieves work to connect with a customer. Brokers in the form of middlemen or organizations may become involved in arranging a deal; the customer may or may not have a preexisting relationship with the broker or the thieves. The task descriptions for brokering reflect this activity and are found in table 5.

These task descriptions are for a relatively simple theft carried out by one person. It is unlikely that one person acting alone can carry out all the tasks necessary to steal nuclear material and escape detection. The addition of other participants and required resources in both the theft and brokering processes raise the level of complexity of the theft and create additional task requirements in all areas, but especially in organization and management.

Example of The Sale to Customer Process

Table 6 shows the high-level description of all the activities necessary to transfer the stolen nuclear material, keep the operation secret, and receive payment for the material transferred to the customer. At this point, the broker locates a buyer and negotiates a sale. The sale and delivery are then made, which can involve transporting material for thousands of miles, transferring large sums of money, and escaping detection all the while.

Applications

Some of the major advantages of the nuclear smuggling pathway model lie in the applications for which the model can be used. We have identified three basic applications:

- Risk assessment
- Postincident investigation
- Integration of multisource information.

These applications are not mutually exclusive, but instead complementary. They also represent variants of scenario-based analysis and planning that has been used successfully for strategic planning and the development of problem solutions.[1] In addition to having several useful applications, the model is quite easy to use.

Risk Assessment

Decomposition of critical system elements into lower level sub-elements, task descriptions, and requirements produces a detailed and extensive blueprint of a potential protracted nuclear theft and smuggling scenario. The participants, motives, and resources required are identified; the flow of activities and coordination required to

Table 4. ***Level 2 and 3 task descriptions for theft***

Level 1	Level 2	Level 3
Theft	Planning	Personnel requirements Logistics requirements Time sequencing
	Entry	Entry route (approach) Entry into building Vault or storage access Defeat technical safeguards Avoid or overcome other safeguards
	Identify material	Identify storage location Identify container Identify material in container
	Remove material from storage	Remove material from container Replace container Restore to original condition (seals, etc.)
	Pack for transport	Detection shield Transport medium (container)
	Conceal theft	Provide cover for missing material Avoid detection
	Egress building	Defeat technical security systems Avoid detection by building guards
	Egress site	Avoid detection by site guards Avoid other detectors Exit facility
	Store material (temporary)	Provide appropriate safeguards and security Conceal from inadvertent discovery

Table 5. *Level 2 and 3 task descriptions for brokering*

Level 1	Level 2	Level 3
Brokering	Identify broker (search)	Prior contact Link through friends Link through other association Initiate unstructured search Focus search
	Identify broker (contact stage)	Establish communication Check broker validity Broker checks buyers validity Negotiate sale
	Negotiate sale (with broker)	Provide sample of material (if desired) Broker may conduct material assay Reach agreement on all pertinent details
	Transport material to broker	Remove from interim storage Transport to rendezvous site Provide appropriate security
	Consummate sale	Verify payment Turn over material Provide for personal security
	Return to "normal" life profile	Secure funds from sale Avoid suspicion from change in lifestyle Maintain cover

Table 6. *Level 2 and 3 task descriptions for sale to customer*

Level 1	Level 2	Level 3
Delivery to customer	Locate buyer	Begin structured search Use prior contacts Prearranged sale Establish buyer's credentials
	Negotiate sale	Establish communication with buyer Arrange terms of sale Establish schedule
	Identify material	Buyer evaluates sample (if desired)
	Prepare for transport	Plan route and transport method Prepare documentation Prepare shipping container Arrange transport (road, rail, air)
	Transport	Security and surveillance Logistic support Communications arrangements Hand off procedures Maintain cover
	Cross international borders	Proper documentation Avoid detection of material Escape detection if border crossed illegally
	Consumate sale	Payment from customer Verify payment
	Final delivery	Turnover of material Each side verifies transaction as agreed Customer may assay material
	Return to "normal" profile	Maintain cover indefinitely Avoid suspicion from change in habits Maintain "business as usual" activity

execute theft, brokering, and sale processes are specified; likely facilities and materials and their special characteristics that would make them attractive targets for a theft and smuggling scenario are documented. Experts studying this kind of blueprint could identify weaknesses and vulnerabilities in all system components for which countermeasures should be developed. For example, the model could be used to develop a task analysis of what a thief would have to do to steal materials at a particular facility. The first steps would be to develop the appropriate system element array and decompose more general, higher level elements into lower level and more specific people, skills, resources, motives, activities, equipment, etc. At a very basic level, this kind of analysis would entail defining what thieves would have to do to steal the materials and what they would need to execute the theft. With this information, it would be possible to develop countermeasures.

A security manager might do a task and requirements analysis on what would be needed to steal a spent fuel cask from a given storage location. Requirements would include special lifting equipment, shielding materials, and a truck for transport. Countermeasures developed from this information might include placement of concrete road barricades to deny nonauthorized access to the building, and removing the chain from the hoist in the storage building when the hoist is not in use. These measures would not stop determined thieves but would add more obstacles to stealing a cask.

In thinking about this application, recall the thefts of nuclear material from the two naval fuel storage bases at Andreeva Guba and Sevmorput Shipyard. It was readily apparent from the investigations following the thefts that physical security of the facilities as well as protection of the nuclear material within the facilities were inadequate. It is obvious that the security managers had not done an adequate security analysis of their facilities.

The system structure that emerges from application of the model is also useful for defining what information should be monitored concerning off site activities which may be of direct relevance to security on a site. Brokering functions and the requirements for the subsequent stages of theft are obvious areas for careful scrutiny. By adopting a holistic view of the theft process, law enforcement personnel at various levels can also identify information which should be shared among agencies to deny access or respond more quickly.

Postincident Investigations

If a theft has already occurred, the nuclear smuggling pathway model can be applied in the postincident investigation to reconstruct the likely events surrounding the theft and, from that, gain insights on the probable brokering and sale scenarios. Reconstruction will enable identification of the vulnerabilities that allowed the security system to be breached. The detailing of necessary inputs, decomposition of activities, and the analysis of the context in which the theft of particular materials occurred may also help point to possible suspects involved in the theft, likely participants in the brokering process, and probable final location of the stolen materials. In systems terminology, event or incident reconstruction provides important *feedback* to the system about vulnerabilities and the effectiveness of current countermeasures.

In the analysis process, an analyst can quickly structure the reported information and make an evaluation of what may have happened or what was required to allow the theft to happen. The framework will provide the means for an analyst to infer what human and other resources were needed to carry out the theft. For example, if a theft could not have occurred without inside access to information and equipment, an analyst can develop reasonable inferences about who needed to be involved and what they needed to do. The model is especially useful in cases where very limited information is available because it helps define what specific data are missing and where useful information may be found to fill in the blanks.

While the model could be applied to any case and yield results, it would be especially helpful in complex cases such as the Tengen incident. On May 10, 1994, German police in Tengen discovered by chance a vial containing 5.6 grams of nearly pure Pu-239 in the garage of a petty criminal under investigation for counterfeiting. The origin of the material is not certain, although there is speculation that it came from Arzamas-16 in Russia. There are many other questions that remain unresolved, to include who did the brokering and were the intended customers; speculation includes a KGB-Bulgarian-Iraqi nuclear supply chain with Iraq and North Korea as the most frequently mentioned potential customers in press reports.[2] Application of this methodology to this case could result in a robust assessment of facts and speculation, and this could ultimately yield new insights.

Integration of Multisource Information

The major difficulty or weakness of taking a singular versus holistic approach to the nuclear security problem is that a narrow focus will restrict what information is considered relevant for either a risk assessment or a postincident investigation. The components (and their constituent elements) in the system we have defined as protracted nuclear theft and smuggling are not simply independent sets of factors and events whose sum defines a particular nuclear theft and smuggling scenario—they are interrelated and will affect each other and the outcome of any theft and smuggling attempt. The nuclear smuggling pathway model helps integrate information from multiple sources by providing a tool for analyzing the effect of each source of information on the overall situation.

By providing a framework of the entire theft process, whether protracted or abrupt, plus any additional activities such as brokering and sale of nuclear material, an analyst has an additional means to interpret observed events that may have significance for nuclear materials security. This includes developing an understanding of what information would be useful to know about the operation and capabilities of potential brokers in a locale, the growing or declining state of organized criminal groups in an area, and so forth. In short, the model allows analysts to organize many disparate pieces of information which may appear unrelated, to identify gaps in knowledge which need to be filled, to assess events that are observed, and to assist in the development of countermeasures designed to protect material and personnel.

User Insight

Yet another benefit of utilizing a systems approach to the nuclear security threat problem is the clarity inherent in using the general systems approach. Following the top-down procedure, the system can be defined initially with only the very basic input, transformation process, and output components. Each of these major components can then be decomposed to whatever level of detail is desired. There is no special terminology or notation to be learned; the model uses whatever terminology and notation is appropriate to the system being analyzed. The only major requirement of analysts to use the model is sufficient knowledge of the system or portion of the system they are contributing information for decomposition and detail. For very complex and extensive systems, using a team of specialists or experts to jointly develop the decomposed model may be preferable to having individual specialists provide the decomposition of their areas of expertise and then relying on others to ensure integration among the separate contributions.

Comparison to Existing Approaches

The U.S. national security community has tended to approach nuclear security problems by focusing protective strategies on specific facilities. As a result, an integrated national level strategy for analysis and management does not exist. Additionally, sites have the initial responsibility for other high profile activities:

- The protection of nuclear material
- Response to a potential nuclear theft scenario
- Containment of adversaries
- Recovery of material while it is under the jurisdiction of the site protective forces
- Management of an emergency until relieved of the responsibility by federal authorities.

While the U.S. Material Protection, Control and Accounting (MPC&A) Program represents an integrated system of physical protection, material control, and material accounting measures designed to deter, prevent, detect, and respond to unauthorized possession, use, or sabotage of nuclear materials, the system measures cover the materials only while they remain on site. There is no integrated follow-on system for search, detection, and reaction. On site, DOE has responsibility; off site, the Federal Bureau of Investigation has responsibility for the material's recovery. This fragmentation of responsibilities does not allow for continuity in the management and analysis of a theft situation.

Notes

1. L. Markus, personal communication; R. Zmud, personal communication.

2. Phil Williams and Paul N. Woessner, "Nuclear Material Trafficking: An Interim Assesstment," *Ridgway Viewpoints No. 95-3* (University of Pittsburg, PA:The Matthew B. Ridgway Center), 12.

4.

ILLUSTRATIONS OF THE FRAMEWORK

To illustrate the use of the nuclear smuggling pathway model, two cases will be viewed, one a known supply-side transaction and the other a demand-side example. As mentioned earlier, all the significant diversions of nuclear material that have occurred since the collapse of the Soviet Union have been supply-side—that is, they were initiated by someone inside a nuclear facility with access to the material but probably no customer at the time of theft. We know of no real-world demand-side case initiated by an end-user such as a state or terrorist group. In addition to developing an indigenous capability to produce both highly enriched uranium and plutonium, Iran has launched a parallel effort to purchase fissile material from sources in the former Soviet Union.[1] To illustrate use of the model, however, we will use Iraq as a hypothetical demand-side case, drawing on information collected on the Iraqi nuclear weapons program by International Atomic Energy Agency (IAEA) inspectors after the Gulf War.

Supply Side

We chose the seizure by Czech authorities of 2.7 kilograms of 87.7 percent enriched uranium 235 to illustrate use of the nuclear smuggling pathway model from the supply side of a protracted nuclear theft. The seizure, which occurred in Prague in December, 1994, was notable both for the amount of nuclear material seized and the high enrichment of the material. Responding to an anonymous tip, Prague police seized the highly enriched uranium, contained in two cylindrical containers, from the back seat of a car parked in a city street. Police arrested three individuals, all of whom had backgrounds in the nuclear industry. The car's owner had previously worked at the Nuclear Research Institute at Rez and at two nuclear power stations. He reportedly left his last job at one of the power stations because of poor wages. The other two individuals, one from Belarus and the other from Russia, had been previously employed as "nuclear workers" and had recently come to the Czech Republic.[2]

A complete system decomposition of this incident is not in the scope of this unclassified paper. In lieu of extensive depth, we shall present greater breadth– showing how system decomposition can begin anywhere in the basic systems model (e.g., inputs --> transformation processes --> outputs --> environment/feedback). Figures 10a through 10d show the system decomposition applied to the Czech seizure and based on input, transformation process, output, and context/environment information about the case available in unclassified documents.

System decomposition provides structure and detail to information and suggests new pathways to understand and interpret the available information and to collect additional information. When system decomposition begins with *inputs* (table 10a), structure and detail about people, motives, and resources emerge. In the Czech seizure example, system decomposition about people approaches the detail necessary for identification of specific individuals. Because the information available regarding motives and resources is sketchy, an appropriate strategy for system decomposition is to continue to fill in detail elsewhere in the system and to gather information from other sources (e.g., other law enforcement agencies and databases). The recommended strategies are indicated in figures 10a-10d with the symbols (*) and (#).

Little detail and considerable gaps in structure beyond Level 3 sub-elements are evident in the information available in figure 10b on the theft of the material recovered in the Czech seizure. However, the brokering and sale *process* decompositions suggest some avenues of inquiry for this supply-side scenario. Pursuing pathways related to potential brokers/buyers may guide an analysis or investigation toward links with nuclear security threats that originate from the demand side.

System decomposition that begins with *outputs* (figure 10c) summarizes the current situation's "bottom line:" (1) the theft was successful and resulted in the removal of a substantial amount of highly enriched uranium (HEU); the amount and enriched level of material flag this information as extremely important; (2) brokering and/or sale of the material was only partly successful; although a connection was established to transfer the stolen material, the transfer was interrupted through an anonymous tip. The search strategy suggested is for obtaining additional information about the theft and brokering from other sources and from continued system decomposition (e.g., of materials and processes).

System decomposition that begins with the context/environment (figure 10d) provides both the background and critical detail to the event or incident being analyzed. In the Czech seizure example, little information is available (in unclassified documents) about the facilities from which the material was, or could have been, removed. Although theoretically it is possible to identify a facility by the unique "signature" of the material handled (e.g., enriched, reprocessed, etc.) there, it is not always actually possible to do so nor is it possible to do so with absolute accuracy. Information about the unique signatures of stockpiled nuclear materials necessary to identify the originating facility is not always shared by governments. Also, nuclear material (cocktails) created to hinder efforts at tracing material constrain identification of the source of nuclear materials.[3] The information about the material in the Czech seizure is notable for its amount and level of enrichment. The inability to link the material to a facility limits the additional detail that can be provided with the available information. The existence of hundreds of sites from which material may have been removed in the FSU compounds the difficulty of the analysis of material information.

For this example, the richest source of information for analysis and inference may lie in the system decomposition of the context provided by the surrounding national and international events, or conditions and the social environment against which the theft and brokering events unfolded. Clues about potential brokers and buyers can flow from a detailed analysis of the available information on the political and social context that precipitated both the theft (supply side) and the desire for nuclear materials by others (demand side).

A number of benefits accrue to the analyst or investigator who applies the NSPM as demonstrated here. First and foremost, it assists in the structuring and organizing of large amounts of disparate information at any level of detail to include known facts and speculation. This in turn results in the display of information in an

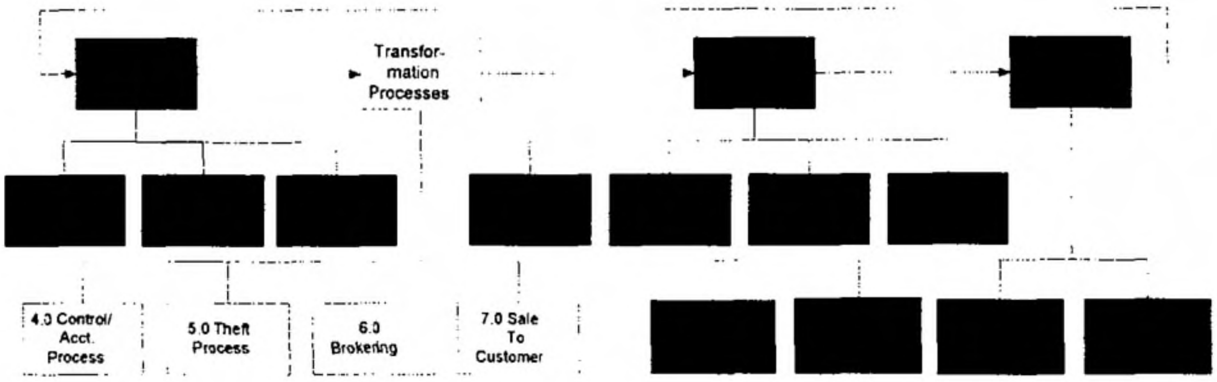
Figure 10a. *System decomposition that begins with inputs*

1.0 People	**1.1 Ad hoc group**	**1.1.1 Specialized skills/ knowledge**	**1. Technical** **2. Nontechnical**	**1. Nuclear physicist** **2. Former nuclear workers (2)**
		1.1.2 Insider/outsider	1. Former insider	1. Access to material, information, other insiders
		1.1.3 Criminal record	1. No	*
		1.1.4 Nationality	1. Czech 2. Russian 3. Belarusian	*
		1.1.5 Associates	1. No criminal/ terrorist associates	* #
2.0 Motives	2.1 Instrumental value	2.1.1 Money 2.2.1 Retaliation	*	
3.0 Resources	3.1 Equipment	3.1.1 Container for storage, transport	1. 12″x4″x0.16″thick cylindrical container; no additional shielding	
	3.2 Information and data	3.2.1 Location of material; access; records procedures	1. Former insider	*
	3.3 Insider connection	3.3.1 Former insider	*	
	3.4 Money	3.4.1 ?	#	

* Go to another component (i.e., inputs, processes, outputs, context/environment)

\# Obtain information from other sources

Figure 10b. *System Decomposition that begins with Transformation Processes*



Level 1	Level 2	Level 3	Level 4	Level 5
4.0 Control/Accounting Process	4.1			
5.0 Theft Process	5.1 Planning	5.1.1 Access	1. Former insider	* #
	5.2 Entry	5.2.1 Access required 5.2.2 Defeat sensors/ detectors	1. Former insider	* #
	5.3 Identify object of theft	5.3.1 ?	1. Former insider	* #
	5.4 Pack for transport	5.4.1 Detection shield 5.4.2 Accompanying certificate	1. 12"x4"x0.16" thick cylindrical container; no additional shielding required 2. Automobile 3. Certificate written in Russian	* #
	5.5 Conceal theft	5.5.1 Locate records 5.5.2 Access records 5.5.3 Alter records 5.5.4 Replace records 5.5.5 Avoid detection	1. Former insider	* #

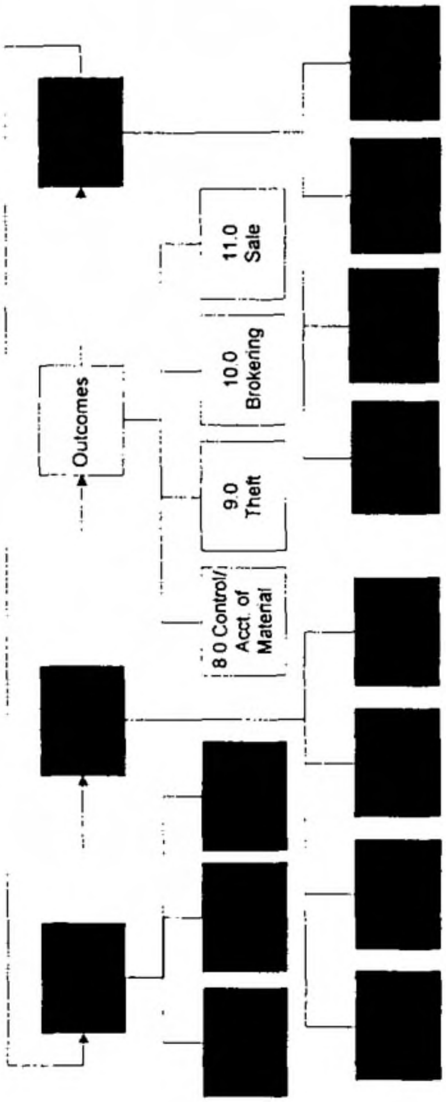
Level 1	Level 2	Level 3	Level 4	Level 5
	5.6 Escape undetected	5.6.1 Defeat alarms; sensors/ detectors 5.6.2 Avoid detection by guards	1. Former insider	* #
	5.7 Store material (temp.)	5.7.1 ?	*	
6.0 Brokering	6.1 Identify broker/buyer	6.1.1 Prior contact 6.1.2 Link through friends 6.1.3 Link through other associates 6.1.4 Initiate unstructured search	1. No 2. No/? 3. ? 4. ?	3. Russian researcher; Nigerian drug dealers; Irani and Iraqi agents #
	6.2 Negotiate sale	6.2.1 ?	*	
	6.3 Remove object from storage	6.3.1 ?		
	6.4 Transport object	6.4.1 Unmodified automobile	* #	
	6.5 Arrange for sale	6.5.1 ?	*	

Level 1	Level 2	Level 3	Level 4	Level 5
7.0 Sale to customer	7.1 Identify customer	7.1.1 Prior contact 7.1.2 Link through friends 7.1.3 Link through other associates 7.1.4 Initiate unstructured search	1. No 2. No/? 3. ? 4. ?	3. Russian researcher; Nigerian drug dealers; Irani and Iraqi agents #
	7.2 Customer verifies object	7.2.1 ?	1. Russian researcher; Nigerian drug dealers; Irani and Iraqi agents #	
	7.3 Receive payment for object	7.3.1 Sale not completed		
	7.4 Transfer object	7.4.1 Sale not completed		

* Go to another component (i.e., inputs, processes, outputs, context/environment)

Obtain information from other sources

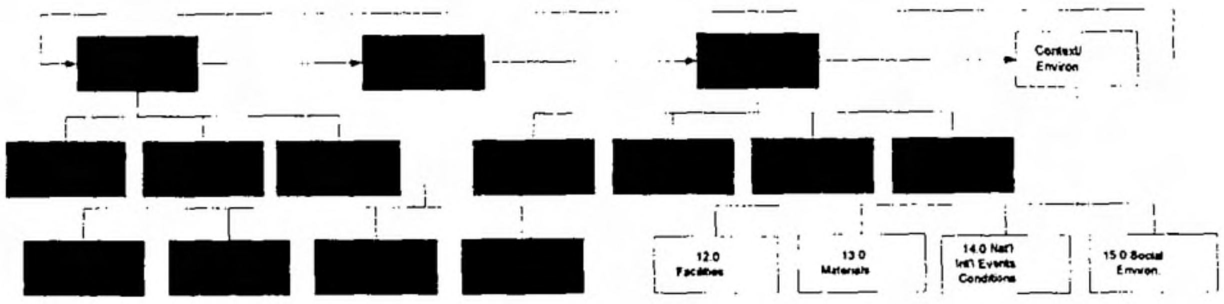
Figure 10c. *System Decomposition that begins with Outputs*



Level 1	Level 2	Level 3	Level 4	Level 5
8.0 Control/Accounting of Material	8.1 Outcome	8.1.1 Successful 8.1.2 Unsuccessful	#	
9.0 Theft	9.1 Outcome	9.1.1 Successful	1. Undetected 2. Brokering initiated 3. Date discovered	1. 2.7 Kgs U235 removed ///////////////////// ///////////// * #
		9.1.2 Unsuccessful	1. N/A	
10.0 Brokering	10.1 Outcome	10.1.1 Successful	1. Contact made	* /////////////
		10.1.2 Unsuccessful	1. Brokering interrupted	1. Anonymous tip #
11.0 Sale	11.1 Outcome	11.1.1 Sale completed	1. N/A	
		11.1.2 Sale not completed	* #	
	11.2 Potential for future deals	* #		

* Go to another component (i.e., inputs, processes, outputs, context/environment)
\# Obtain information from other sources
/////// Flag important; Red flag critical
N/A=Not Applicable

Figure 10d. *System Decomposition that begins with Context/Environment*



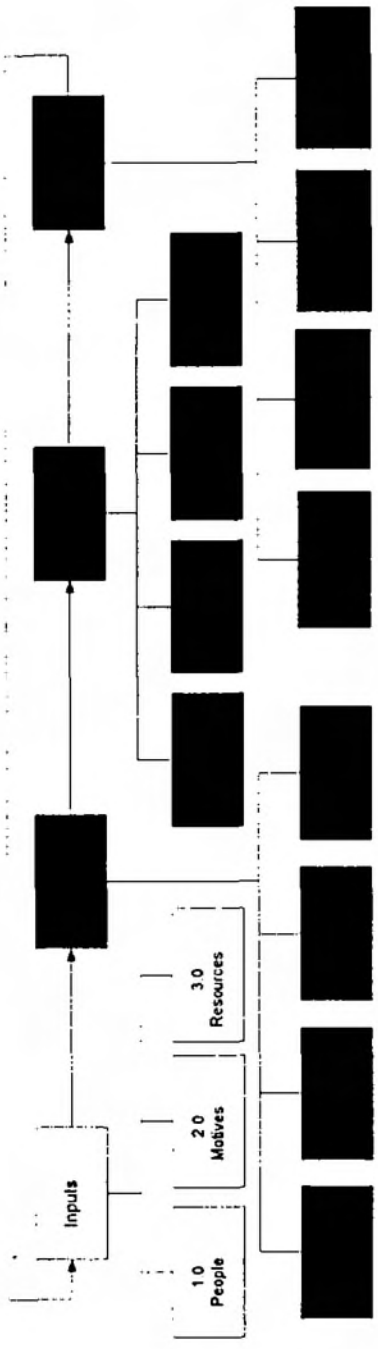
Level 1	Level 2	Level 3	Level 4	Level 5
12.0 Facilities	12.1 Russian Navy storage site 12.2 FSU fuel fabrication plant 12.3 FSU nuclear power stations (former places of employment) 12.4 Any of 950 potential sites for enriched uranium and plutonium in FSU	12.1.1 Unique signatures?	* #	
13.0 Materials	13.1 87.7% U235	13.1.1 2.7 Kgs.	1. Related to HEU seized by German police in Bavaria?	* # /////
14.0 National/International Events & Conditions	14.1 Location: FSU 14.2 Willingness of governments to cooperate 14.3 Political conflict	14.1.1 Russia, Czechoslovakia, Belarus 14.2.1 Varies 14.3.1 FSU, SE Asia, Middle East, Africa, etc.	* #	
15.0 Social Environment	15.1 Underdeveloped economy 15.2 Newly democratizing 15.3 Social/economic collapse 15.4 Political unrest	1 Depressed economy; job loss 2. Economic hardship; economic disparity 3. Lack of control; loss of order 4. Search for remedies	1. Increase in crime 2. Frustration 3. Emergence of new social, economic classes; black market economy	* #

* Go to another component (i.e., inputs, processes, outputs, context/environment)

\# Obtain information from other sources

///// Flag important; Red flag critical

Figure 11a. System decomposition that begins with inputs



Level 1	Level 2	Level 3	Level 4	Level 5
1.0 People	1.1 Established group	1.1.1 Specialized skills/ knowledge	1. Technical 2. Nontechnical	1.1 Uranium enrichment 1.2 Weapons design 2.1 International finance 2.2 International marketing
		1.1.2 Criminal record	1. ?	* #
		1.1.3 Nationality	1. Iraqi 2. Jordanian	* #
		1.1.4 Associates	1. ?	* #
2. Motives	2.1 Instrumental value	2.1.1 Nuclear weapons 2.1.2 Money (suppliers) 2.1.3 Credible threat	1. Likely uses of weapons 3. Likely targets of threat	1. Terrorist activities, * # 3. Aggression, * #
3.0 Resources	3.1 Equipment	3.1.1 EMIS systems 3.1.2 Gas Centrifuge systems 3.1.3 Pu production systems 3.1.4 Weapons fabrications systems	-Likely sources for acquisition -Infrastructure necessary to support systems	* #

Level 1	Level 2	Level 3	Level 4	Level 5
	3.2 Information and data	3.2.1 Information about materials needed 3.2.2 Information about suppliers 3.2.3 Specifications for equipment	-Public availability of information -Classified information sources (legit and illegit)	* #
	3.3 Insider connection	3.3.1 Suppliers of common and unique components	* #	
	3.4 Money	3.4.1 Legitimate and illegitimate sources	-Finance and banking -Criminal activities	* #
	3.5 Other: strategy	3.5.1 Maintain cover	3.5.1 purchase low profile items 3.5.2 Avoid "trigger list" items 3.5.3 Build covert supplier network	* #

* Go to another component (i.e., inputs, processes, outputs, context/environment)

\# Obtain information from other sources (e.g., law enforcement, intelligence, nuclear-related agencies) understandable format that facilitates the integration of information from multiple sources. The analyst then has a complete or holistic picture of what is known and what is not known about a situation,thereby greatly enhancing the analyst's ability to identify gaps, to plan, and to draw conclusions.

Demand Side

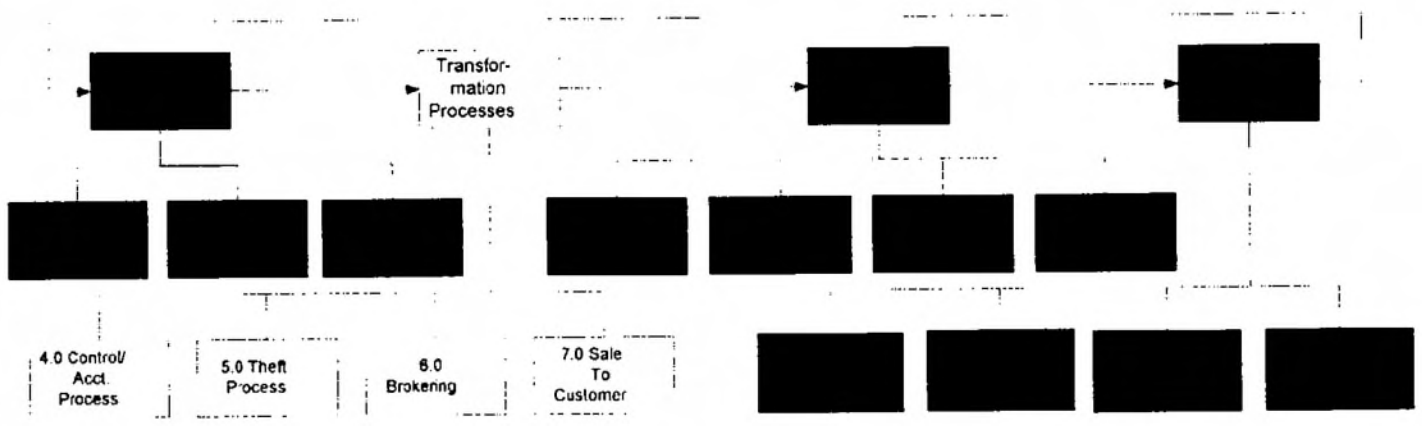
As stated earlier, we used the NSPM framework to evaluate Iraqi acquisitions for developing their nuclear weapons capability to illustrate a demand side scenario analysis. Information for this analysis was taken from testimony provided at a joint hearing of the Subcommittees on Europe and the Middle East and International Security, International Organizations and Human Rights regarding the International Atomic Energy Agency (IAEA) inspections conducted in Iraq after the Gulf War. The subcommittee report concluded that Iraq:

- Has reconstructed 80 percent of its military manufacturing capability it possessed before *Desert Storm*
- Has re-established its clandestine procurement network, using "front" companies in Jordan, France, and Germany to purchase critical items and spare parts for its weapons industries
- Has developed an internal scientific and technical infrastructure and expertise necessary to support a weapons program
- Continues to represent a major threat to world peace.

Figures 11a through 11d show the results of a system decomposition for each of the system elements in this demand side scenario.

Organizing the available information on Iraqi acquisitions for developing nuclear weapons capability within a systems framework allows an analyst to integrate the large amount of information available on the people, motives, and resources (system *inputs*) associated with this scenario. While an analysis of relevant inputs to Iraqi acquisitions could be quickly overwhelmed with detail, the NSPM provides a structure that can effectively deal with increasing complexity and detail. As more detail is added in the system decomposition for information available on *processes* associated with the Iraqi acquisitions, the connections between process and inputs becomes clearer. For example, the processes used to procure materials and

Figure 11b. *System Decomposition that begins with Transformation Processes*

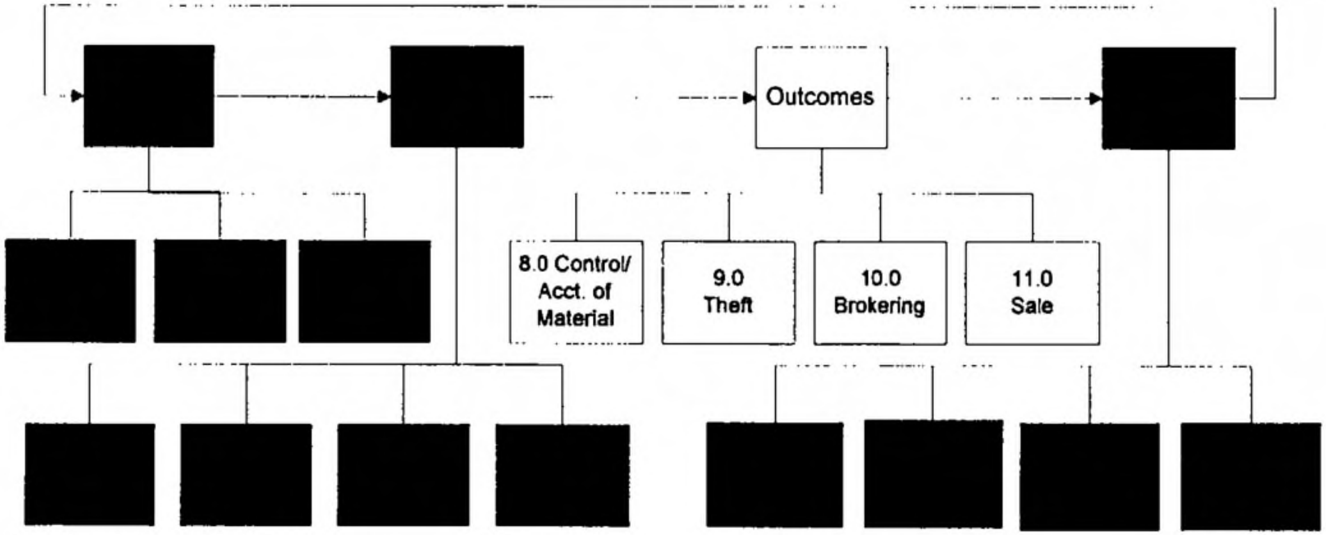


Level 1	Level 2	Level 3	Level 4	Level 5
4.0 Procurement and acquisition process	4.1 Procurement through cover organizations	4.1.1 Identify potential cover organizations or establish them 4.1.2 Negotiate business relationship or incorporate organization 4.1.3 Place own staff in organization 4.1.4 Maintain legitimate business relationships	* #	
	4.2 Detail requirements needs	4.2.1 Identify potential sources of requirements 4.2.2 Negotiate purchases 4.2.3 Conduct purchases 4.2.4 Track needs acquisitions	* #	
5.0 Maintain cover	5.1 Cover activities	5.1.1 Purchase common subcomponents for critical equipment 5.1.2 Trans shipment 5.1.3 Utilize collaborators 5.1.4 Conceal operations	-Dual use items -Chilean companies -Covert supplier network	-Capacitors, * #

* Go to another component (i.e., inputs, processes, outputs, context/environment)

Obtain information from other sources (e.g., law enforcement, intelligence, nuclear-related agencies)

Figure 11c. *Decomposition that begins with outputs*

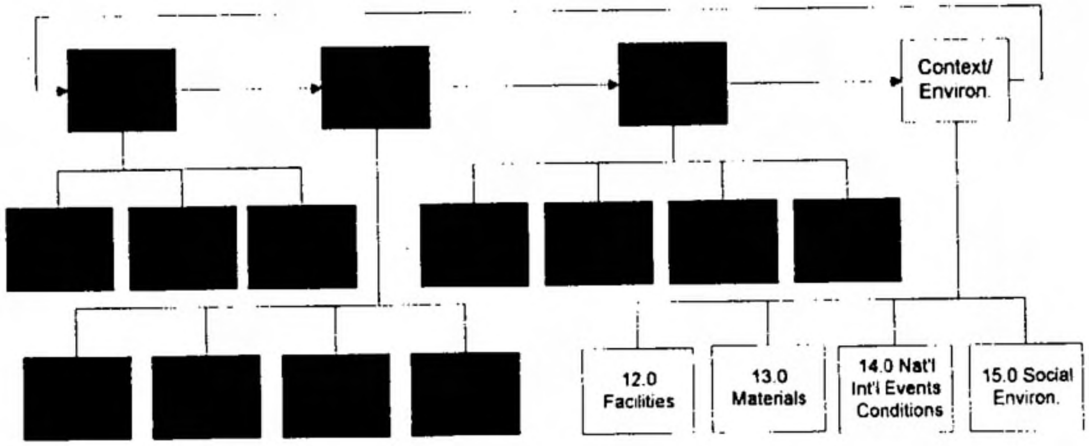


Level 1	Level 2	Level 3	Level 4	Level 5
1.0 Nuclear weapons capability	1.1 Military manufacturing capability 1.2 Internal scientific and technical infrastructure and expertise	1.1.1 80% reconstructed 1.1.2 Networks established to purchase items and parts 1.2.1 Being developed	-"Front" companies re-established in Jordan, France, Germany	* #
2.0 Terrorist activities	2.1 Capabilities required	* #		

* Go to another component (i.e., inputs, processes, outputs, context/environment)

\# Obtain information from other sources (e.g., law enforcement, intelligence, nuclear-related agencies)

Table 11d. *Decomposition that begins with Context/Environment*



Level 1	Level 2	Level 3	Level 4	Level 5
6.0 Facilities	6.1 Construction	6.1.1 Conceal real use	1. Non-standard configuration 2. Buried structures 3. Dispersed structures 4. Dummy structures 5. Minimal overt security	* #
	6.2 Purchase facilities	6.2.1 Conceal real use	1. Dual use facilities 2. Unobtrusive renovations	* #
	6.3 Operate facilities	6.3.1 Conceal real operations	1. Bury high profile power lines 2. Disguise emissions 3. Minimize suspicious traffic/equipment	* #
7.0 National/International Events and Conditions	7.1 Regional political context	7.1.1 Relations with Iran 7.1.2 Relations with Israel 7.1.3 Relations with other Middle East Nations	-Ongoing conflicts -Emerging conflicts -Alliances	#
	7.2 Relations with other weapons programs	7.2.1 Pakistan 7.2.2 China 7.2.3 North Korea 7.2.4 Others	-Ongoing conflicts -Emerging conflicts -Alliances	#

Level 1	Level 2	Level 3	Level 4	Level 5
	7.3 International relations	7.3.1 European nations 7.3.2 Americas 7.3.3 Others (includes U.N.)	-Economic relations -Ongoing conflicts -Emerging conflicts -Alliances -Sanctions	#
	7.4 Domestic political context	7.4.1 Control of Baata Party 7.4.2 Kurdish issue 7.4.3 Internal opposition	#	
8.0 Social environment	8.1 Political unrest 8.2 Depressed economy 8.3 Human rights violations	- Economic hardships - Emergence of new social, economic classes - Potential for revolution		

*Go to another componet (i.e., inputs, processes, outputs, context/environment

#Obtain information from other courses (e.g., law enforcement, intelligence, nuclear-related agencies) supplies requires considerable collaboration and networking to obtain the desired goods. Identification and investigation of individuals and groups (or companies) supplying materials (common and unique) to Iraqi companies can provide additional insight on supply-side activities that may be emerging.

As noted in the supply-side system decomposition for *outputs*, this analysis produces an organized summary of the basic facts of the scenario and helps link the facts to other relevant factors (i.e., inputs, processes, and context). In this case, the basic facts are the major findings of the IAEA reports from the inspections of Iraq.[4] Similarly, in the system decomposition of the context/environment in this demand side scenario summarizes relevant background information that can suggest connections among various inputs and processes that might otherwise not be evident.

Application of the NSPM framework to the Iraqi acquisitions demand-side scenario has not uncovered any new information. However, it has organized the existing information in a format that reinforces viewing information from different sources on different aspects of the situation. The framework also aids in directing the searches for additional information to several areas rather than only to one. Finally, the framework provides a means by which areas can be identified as appropriate for countermeasures to deal with existing or anticipated threat.

Notes

1. John Deutsch, Director of Central Intelligence, in a statement for the record, to the Permanent Subcommittee on Investigations, Senate Committee on Government Affairs, March 20, 1996.

2. This incident has been well covered by both press and scholars, among them: Allison, et al.; Potter, Mark Hibbs, "Czech find may be re-enriched, reprocessed uranium to fuel naval or research reactors," *Nuclear Fuel*, January 2, 1995, 12; and David Hughes, "Uranium Seizures Heighten Terrorism Concerns," *Aviation Week and Space Technology*, April 3, 1995, 63-64.

3. Mark Hibbs, "Which Fissile Fingerpring," Bulletin of the Atomic Scientists,(May/June 1994): 10-11.

4. Details of the Iraqi inspections are contained in several publications, including: *The United Nations and the Iraq-Kuwait Conflict, 1990-1996*, Dept. of Public Information, United Nations: New York, 1996; and Peter D.

Zimmerman, *Iraq's Nuclear Achievements: Components, Sources, and Stature,* Congressional Research Service (Washington, DC: The Library of Congress, February 18, 1993), rev. June 4, 1993.

5.
THE ROAD AHEAD

Conclusions

In testimony before the Senate in March 1996, John Deutsch, Director of the CIA, stated that "we've just been lucky so far," explaining why the world has not witnessed a very serious incident as a result of the considerable threat from real and potential illicit transactions in weapons-grade nuclear materials.[1] We were also reminded by William Potter of the Monterey Institute, in his article, "Potatoes Were Guarded Better," that the international community may be living with a false sense of complacency.[2]

To anticipate, mitigate and protect effectively against the increasingly complex, organized, and international nuclear threats, nuclear security systems and measures must be designed to reflect the complexity, organization, and scope of the threat. Approaches to nuclear security that take a limited, singularly focused, or unstructured perspective will no longer be adequate to meet the threat. The general systems model proposed in this paper provides a structured, holistic approach that provides a flexible tool to the U.S. national security community to match the complexity, organization, and scope of the current and future nuclear threat.

In this paper, we have presented a comprehensive model from which to understand and analyze various types of nuclear threats and then demonstrated the model's utility when applied to protracted theft and smuggling of nuclear materials. The strengths of the nuclear smuggling pathways model (NSPM) include:

- Broad application
- Understandable format
- Usefulness in structuring large amounts of information
- Ability to simplify complex situations

- Scalability for use at a national, international, or site levels (for pre- and post-incident analyses).

This general systems-based framework can also be used for developing effective countermeasures and interventions to mitigate increased threats to nuclear security and for identification of individuals and groups whose actions could hold nations hostage.

The application of the framework to supply-side and demand-side examples illustrates how existing information about an event or incident can be organized into a structure that allows better integration of information from multiple sources. The framework can also provide structure and detail to explorations of potential outcomes resulting from gaming scenarios about facilities, materials, international events, and changes in sociopolitical environments worldwide. These kinds of scenario-based explorations or exercises can be a basis for enhanced training for law enforcement and intelligence personnel for both better identification of threat risks and development of better countermeasures.

Next Steps

Realization of the potential offered by the Nuclear Smuggling Pathways Model (NSPM) requires that the model be adequately tested first. There are two stages of tests of the model: test and evaluation of the substantive elements of the model, and validation of the effectiveness of the overall model. The first stage of testing and evaluation can be completed through a review of the model, paying particular attention to the Level 1 and Level 2 elements, by a panel of experts. These represent the elements of the model that should be common to any application for which the model would be used. This was accomplished in a workshop on February 19, 1997 (appendix E). The second stage of testing is more challenging.

The most rigorous validation of the NSPM's effectiveness would use it to analyze a new theft or smuggling incident. However, because the attempted or successful thefts and selling of nuclear materials still occur relatively infrequently, waiting to validate the model on the next incident could prove untimely. Some alternative approaches to validating the model would include the following, all currently planned or under way:

- Comparing the results of application of the model in assessing the vulnerability of a facility with the results obtained from such an assessment conducted with currently used methods.
- Having law enforcement and intelligence experts use the model and evaluate its effectiveness for field investigative work.
- Evaluating the model's ability to integrate information and improve the coordination of actions of different agencies participating in scenario-based "war games."

The process of validating the model also affords the opportunity to evaluate the model's potential applications. We have already discussed applications related to post-incident investgations, risk assessment and the development of countermeasures, and integration of multi-source information (see chapter 3). Additional applications include:

- Event or emergency management
- Training of staff in risk assessment, postincident investigations, event mitigation, etc.
- Resource allocation planning at national and site levels.

Because of its basic structure, the NSPM can be automated for use in integrating information at various levels of detail from different individuals and groups. For example, the model could be used to evaluate threats at any level of detail by law enforcement personnel, nuclear security experts, intelligence officials, the national security community and individuals involved in determining national policy. As a training and analysis tool, the model can be utilized to conduct gaming analyses and for identifying trends or patterns of behavior or activity that may be indicative of security threats. The outcomes of these analyses can include more effective countermeasures that address threat within and outside the physical boundaries of any site.

Because the framework structure can be easily adapted into an electronic format, it can be used to turn information databases used within and across law enforcement and intelligence agencies into shared knowledge databases— databases of information that have been integrated and interpreted into a more useful form. As work across industries and occupations relies more heavily on the efficient and effective use of large amounts of information, all workers become information users. The information available to organizations and workers, however, has little value until it has been structured, organized, and turned into knowledge.

The framework described in this paper can help turn the databases of information on inputs, processes, outputs, and contexts within which nuclear threat exists into useful knowledge that can be readily shared across the agencies that help protect against all types of crime. Further application or use of the framework on which the NSPM is based could involve integration of the framework with different agencies' successful techniques and approaches for solving various kinds of problems.

Notes

1. John Deutsch, Director of Central Intelligence, in his oral statement to the Permanent Subcommittee on Inverstigations, Senate Committee on Government Affairs, March 20, 1996.

2. Oleg Bukharin and William Potter, "Potatoes Were Guarded Better," *The Bulletin of the Atomic Scientists* (May/June 1995): 46-50.

APPENDIX A:
Nuclear Material Susceptible to Theft

Proliferation

Nuclear fission materials are of value for two main reasons: the commercial value as fuel for power plants and ships, and for use in making nuclear fission weapons. The primary focus of all international control programs over the past 40 years has been on preventing the spread of nuclear materials that can be used in weapons. The principal discussion here will focus on materials to make fission weapons.

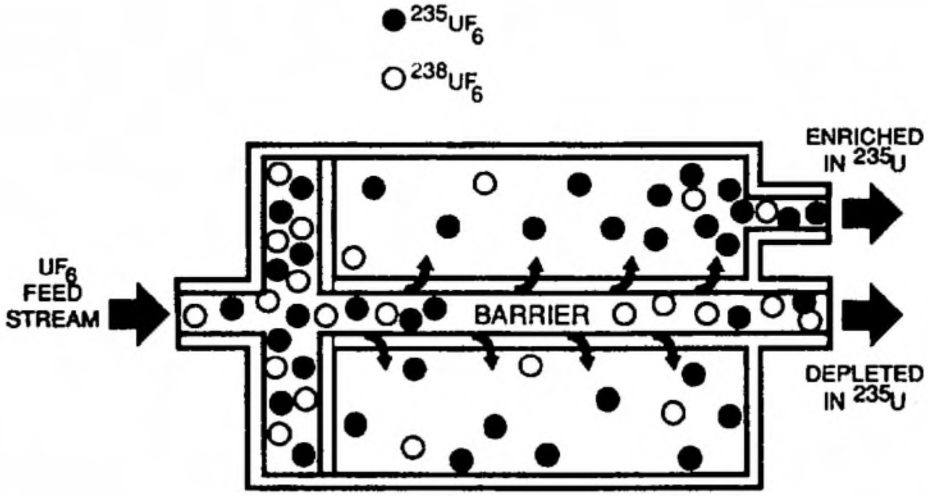
Early in the nuclear era, the technology and scientific base required to build nuclear weapons was well beyond any except the most wealthy and technically sophisticated countries. Until the late 1960s only the United States, the Soviet Union, France, Great Britain, China and India had demonstrated the capability to build workable nuclear devices. The principal barrier to developing fission weapons had been the ability to isotopically separate uranium-235 or create weapons grade plutonium-239.

At the beginning of the nuclear weapons era, the United States was able to develop two means of making fission bombs: enrichment of uranium and chemical separation of plutonium which had been created in a reactor. In the early 1950s the United States began building a stockpile of several thousand nuclear war heads. The technology and industrial infrastructure needed to make huge quantities of enriched uranium and plutonium was both highly complex and massive in scale.

The principal technology for enrichment was called gaseous diffusion (figure A-1). This involved isotopically separating the lighter fraction of U-235 occurring in natural uranium from the heavier U-238. The facilities for doing this work were gigantic. The K-25 plant at Oak Ridge, Tennessee covered over 50 acres and had a workforce of 9,500 during peak operation. Two other facilities at Portsmith, Ohio, and Padukah, Kentucky, were of similar size.

Uranium enrichment using the technology of gaseous diffusion was well beyond the capabilities of any but the most wealthy and technically sophisticated countries. In addition, the technology required huge amounts of electricity, which was simply beyond the capacity of most nations to provide. For example, in the early 1970s the U.S. enrichment facilities used almost as much electric power as the state of Illinois each day.

Figure A-1. *Gaseous diffusion process*



Because gaseous diffusion was essentially beyond the capabilities of most potential proliferators, the international arms control community focused attention on the most likely route to proliferation, which was making plutonium-239 in a reactor. Most of the controls devised and implemented under the Non-Proliferation Treaty were based on controlling the quantities of Pu-239 which were allowed to accumulate in any non-weapons country.

Over a period of nearly 50 years, several changes have emerged. One has been the spread of the knowledge required to make weapons or make the facilities necessary to make weapons. A second change has been in the technology needed to isolate the fissionable isotopes for weapons. Finally, a change has come about in the needs of various parties who might desire to have weapons.[1]

The knowledge base required to make nuclear weapons was initially the exclusive province of a few weapons states. However, the development path was based on published fundamental physics, that could be mastered by a competent group of scholars. Much of the engineering information needed to build a weapons complex had been in the public sources for decades. Thus, the knowledge base was not a limitation on any nation state that had weapons ambitions and would devote the necessary resources to building up a cadre of scientific and technical personnel.

The skills and support technology required to make either of the weapons were far more demanding than for making other types of explosives, or for making chemical weapons. However, they were well within the capabilities of a nation state. Since 1980, there have been several indications that the technical barriers to creating nuclear weapons are still formidable, but not nearly as formidable as in the 1950s and 1960s. South Africa developed six weapons before eventually destroying them before international observers in 1993.[2] Several other nations were considered to be nuclear capable. The knowledge barriers had been down for some time. Technical barriers remained formidable, but not nearly so formidable as decades earlier.

At the conclusion of *Desert Storm,* IAEA inspectors discovered that Iraq had been pursuing development of nuclear weapons using an entirely unexpected route. The program had been built carefully over a decade by using a mix of technology long since rejected as too inefficient by the major nuclear powers. The Iraq program was based on enriching uranium using calutron technology, which combines newer gas centrifuge technology with an old form of electromagnetic arc separation. Such a process involves several small units and also requires far less electricity than gaseous diffusion.[3]

Intelligence analysts initially missed the direction that Iraq was moving, in part because the technology being used was considered antiquated and in part because it did not provide the obvious intelligence signature of a gaseous diffusion plant. It became evident in hindsight that Iraq was moving toward production capability for a few weapons, not for thousands. Thus, the capability they were building was aimed at producing tens of weapons per year, not hundreds. Iraq had originally attempted to build a reactor capable of producing plutonium, but the Israeli Air Force obliterated that plant in a 1983 raid. The second attempt at producing weapons had then taken a totally different route, one that was not expected.

What had been a limitation on national ambitions was the size and scale of some parts of the technology. The creation and separation of fissionable uranium and plutonium are not simple tasks. As noted, enrichment is a costly and demanding technology. Natural uranium contains only about 0.7 percent U-235; it must be enriched to at least 20 percent U-235 before it can be used in any weapon.

The major weapons states used a process called gaseous diffusion to enrich uranium to over 90 percent U-235 composition. Such enrichment levels produce weapons of higher explosive power than would lower enrichment levels. The process for producing such purified U-235 in sufficient quantities to create weapons is very expensive and time consuming and requires huge industrial complexes to produce.

Producing plutonium-239 was a relatively simpler route to take to a weapons capability. It involved creation of Pu-239 from U-238 through fission in a reactor. The Pu-239 can then be chemically separated from the other elements to obtain the weapons usable material. The chemical separation is a relatively simple process compared to the isotopic separation required to obtain uranium-235.

The term "easy" should be taken in context here. Extracting Pu-239 required physical and technical resources that generally can be provided only by a nation state. Although relatively less complex than isotopic separation, the processes are still very demanding and can be carried out only by highly skilled personnel with good equipment.

When separated, both U-235 and Pu-239 can be fabricated into a nuclear fission weapon by a capable designer. U-235 weapons can be made to detonate with a far simpler design that required by a Pu-239 device. The U-235 weapon can be exploded by simply impelling two subcritical masses together. This is referred to as the "gun" design. Detonation of Pu-239 requires simultaneous implosion of a subcritical sphere of Pu metal; the implosion is driven by a conventional explosive. If the implosion is not uniform, the weapon will not detonate or will produce a low-yield explosion (see appendix C for a discussion of fission weapons).

Part of the reason that obtaining weapons has become easier for nation states is that the technology needed to separate isotopes of uranium had advanced significantly. Driven in part by the competition for making fuel for civil nuclear power programs, new techniques for enriching uranium emerged in the 1970s and 80s. The gas centrifuge was a major innovation pioneered in Germany and developed independently in South Africa (figure A-2).

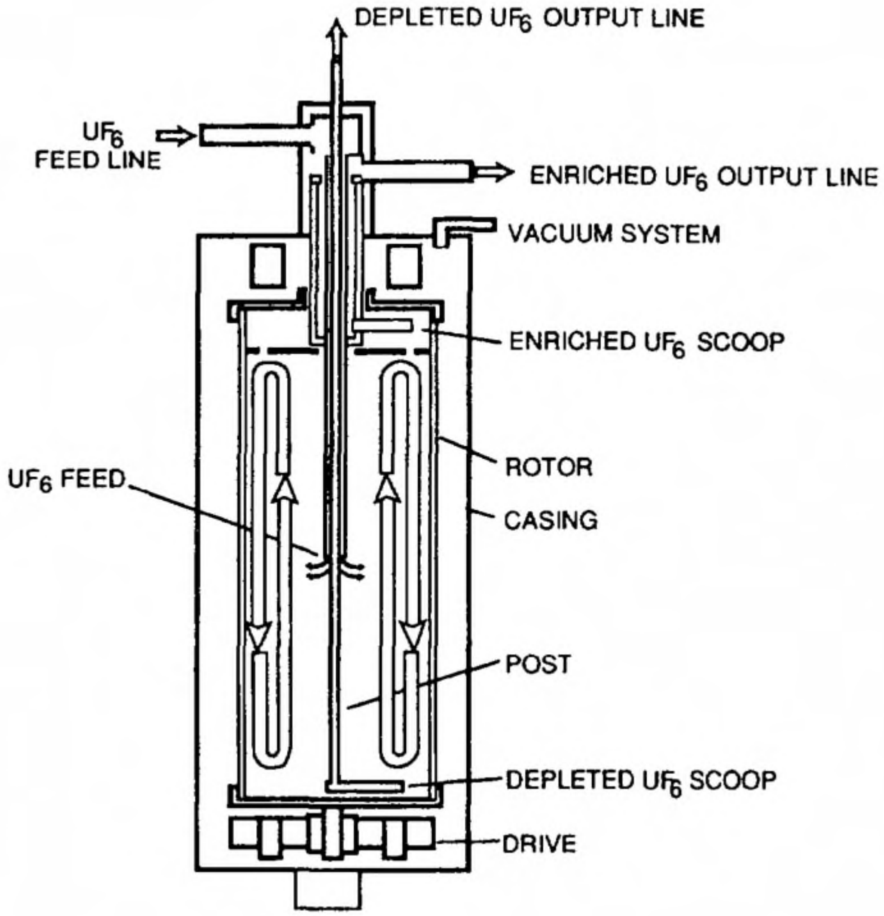
The Soviet Union also used centrifuge technology in its weapons program from the mid 1970s. The centrifuge was developed essentially in the open. The classification that had restricted information about the gaseous diffusion technology did not hinder the spread of knowledge about the centrifuge. In addition, the centrifuge required very minuscule amounts of electricity compared to that required by gaseous diffusion. Thus it became more within the reach of nations with the technical skill base and the determination to develop the capability.

Another technology that has emerged in recent years is laser isotope separation. This permits isotopes to be "stripped" from any mixture containing uranium-235 or plutonium-239. The other feature of laser separation worth noting is that it can be operated on a small scale to produce enough material for a few weapons.

There is also the issue of outdated technologies such as calutrons. Initially rejected by the United States because they could not produce the volumes of material required, these approaches have been re-discovered by potential proliferators who want an arsenal of 10 to 50 weapons rather than thousands.

This highlights the third element in the nuclear arms situation that has changed since the end of the Cold War. Nations and subnational groups with nuclear ambitions in the present world political situation have a broader range of goals than did the nuclear super powers. In the era of East-West deterrence, both sides had the capability to obliterate the other. This required thousands of war heads on both sides. The current aspirants to nuclear capability have more diverse goals. Nation states such as Iraq are seeking regional dominance as a basis for advancing their political agenda. To Iraq, possession of a dozen weapons becomes a formidable power base. Possession of 100 creates a dominant position in the region. Terrorist groups who might harbor nuclear aspiration can have an even wider set of objectives. While nation states might require that their nuclear explosive devices work at maximum efficiency and capability, terrorists might be satisfied with a suboptimal device, at least as seen by a skilled weapons designer.

Figure A-2. *Gas centrifuge process*



Terrorists might also be quite satisfied with a single weapon, even of limited capability, or even a radiological dispersal device (RDD). A radiological dispersal device is not a nuclear explosive but uses nonnuclear explosives to disperse radioactive material around an area. This is an attractive type of weapon for terrorists because they do not have to master the difficult technology of nuclear explosives, but can create significant damage or chaos by contaminating an area using a variety of nuclear materials, including some wastes, with conventional explosives. The contaminated area is likely to be relatively confined, since the dispersal will depend entirely on the power of the conventional explosive. It is very difficult to disperse plutonium or other heavy metals very far because they are so heavy and can be impelled only a few hundred feet by a conventional explosive. The impact would be primarily on the site where the conventional explosive detonated.

Thus, when thinking about what nuclear materials might be attractive to potential thieves in the current world, there is less certainty than there was prior to the end of the Cold War. Previously, it was generally believed that material controls had to be placed on the most critical or important materials in the weapons production cycle. The nuclear materials safeguards and accounting standards that have developed since the 1950s have focused on uranium and plutonium and specific quantities of each.

The International Atomic Energy Agency, through the Nuclear Non-Proliferation Treaty, has sought to apply full safeguards to both uranium-235 and plutonium-239. The IAEA has defined significant quantities of the materials to be 8 kg for direct use nuclear material (U-235 or Pu-239), and 25 kg of uranium enriched to 20 percent or more. Recently, critics have expressed the position that these figures are too high and that kiloton yield nuclear devices could be made from far smaller quantities of either substance. The Natural Resources Defense Council has proposed that the significant quantities of U235 and Pu-239 be redefined at 1 kg, and the significant quantity of 20 percent enriched uranium be reduced to 3 kg.[4]

What materials would have been of use to Iraq? Given that they were opting for enriching uranium rather than making plutonium, they would have been interested in obtaining partially enriched uranium. This would have saved them a significant number of passes through their calutrons. This could translate to saving several months or a few years in development time. Thus, any potential proliferator seeking to develop weapons using enriched uranium will find even low enriched uranium to be of potentially significant value to their program.

This issue of what materials will be of interest to a potential adversary has no simple definitive answer. The reason for this is that there are many diverse routes to either building a nuclear explosive device, or obtaining the necessary technology and feedstock materials to manufacture one. In the next section, we examine the range of options open to potential adversaries who would build their own weapons or weapons production capability. This background is essential to begin to understand what materials may be attractive to different categories of adversaries.

Attractive and Unattractive Materials

At the onset of this discussion it is important to emphasize that all nuclear materials are not of value in creating weapons. Almost without exception, the materials of interest to proliferators are the fissionable isotopes uranium-235, uranium-232, and plutonium-239. There are other materials that have considerable commercial value, such as hafnium, which is used in alloying throughout the nuclear industry. Such materials are often stolen because of their potential cash value. They also have some utility in weapons construction but are not generally considered as materials subject to safeguards controls.

There are other factors that define how attractive a given nuclear material may be to a thief. Uranium and plutonium must be refined and purified to a certain point before they become "interesting" to a proliferator. As noted, natural uranium ore has less than 1 percent of the fissionable isotope U-235. As such, unless it can be stolen in shipload quantities, it is of limited interest to a thief.

Essentially, the primary materials of interest for weapons purposes are highly enriched uranium (above 20 percent uranium-235 or -232), and plutonium-239. Rarely do these elements appear in weapons- usable concentrations outside of either the enrichment plants (uranium), the reprocessing plants (uranium and plutonium), or the weapons plants. In addition, significant quantities may appear in laboratories for experiments and design testing. Except in weapons themselves, the nuclear materials of interest are generally in diluted form or in a form for a use other than weapons, such as fuel.

For example, uranium-235 is most attractive when enriched at 90 to 95 percent; this is the premium weapons grade material. There is always a 5 to 10 percent fraction of uranium-238 in the most highly enriched material. In submarine fuel, a concentration of 30 to 50 percent may be found in a ceramic or alloy matrix, which would have to be chemically separated before any weapons could be formed. In commercial power reactor fuel, U-235 constitutes only about 4 percent of the uranium in the fuel, with the balance being U-238 and alloys.

Plutonium-239 is most frequently found in either mixtures or in oxide form. Metallic plutonium burns when in contact with oxygen and thus is stored in oxygen-free environments. High concentrations of plutonium are generally found in only a few locations in the weapons manufacturing process and at the end of chemical separations processes. Plutonium isotopes will exist in spent reactor fuel but will be distributed throughout the fuel and will require chemical separation before being available for any further use.

Depending on how the reactor has been operated, plutonium-239 may be present with several other plutonium isotopes (Pu-236, Pu-238, Pu-240, Pu-241 and Pu-242), which make the fuel less attractive as a source for any weapons application. These other Pu isotopes, plus other heavy elements, can render a given load of fuel less usable for weapons application. All transuranic isotopes are fast fissionable. However, the presence of these isotopes makes for a *poor* weapon, not an *inoperable* weapon.

Thus, there is significant variation in the extent to which fissionable isotopes are attractive or useful to a thief. The most attractive forms are also the most rare. Fission products and other contaminates will often render potentially useful sources of uranium- 235 and plutonium-239 less attractive for short term conversion to a weapon. It should be stressed that any source of Pu-239 or U-235 can eventually be converted to a functional weapon. If an adversary has the time, resources, and inclination, even commercial power reactor fuel can be a source of material for making weapons.

The relative attractiveness of different sources of material is based on the amount of work and resources necessary to create a weapon. Those requiring the least amount of work are ranked as most attractive, and those requiring the most are relatively less attractive:

Most Attractive:	U-235 or Pu-239 in highly concentrated form
Attractive:	Fresh naval and icebreaker fuels (U-235>20 percent) Fresh laboratory test fuels (U235 >20 percent) Weapons production scrap (HEU or Pu) Fresh power reactor fuel (U-235 4 percent)
Less Attractive:	Spent fuel from commercial power plant or submarine power plant.

The Department of Energy has defined specific levels of attractiveness based on material type and quantity. The basic definitions are:[5]

Category	**Definition (from DOE Order 5633.3B)**
A	Weapons: Assembled weapons and test devices
B	Pure Products: Weapons assemblies, major components, buttons, ingots, recastable materials, directly convertible materials
C	High Grade Material: Carbides, oxides, nitrates
D	Low Grade Material: Solutions, process residues requiring extensive reprocessing
E	Highly Irradiated Material forms: All uranium enriched to greater than 20 percent U-235.

Further guidance is provided in terms of the amount of material present in any of the attractiveness categories. This creates a further classification of "categories" I-IV within the attractiveness categories. The categories are based on the *quantity* of material present in any attractiveness level.

Category I quantities are those considered to be of strategic importance by themselves. In this case, 2 kg or greater of Pu-239, or 5 kg of highly enriched U-235. Category I quantities of high grade material are 6 kg or greater Pu-239 or 20 kg of material with >50 percent U-235.

Category II and lower are those that cannot be immediately converted to a weapon but may still be attractive to a proliferator depending on the route they have selected and the specific technology or feedstock they may need.

When looking at the nuclear materials theft and smuggling problem, it is evident that a wide range of materials of varying degrees of attractiveness are present in the production chain. As fissionable materials are being converted into products for specific uses such as reactor fuel, there are only a few places in the life cycle where these critical fissionable materials exist in "pure" form. For example, U-235 is present in commercial power reactor fuel, but only at a 4 percent concentration. The balance of the fuel elements are U-238 and other alloys used to create a stable structure for the fuel. To extract U-235 from this element would require a major physical destruction of the fuel element and chemical reprocessing of the residue followed by isotopic separation.

To show how this situation bounds the smuggling and diversion problem, figure A-3 shows in dotted lines where potentially "attractive" nuclear materials may exist in the naval reactor fuel cycle. From the point of fabrication at Electrostal through the point where unused fuel is loaded into a submarine or icebreaker reactor, the material has some degree of attractiveness.

Once the fuel has been irradiated in the operating reactor, the fuel assemblies and fuel elements have less attractiveness to unsophisticated thieves. This is because the irradiated fuel has a large load of fission product contamination which can only be removed in fuel reprocessing plants, and the fuel has a very large thermal load. In short, it is too thermally and radioactively "hot" to handle without special equipment.

Summary

Nuclear weapons can be made from three main fissionable isotopes: uranium-235 and -233 and plutonium-239. Any of these substances in pure weapons usable form and in kilogram quantities are of great value to a potential proliferator. These materials remain the most critical to protect and prevent from falling into the hands of adversaries.

Technology and the spread of knowledge needed to make weapons have changed dramatically over the past 20 years. The knowledge needed to make weapons or establish a national level weapons program is available in the open literature. Also, large numbers of scientists and technicians have a large experience base developed in civil nuclear power or in the weapons programs of several countries.

The technology needed to obtain fissionable isotopes for weapons has become more accessible to any country with the financial means and the determination to develop weapons. Laser isotope separation and gas centrifuge technologies, plus older technologies that had been set aside by the United States, have become within the reach of potential proliferators.

The weapons requirements of various potential proliferators have changed as well. Thousands of weapons are not necessary in the current world order; tens of weapons will often suffice. Because of this, the technological options available to aspiring weapons states or groups are much more diverse than in the era of the Cold War. Terrorists may even opt for what would be considered poor- performance devices; any nuclear weapon, regardless of the yield, will be sufficient.

In this situation, the most desirable materials are as they were before: enriched U-235 or -233 and Pu-239. However, several other "sources" for material may also be attractive to nuclear aspirants who have limited ambitions for the number and type of weapons they want to possess.

Notes

1. Joel Ullom, "Enriched Uranium Versus Plutonium: Proliferant Preferences in the Choice of Fissile Material," in *Nonproliferation Review* 2:1 (Fall 1994): 1-15.

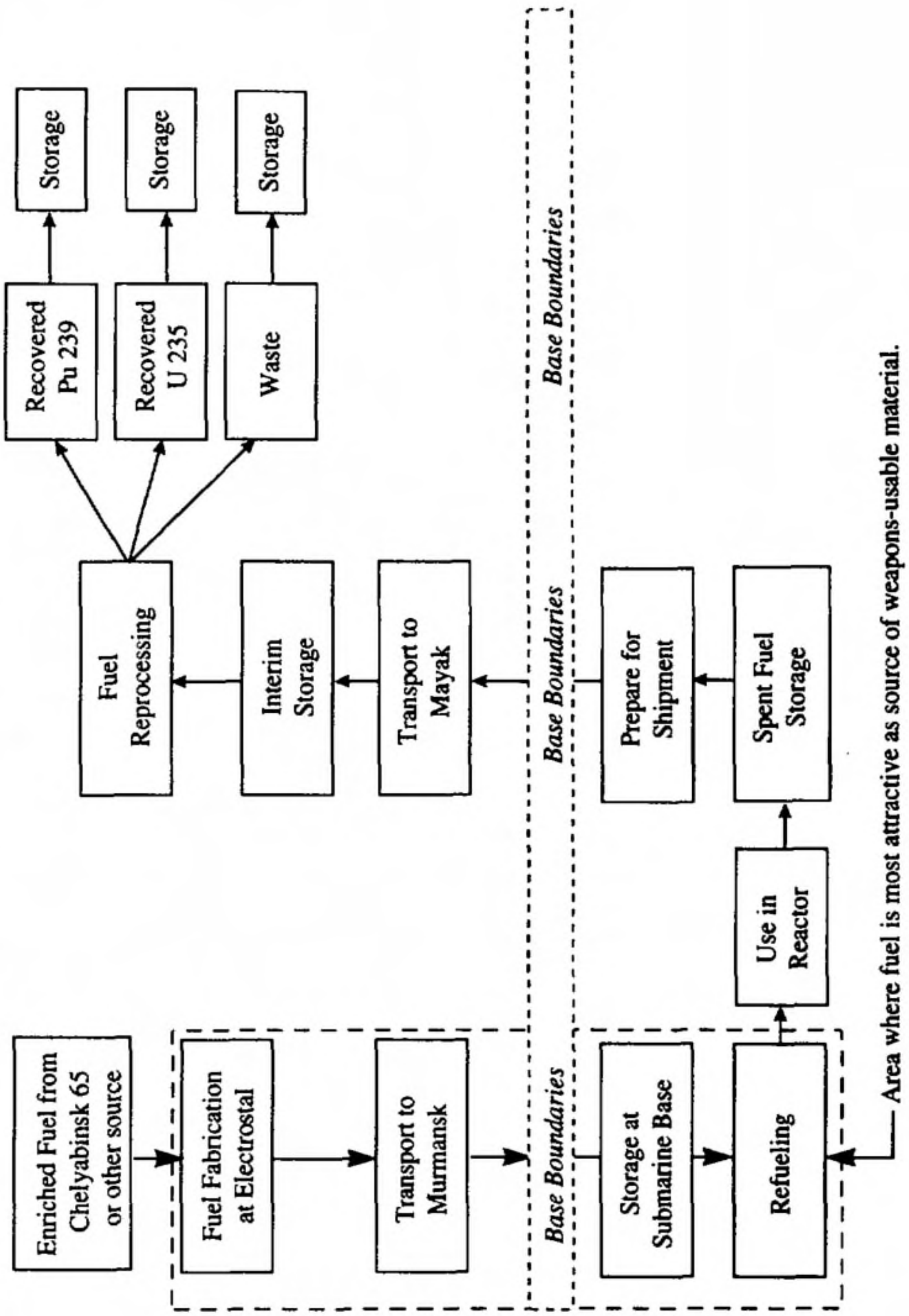
2. William Burrows and Robert Windrem, *Critical Mass: The Dangerous Race for Superweapons in a Fragmenting World* (New York: Simon and Schuster, 199)4, 465.

3. David Evans et al., *Iraq Inspections: Lessons Learned*, Defense Nuclear Agency (DNA-TR-02-115), Alexandria, VA, January 1993.

4. Thomas B. Cochran, "Nuclear Energy's Proliferation Problem," presented at the Institute of National Strategic Studies and Department of Energy Conference: *Energy and National Security in the 21st Century*, National Defense University, Washington, D ., November 10, 1994.

5. Department of Energy Order 5633.3B, dated September 7, 1994.

Figure A-3. *Naval fuel pathway*



APPENDIX B:
Facilities at Risk

Nuclear materials of interest to potential adversaries will be found at many places in the weapons production program and the commercial nuclear power program. However, the number of points in the commercial nuclear fuel cycle where potentially weapons usable material can be found is very small. New technologies for isotopic separation mean that a broad range of materials and forms are potential sources for weapons material. There are several other sources available in the open literature describing in detail the facilities and processes in the weapons complex of the former Soviet Union. The intent of the summaries here is to provide a quick overview of some typical facilities, and to indicate what sort of materials may be located there that would be subjected to theft.[1]

There are several types of facilities of primary interest:

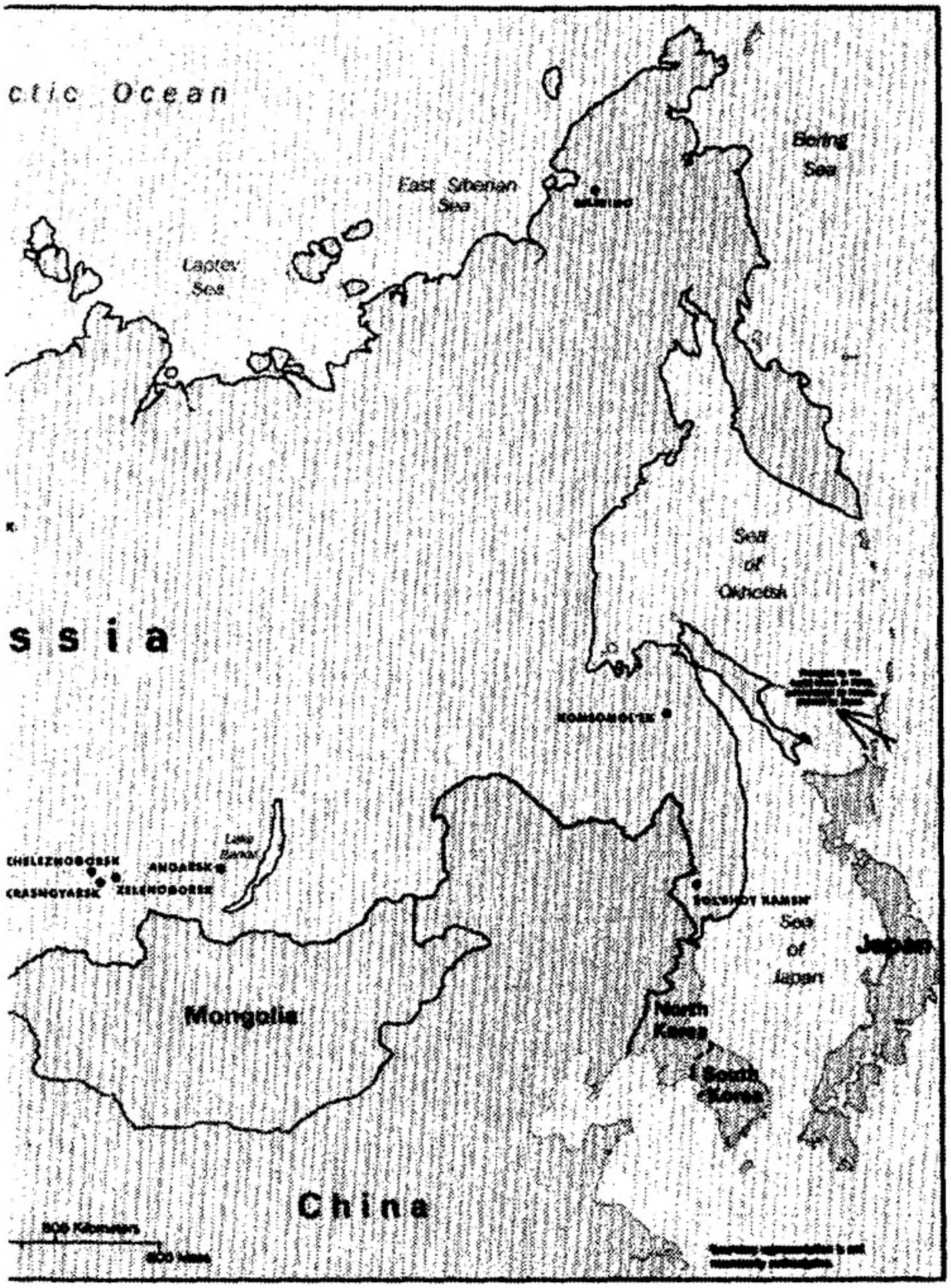
- Weapons production facilities
- Weapons disassembly and stockpile
- Research facilities
- Naval fuel facilities
- Civil reactors and commercial fuel production
- Material transportation system (not a fixed facility)

Of these, by far the greatest amount of potential weapons material, and actual weapons, are located at the weapons production and weapons disassembly facilities. For the most part, these are located in isolated areas of Russia. Laboratories are located in many areas, including several in Moscow. Naval fuel facilities are located in Siberia at Petropovolosk and Vladavostok, and at Murmansk in the northern Baltic area. Civil power reactors are located throughout the country, mostly in European Russia and Ukraine.

Russian Nuclear Weapons Production Facilities

The greatest amount of attractive nuclear material and the greatest volume of material is found in the nuclear weapons complex. The production and stockpile facilities that supported the Soviet Union are still mostly in Russia. The map in figure B-1 shows the locations of the major facilities in the weapons complex. A brief discussion of the materials available at each site should give the reader an overview of the situation.

Figure B-1. *Russian nuclear facilities*


ctic Ocean
East Siberian Sea
Bering Sea
BILIBINO
Laptev Sea
Sea of Okhotsk
ssia
KOMSOMOL'SK
Lake Baikal
ANGARSK
ZELENOGORSK
BOL'SHOY KAMEN'
Sea of Japan
Japan
Mongolia
North Korea
South Korea
China
500 Kilometers
500 Miles

RUSSIAN NUCLEAR FACILITIES

Legend:
* Ministry of Atomic Energy (MINATOM)
\# Nuclear Electric Utility (ROSENERGOATOM)
\+ *Other*

Angarsk
*Angarsk Electrolyzing Chemical Combine (AEKhK)

Arzamas-16 (Kremlev)
*All Russian Scientific-Research Institute of Experimental Physics (VNIIEF)

Asbest
*Malyshevo Mining Directorate

Balakovo
#Balakovo AES

Bilibino
#Bilibino AES

Bol'shoy Kamen'
+Far East Plant "Zvezda"
+Ship Equipment Plant "Vostok"

Chelyabinsk-65 (Ozersk)
*Production Association "Mayak" (PO Mayak)

Chelyabinsk-70 (Snezhinsk)
*Russian Physics (sic Federation) Nuclear Center (RFTaTs)

Desnogorsk
#Smolensk AES

Dimitrovgrad
*Scientific-Research Institute of Atomic Reactors im. Lenina (NIIAR)

Dubna
+Joint Institute of Nuclear Research (OIYaI)

Elektrostal'
*Open Joint Stock Company "Machine Building Plant" (AOOT "Machine Building Plant")
*VNIINM branch

Gatchina
+Petersburg Institute of Nuclear Physics (PIYaF)

Glazov
*Production Association "Chepetskiy Mechanical Plant" (ChMZ)

Kirovo-Chepetsk
*Kirovo-Chepetsk Chemical Plant im. V. P. Konstantivnova

Kolpino
+St. Petersburg Institute of Machine Building

Komsomol'sk
+Joint Stock Company (AO) "Amur Plant"

Korochanskiy
+Production Mining Association (PGO) "Tsentrgeologiya", Belgorod Geological Prospecting Expedition im. S. D.

Igumenka

Krasnokamensk
*Priargunsk Production Mining-Chemical Association (PGKhO)

Krasnoyarsk
*Chemical-Metallurigical Plant (KhMZ)

Krasnoyarsk-26 (Zheleznogorsk)
*Mining-Chemical Combine (GKhK)

Kurchatov
#Kursk AES

Murmansk
*Murmansk Shipping Company
*Russian Transport Enterprise (RTP) "ATOMFLOT'
+Ship Maintenance Plant "Nerpa"

Nizhniy Novgorod
*Experimental Design Bureau of Machine Building (OKBM)
*Gor'kiy AST
+Production Association (PO) "Krasnoye Sormovo"

Noril'sk
+Noril'sk Mining-Metallurgical Combine (NGMK)

Novosibirsk
*Production Association "Novosibirsk Chemical Concentrates Plant" (PO NZKhK)

Novovoronezh
#Novovoronezh AES

Obninsk

*Physics and Power Engineering Institute (FEI)
+Branch of the Scientific-Research Physics and Chemistry Institute im. Karpova (NIFKhI branch)

Podol'sk
*Experimental Design Bureau "Gridropress" (OKB "Gridropress")
*Scientific-Production Association "Luch" (NPO "Luch")

Polyarniye Zori
#Kola AES

Severodvinsk
+Enterprise "Dubrava"
+Northern Delivery Base PO "Krasnoye Sormovo"
+Production Association "Northern Machine Building Enterprise" (PO SMP)
+Production Association "Sever"

Sosnovyy Bor
*Scientific-Research and Technology Institute (NITI)
#Leningrad AES

St. Petersburg
*St. Petersburg Enterprise "Izotop"
*Scientific-Production Association (NPO) "Radium Institute im. V. G. Khlopina"
+Central Scientific-Research Institute im. Krylov (TsNII im. Krylova)
+Production Association (PO) "Baltiyskiy Plant"
+State Enterprise (GP) "Admiralty Yards"

Sverdlovsk-44 (Novouralsk)
*Urals Electrochemical Combine (UEKhK)

Tomsk-7 (Seversk)
*Siberian Chemical Combine (SKhK)
+Scientific-Research Institute of Nuclear Physics at Tomsk Polytechnical University (NIIYaF)

Troitsk
+Troitsk Institute of Innovative and Thermonuclear Research (TRINITI)

Turayevo
*Scientific-Research Institute of Instruments (NIIP)

Udomlya
#Kalinin AES

Yekaterinburg
*Sverdlovsk Scientific-Research Institute of Chemical Machine Building (SVERDNIIKhIMMASH)

Zarechnyy
*Sverdlovsk Branch of NIKIET
#Beloyarsk AES

Zelenogorsk
*Electrochemical Plant (EKhZ)

Nuclear weapons are produced through what may be called the nuclear weapons development cycle, shown in figure B-2. The process begins with mining uranium ore, which occurs with a natural concentration of 0.7 percent uranium-235. The development sequence for both uranium and plutonium weapons begin with the mining and milling of uranium ore.

The next step is the conversion of uranium oxide into uranium hexaflouride, which is the feedstock to a uranium enrichment plant. Enrichment, described in appendix A, is a process used to raise the concentration of U-235 to the levels needed for commercial power reactor fuel (4 percent U-235), submarine and icebreaker fuel (varies from 30 to 93 percent U-235), or weapons grade uranium, 90 percent or above U-235.

To develop uranium based weapons, the process is essentially to enrich the uranium to the optimal level for weapons (90 percent or above) and then proceed directly through the weapons fabrication process. When the components have been built, they are shipped to an assembly plant for final fabrication. This is shown as the top branch in figure B-2.

The plutonium production route is somewhat different. Usually low-enriched uranium or natural uranium fuel rods will be fabricated and then exposed in a specially designed reactor used for production of weapons material. The exposed fuel rods (spent fuel) will be discharged and sent to a chemical reprocessing plant where the plutonium will be separated from the other materials in the fuel. The resulting store of plutonium can then be fabricated into weapons and assembled much the same as was done with the uranium based weapons. This pathway is shown as the bottom branch in figure B-2.

The nonnuclear components of the weapon are developed separately and sent to the assembly plant. Their pathway is shown in the middle of figure B-2.

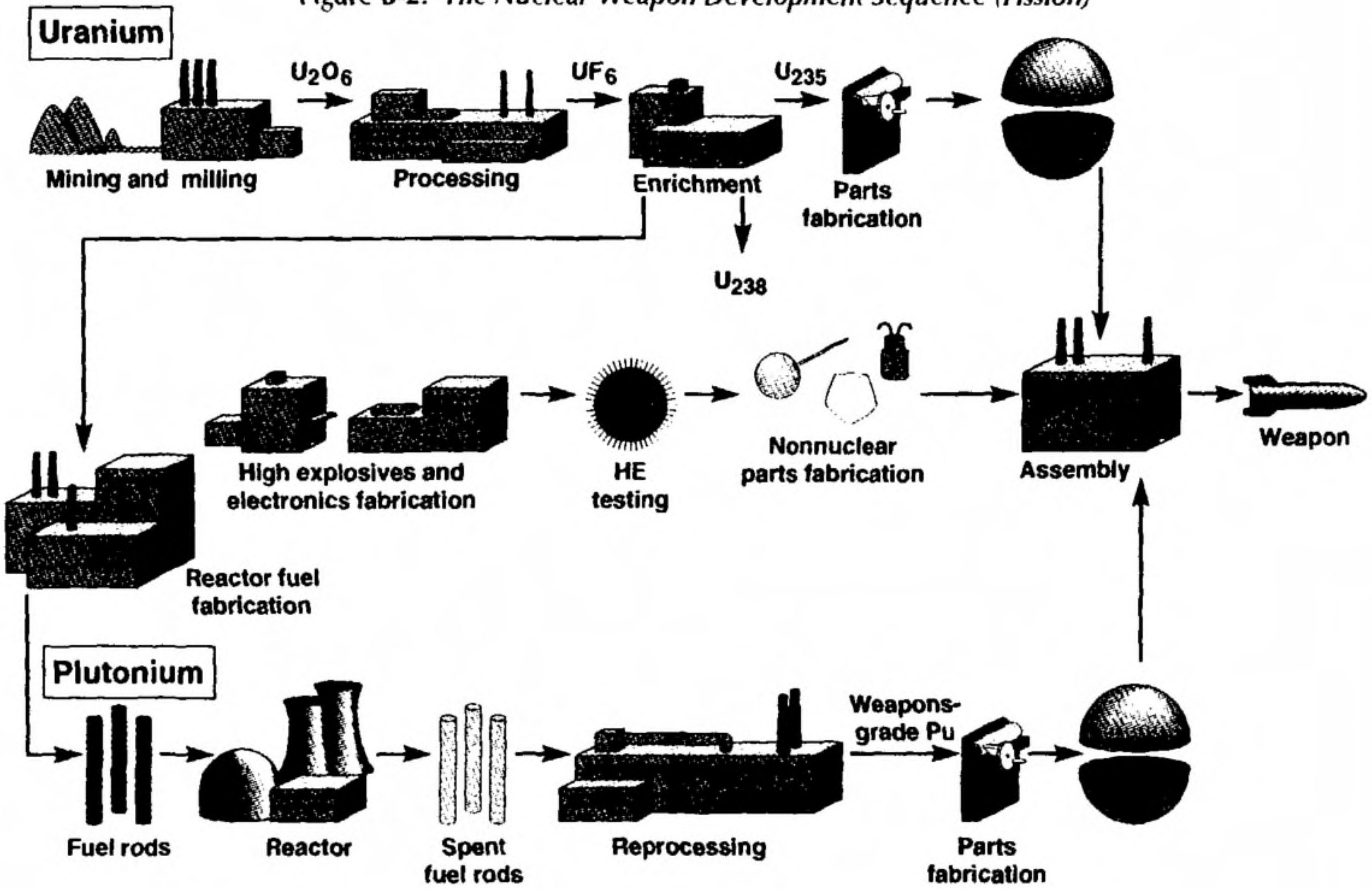
The number and size of the facilities involved in the former Soviet Union weapons complex are considerable. Most of the facilities were located in "closed" cities in Siberia or at some distance from Moscow; thus, most are in very isolated areas of Russia.

Weapons Production Facilities: Uranium Enrichment

Uranium enrichment is the first point in the production process where large amounts of weapons usable material would be available. There are four enrichment sites in the weapons complex, all in Siberia. The plants, which use gas centrifuge technology, are located at Yekaterinburg, Tomsk, Angarsk, and Krasnoyarsk.

These plants produce both the weapons-grade enriched uranium used directly in the weapons program and slightly enriched fuel, which is the feedstock for plutonium production. The plant at Yekaterinburg also produces fuel for commercial nuclear power plants.

Figure B-2. *The Nuclear Weapon Development Sequence (Fission)*



Unclassified sources estimate the total production of weapons grade uranium and other HEU (above 20 percent enriched), to be about 1,250 tons; this has been roughly confirmed by official Russian sources. Plutonium production was done in 13 graphite reactors located at Chelyabinsk-65 (Mayak), Tomsk-7, and Krasnoyarsk-26. In addition, there were two tritium production reactors. By 1994, between three and five of these reactors remained in operation.

Five of the production reactors were designed to be dual use, in that they provide electric power steam for district heating to cities and factories in the areas around the Mayak, Tomsk and Krasnoyarsk. The electric power output of these plants is estimated at roughly 200 megawatts electric (Mwe). Open source reports are conflicting about the number that remain in operation. The highest estimate is five, the lowest, three. The primary driver for operating the plants appears to be generating electricity and heat for the surrounding cities, although they continue to produce weapons usable material.

At Tomsk, there are two dual-purpose reactors in operation that continue to make weapons-grade plutonium. Open-source reports indicate that Tomsk was still making pits for bombs in 1994. At Mayak, two dual-purpose reactors that produce tritium were still operational in 1996. At Krasnoyarsk, one of three production reactors continues to operate; the other two were shut down in 1994. At both Tomsk and Krasnoyarsk there are plans to provide electricity and steam for district heat from new generating plants which are scheduled to be available around the year 2000.

Although not pertinent in the discussion of nuclear materials that are likely to be stolen or smuggled, tritium production is also part of the former Soviet production complex. Tritium is used in thermonuclear bombs but is not a likely material of interest for the present generation of proliferators.

Weapons Production: Chemical Reprocessing

Separation of plutonium to make weapons is done at all three production reactor sites. However, the largest of the chemical separation facilities is as Chelyabinsk-65, the Mayak Chemical Combine. This facility reprocesses fuel from the production reactors and reprocesses spent fuel from propulsion reactors and from commercial power plants. The reprocessing facility at Krasnoyarsk was shut down in 1992. Any material for reprocessing is either stored on site or shipped to Mayak.

Spent fuel from the commercial power reactor program is being stored at a partially completed reprocessing plant at Tomsk. The plant had been designed to reprocess fuel from VVER reactors. It was about 30 percent completed when construction stopped in 1989. Construction was restarted in 1994, but it is unclear when the facility will be completed.

Open source estimates are that the plutonium stockpile is about 165 tons of weapons-grade plutonium-239. There is additional plutonium contaminated with Pu-236 and Pu-240 from the commercial nuclear fuel recycling program.

Weapons Disassembly

A portion of the stockpile of nuclear weapons from the former Soviet Union is being disassembled under the terms of international agreements. The immediate impact is to remove weapons from the arsenal, but then to place large amounts of weapons grade plutonium and uranium into storage locations in Russia. Currently several thousand warheads are being disassembled each year at four sites in Russia: Sverdlosk-45, Arzamas-16, Zlatoust-36, and Penza-19. At its peak, the Soviet warhead inventory was estimated to be around 45,000.

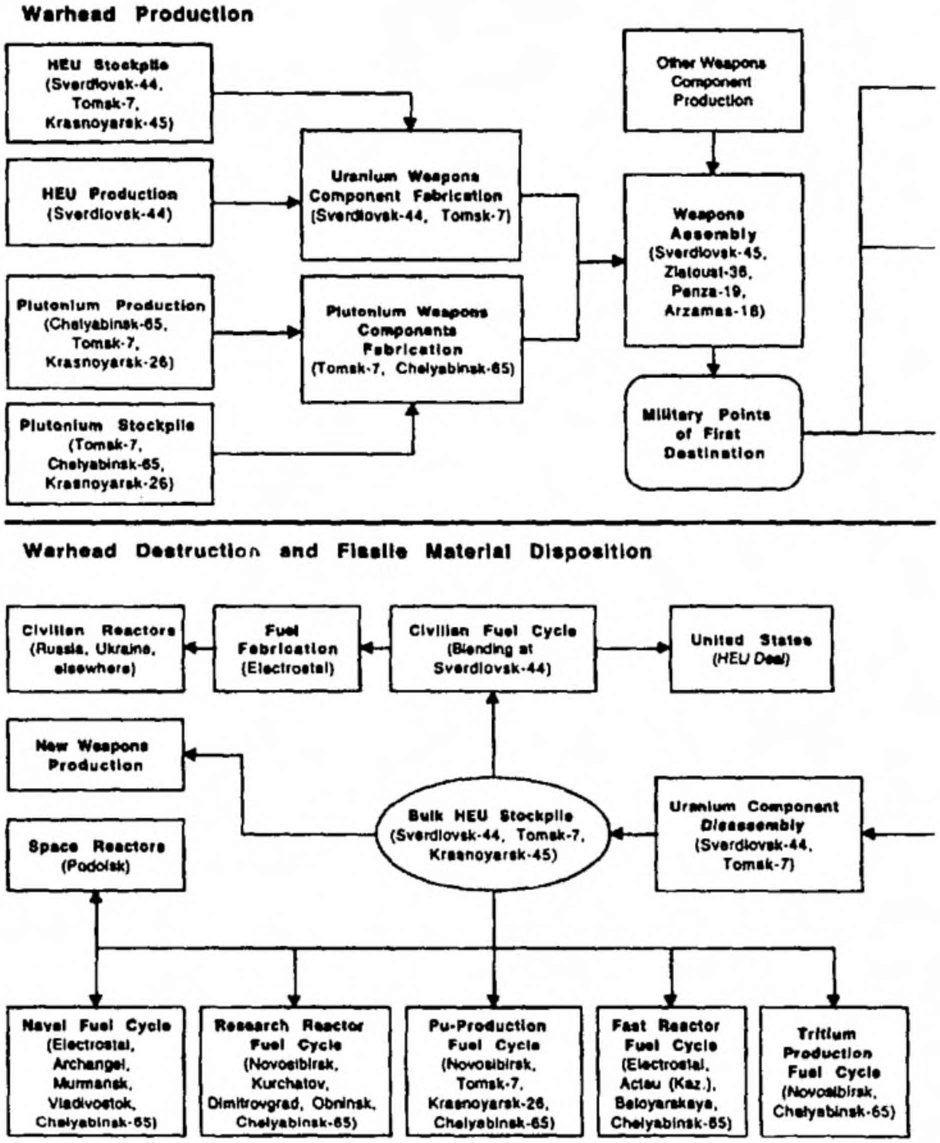
Disassembly processes are flow charted in figure B-3. Of particular importance is the fact that during the process of disassembly, large amounts of weapons grade material are placed in interim storage. Also, major working components of weapons are placed in interim storage prior to final demilitarization. Of genuine significance is the fact that thousands of tons of weapons grade material are being taken out of weapons and placed in storage.

Research Facilities

Research facilities include both laboratories specializing in weapons design and those involved with other aspects of nuclear application. The two main weapons-design laboratories are Arzamas-16 and Chelyabinsk -70. They are officially known as the All Russian Institute for Scientific Research of Experimental Physics, and the All Russian Institute of Scientific Research in Technical Physics. The principal task in the laboratories at both locations is the design and prototyping of nuclear explosives. As with other sites in the weapons complex, several different activities occur at the same location. In the case of Arzamas, other activities include assembly and now disassembly of warheads and maintenance of the nuclear weapons stockpile.

The types of materials routinely around working areas in laboratories include all things necessary to make and test a nuclear weapon. Although the tasks are primarily in design, there are many experiments and testing operations that require the use of weapons- grade uranium and plutonium, to be available in undisclosed quantities in the area. Thus, the laboratory areas are believed to house large quantities of highly attractive material.

Figure B-3. *Flowchart of the Russian nuclear weapon complex*



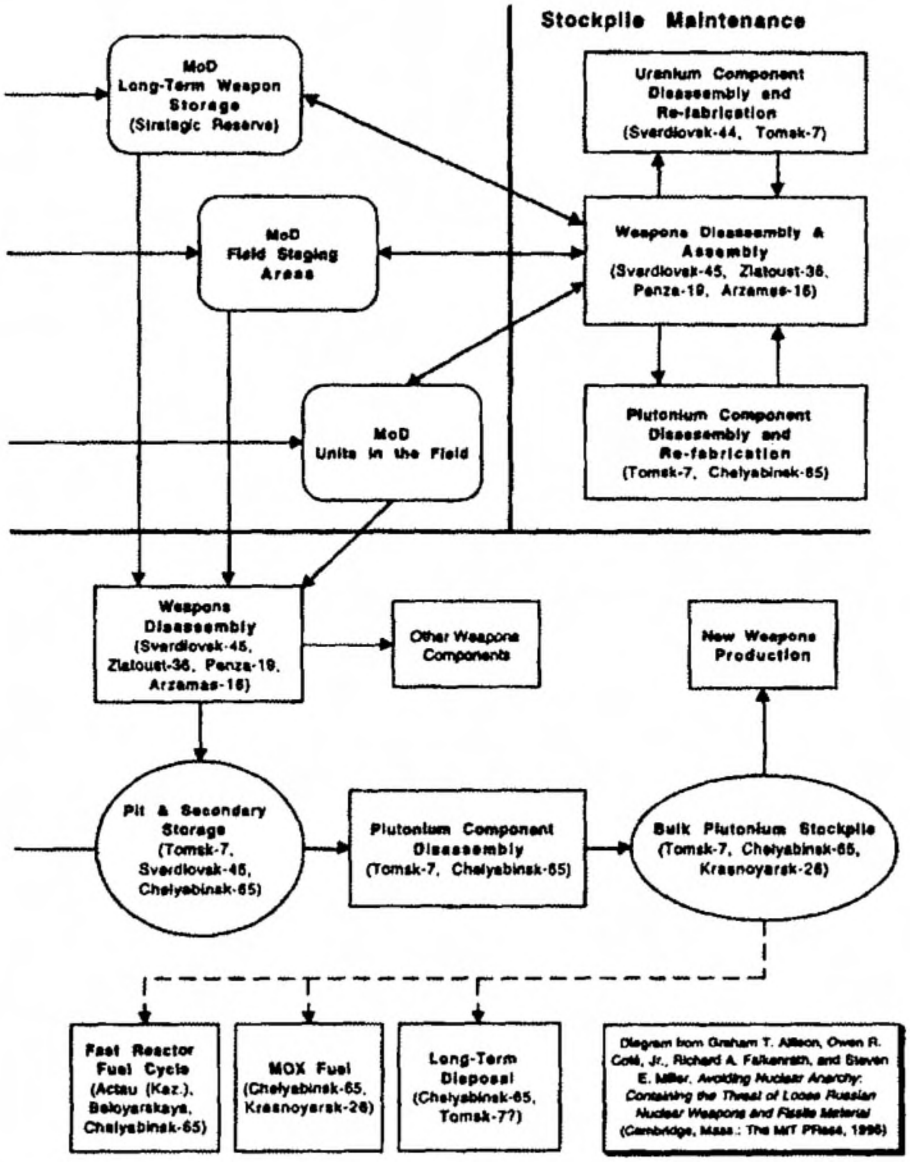


Diagram from Graham T. Allison, Owen R. Coté, Jr., Richard A. Falkenrath, and Steven E. Miller, *Avoiding Nuclear Anarchy: Containing the Threat of Loose Russian Nuclear Weapons and Fissile Material* (Cambridge, Mass.: The MIT PRess, 1996)

Other laboratories, such as the Kurchatov Institute in Moscow, carry out research on propulsion systems and power reactors. Thus, these facilities have significant quantities of highly attractive material for use in experiments, critical assemblies and other types of development work. In addition, there are 20 research reactors at laboratories throughout Russia, 3 reactors in Kazakstan, and 1 in Ukraine. The vast majority of these reactors are located at two sites. Six research reactors are located at the Kurchatov Institute in Moscow, and six are located at the Research Institute of Atomic Reactors (RIAR) in Dimititrovgrad. These reactors all have very low power outputs, but because of their role in experimentation, they will use a wide variety of fuels, some of which are highly enriched uranium and plutonium.

Naval Fuel Facilities

Submarine reactor fuel and fuel for the nuclear powered icebreakers is highly enriched uranium (HEU) which varies from 30 to 93 percent. Newer submarines generally use the most highly enriched fuel. The older boats use fuel in the 30 to 50 percent enriched range. The Northern Fleet submarine bases are in the Murmansk area, and the Pacific Fleet bases are at Petropovolosk and Vladavostok. It is in these locations that some of the most potentially attractive materials for theft exist. Unused submarine fuel for newer boats may be up to 95 percent enriched uranium. The purpose of such high enrichment was to allow the sub to extend the time between refueling.

The fuel is fabricated at the Elektrostal plant near Moscow and then transported to one of the bases for use. Spent fuel is generally stored at the base on barges or in facilities using the natural circulation of sea water for cooling. After a few years of onsite storage, some of the fuel had been returned to Mayak for reprocessing. However, indications are that little fuel is being reprocessed currently, and that most of the spent fuel is being kept at the bases.

The situation with icebreakers is similar. Fuel is fabricated at Elektrostal and then shipped to the icebreaker base for use in the ships. Spent fuel is placed in interim storage at the base. Eventually, the fuel might be shipped to Mayak for reprocessing.

Civil Reactors and Commercial Fuel Cycle

There is not a strict separation between the nuclear fuel cycle facilities used for civil reactors and for military production. This is particularly true in enrichment for making fuel and reprocessing. Most of the civil reactor fuel is enriched at Sverdlosk-44 and fabricated by Elektrostal or another plant near Novosibirsk. Fuel reprocessing has been done at Mayak.

The civil-reactor complex in Russia and the former Soviet Union is quite extensive. Most of the 29 operating power reactors are in the European part

Figure B-4. *Nuclear power plants in the Former Soviet Union*

◆ **GCHWR** Gas cooled heavy water reactor
LWGR Light water cooled graphite reactor

■ **BWR** Boiling water reactor

▲ **PWR** Pressurized water reactor

of Russia, Ukraine, and Lithuania. There are four power reactors at Bilibino in far northern Siberia (figure B-4).

There are two main types of civil reactors: the VVER series, which is a pressurized light-water reactor, and the RBMK, a boiling- water, graphite-moderated, pressure-tube reactor. There are 12 operating RBMKs in Russia, two in Ukraine at Chernobyl, and two in Lithuania at Ignalina.

The VVER reactors use low-enriched uranium fuel (4 percent U-235) and are approximate equivalents to western pressurized-water reactors (PWRs), with some differences in the safety systems. The newer plants of the VVER-1000 series meet virtually all western safety standards; earlier designs, particularly the VVER 44/230 do not.

As noted, the RBMK series reactors are pressure-tube reactors. The design does not meet Western safety standards, and at present no plans exist for building any more RBMK plants. The Chernobyl-4 plant, which had an extreme accident in 1986, is an RBMK design. The RBMK plants use a low-enriched uranium fuel (2.5 percent U-235).

The materials available for theft in the civil nuclear program are relatively less attractive for making weapons than those found in most other parts of the nuclear complex. Fresh power reactor fuel might be the most attractive, because it contains some uranium-235 and large amounts of uranium-238, which can be used as a target to make plutonium-239. Spent reactor fuel is of little use in making nuclear explosives. However, spent fuel could be used with conventional explosives to make a radioactive dispersal device.

Material Transportation System

Under the Soviet system, warheads were transported throughout the system using heavily guarded truck convoys or specially designed rail cars. Very little public information exists about either the location of storage facilities for warheads or the transport system for moving them around the country. Currently, Russia is dismantling warheads at four sites. The transportation system to support this has been the focus of considerable attention under the U.S.-Russian program for Material Protection, Control and Accountability supported by the Departments of Energy and Defense.

Attractive Materials and Facilities: What Makes Them So?

There is a general caveat important to bring out in the discussion of what facilities and materials are at risk. The potential threats posed by stealing materials vary greatly depending on the physical state of the materials—that is, all components containing highly enriched uranium (HEU) are not uniformly attractive. Thus it is important when defining a risk situation that the physical state of the materials be clearly defined and understood. To illustrate this point, the situation with naval propulsion fuels will be discussed.

The definition of attractive or unattractive in the context of nuclear theft is inherently imprecise. There are some forms of material, discussed in appendix A, that are inherently attractive. When getting down to a specific facility, the important thing is how attractive are the materials that are *available* for potential thieves to steal? The general considerations of what make a target attractive are the *type* of material (U-235 or Pu-239), the *amount* of weapons grade material which may be present, the *form* in which this material is present (e.g., fresh reactor fuel vs spent fuel), and the *availability* to any given thief. For example, highly enriched uranium metal may in theory be the most desirable for a weapon, but, if thieves have access only to spent fuel, fresh fuel, or laboratory waste, then those become the target of potential thefts.

Naval propulsion fuels are often a topic of concern when discussing potential nuclear materials theft. These fuels all include HEU, at levels varying from 30 to 93 percent. However, naval fuels are relatively more attractive targets for theft at different stages of their life. To make a reasonable evaluation of the potential security risk, it is essential to clearly define when the fuels are in a physical state which would make them useful to a potential thief.

To do this, it is necessary to trace the fuels through their life cycle and determine the physical conditions which characterize each stage. The greatest risk occur when U-235 is in a pure form or simple mixture. Once the fuel is fabricated, U-235 is always chemically bonded with other elements, and does not exist in a pure form. There are always alloys present, and once irradiated, there are a huge number of other elements present that present problems.

The life cycle of naval fuels is shown in figure A-3 in appendix A. The beginning of the cycle is when the uranium is enriched to the appropriate level. As noted above, this can range from 30 to 93 percent U-235. The variation will depend on the design of the reactor for which the fuel is being prepared. Older submarines and ice breakers use fuel enriched in the 30 to 50 percent range. Newer submarines use materials at a much higher enrichment level. The variation is due to the improvements over time in reactor design. High enriched fuels permit boats to operate far longer between refueling. The older boats refueled about every 7 years. The higher enrichment levels used in newer designs mean far longer time spans between refueling.

Looking at the diagram, the reader will note a dashed line around four boxes running from the time the fuel is fabricated until the time the fuel is loaded into the reactor on the vessel. It is in these stages, when the fuel is fresh, that it is an attractive target for thieves. This is because there are no other products in the fuel other than the U-235, the alloying materials, U-238, and some other elements used to control burnup rates. These material are chemically bonded and cannot be separated without some form of destructive chemical separation. Nonetheless, the fuel has no thermal load, can be handled with minimal or no shielding, and carries no other contaminates.

Table of Material Located at Different Facilities

Weapons Production

Enrichment Plants
- UF^6

Production Reactors
- Pu^{239}
- U^{235}
- Spent Fuel

Weapons Fabrication
- Weapons Grade U^{235}
- Pu^{239}
- Weapons Components

Weapons Disassembly
- All weapons components
- Complete weapons

Submarine Base (naval fuel)
- Fresh reactor fuel
- Spent reactor fuel

Fuel Fabrication Plant
- HEU*
- UF^6

Fuel Reprocessing
- HEU
- Pu^{239}
- Spent Fuel

Civil Power Plants

Fresh Fuel (Low Enriched)**
- Spent Fuel

Fuel Fabrication
- UF^6 (4% Enriched)
- Pu^{239}

Fuel Reprocessing
- Spent reactor fuel
- Pu^{239}
- U^{235}

Research Facilities
- HEU
- LEU
- Pu^{239}
- Th^{233}
- Test fuels

*HEU: Highly enriched uranium (>20% U^{235} vs. U^{238})

** Civil reactor fuel approximately 4% U^{235}

Once the fuel has been loaded into a naval reactor, the attractiveness for most thieves diminishes rapidly. During the process of burning the fuel, some fraction of the U-235 will be fissioned. However, even in spent fuel, even a sizable fraction of U-235 remains. What is also present in abundance are fission products that are both extremely difficult to separate from the fuel and also present major problems for fuel handling.

The spent fuel contains a wide array of radioactive elements created as a consequence of "burning" or fission of the fuel. These fission products include isotopes of uranium and plutonium that create significant handling problems. Among the most pronounce of the handling problems is that several elements continue to fission and decay releasing large amounts of heat in the process. The fuel elements are extremely "hot" both radioactively and thermally.

Because of this, fuel elements removed from a naval reactor are placed in an interim storage facility where they are allowed to undergo decay until they have cooled sufficiently to be transported. Even then, the load of fission products is such that they will require cooling and special transport casks that shield workers and the general populace from radiation exposure. For a thief, the attractiveness of the U-235 remaining in the spent fuel may be more than offset by the significant difficulty, and physical danger associated with handling the spent fuel. Because of this, spent fuel is deemed relatively less attractive to a thief than fresh fuel, which requires no shielding or special handling casks.

In the Soviet era, the naval fuels were sent to the Mayak complex, where they were reprocessed and the extracted uranium and plutonium put to other uses. Currently, most of the spent fuel remains in interim storage, much of it at the naval fuel facilities.

It should be noted that spent fuels are not difficult to handle if the work is being done with specialized equipment in facilities designed to carry out such operations. The fuel bundles are heavy enough to require cranes to lift them. The spent fuel storage areas are designed to be accessed only with special heavy equipment. Spent fuel must be constantly cooled, and this is done in special facilities designed for the purpose.

These types of facilities and equipment are not of the variety that could be casually improvised by a thief or a group of thieves. Spent fuel is thus not likely to be an attractive target for some group seeking to make nuclear weapons. It is conceivable that spent fuel could be used with conventional explosives in a radiation dispersal weapon. Again, the fact that most of the material is heavy metal, and will not disperse easily, makes spent fuel a target of lesser attractiveness.

The example of the naval fuel is intended to illustrate that while the fuel will contain desirable isotopes throughout the life cycle, there are reasons why some forms of the fuel may be more or less attractive to thieves. In short, the threats and risks are not uniform across the life cycle of a nuclear product. In conducting analysis, it is important to understand what form the nuclear material may be in at a given pint in the life cycle. The presence or absence of fission products or other contaminants may significantly impact the relative attractiveness of the material at different stages.

Summary

In summary, when reviewing the risks posed by weapons usable materials in different parts of the former Soviet nuclear complex, it is essential to distinguish whether the materials are in a highly concentrated state or are in a condition that would make them less attractive to thieves. The few points where materials exist in pure form are often given the closest attention. They are naturally the points where the most attractive substances exist. They are also the fewest in number.

Other points in the life cycle of a particular nuclear product may be relatively less attractive in a general sense but are still attractive to thieves because the desired fissionable materials are present, just not in relatively pure forms. Also, many thieves may not have access to the most inherently desirable materials.

Throughout the nuclear complex, both military and civil, there are many places where potentially attractive materials are found. When evaluating the threat posed by a situation, it is important to understand what materials are actually available at a given point in the life cycle of a nuclear product, and what value these may be to an adversary.

Note

1. Two excellent sources: Thomas B. Cochran, Robert S. Norris, and Oleg Bucharin, *Making the Russian Bomb: From Stalin to Yeltsin* (Boulder, CO: Westview Press, 1955), and The Monterey Institute of International Studies and The Carnegie Endowment for International Peace, *Nuclear Successor States of the Soviet Union: Nuclear Weapon and Sensitive Export Status Report*, no. 4, May 1996 (see sections 1-E and 1-F and appendix A).

APPENDIX C:
A Primer on Fission Weapons [1]

The variety of methods available to both nation states and terrorist groups to produce fissile isotopes suitable for making fission bombs is both extensive and potentially hard to detect. This is in part because of advances in technology over the past 50 years, but also because nation states and terrorists may not need to manufacture more than a few weapons to attain their objectives. Terrorists may even be satisfied with relatively low yield or inefficient weapons.

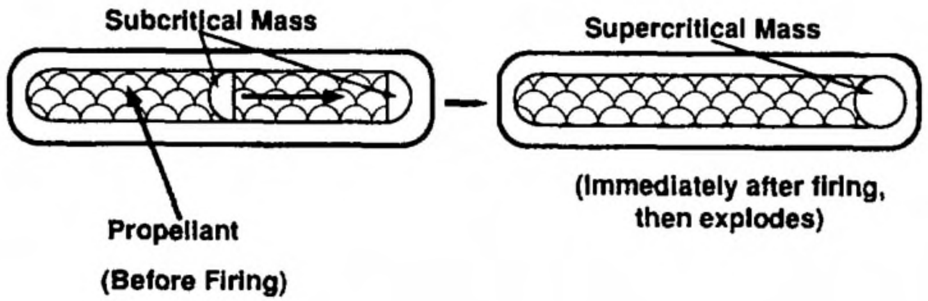
There are a large number of potential routes to nuclear proliferation, if all of the weapons-making options available to terrorists and rogue states are to be considered. Many of the approaches reviewed and rejected by the United States and other nuclear weapons states as being impractical for producing a large arsenal of weapons may be attractive to entities who need only a small number of explosive devices. Indeed, some terrorists may be satisfied with one mediocre bomb.

Uranium and thorium as found in nature are the ultimate sources of fissionable materials for nuclear weapons. Uranium is unique in that it has three natural isotopes providing two distinct methods to make the primary fissionable material for nuclear bombs, whereas thorium provides only one method. A primary bomb material must be capable of sustaining a nuclear fission chain reaction, and uranium-235 is the only natural occurring isotope that can do this. However, naturally occurring uranium-238 is transformed to plutonium-239, and thorium-232 is converted to uranium-233 upon absorbing a neutron. Both of these materials can also sustain a nuclear chain reaction for a bomb.

Depending on the isotopic purity, one needs on the order of 10 to 25 kg of special nuclear materials (plutonium-239, uranium-233, or uranium-235) to provide a self-sustaining chain reaction. The above quantities need not be 100 percent pure. This allows many possible combinations to make a weapon, and all these combinations must be considered weapons-grade materials where terrorists are concerned.

A gun assembly device is the easiest and cheapest nuclear weapon to build (figure C-1).[2] This design consists of two subcritical masses located at opposite ends of a gun tube prior to assembly. On assembly, the two subcritical masses are impelled together by an explosive charge to create one super-critical mass. Simple versions of this design will not produce anything near an optimal yield. However, the design will produce a significant nuclear explosion.

Figure C-1. *Gun-type assembly weapon*



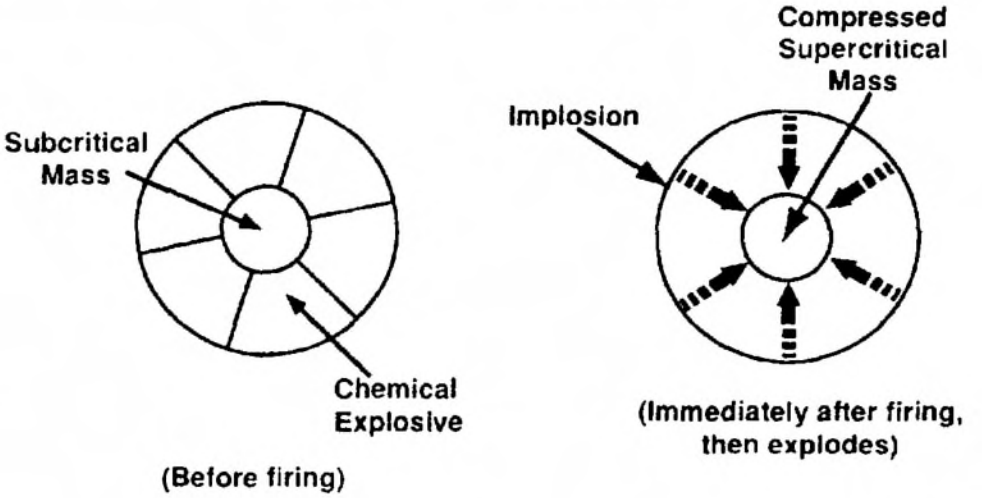
The implosion design consists of a subcritical sphere of plutonium-239 surrounded by a high explosive (figure C-2). The detonation compresses the plutonium from all sides simultaneously within a millionth of a second to create a super-critical mass and thus a nuclear explosion. This process is easy to describe but very hard to create, because it is necessary to have a uniform and instantaneous compression of the subcritical mass. Without this instantaneous compression, the yield of the weapon may be very low or the weapon may fail to detonate at all.

Uranium ore contains only a very small fraction of the fissionable isotope uranium-235. As mined, the fractions of the various isotopes are: uranium-238, 99.28 percent; uranium-235, 0.71 percent; and uranium-234, 0.006 percent. Thus, in order to develop any weapons capability, uranium-235 must be "enriched" to a level where it can sustain a nuclear fission chain reaction. The minimum level of enrichment for this to occur is generally accepted as 20 percent uranium-235 in a mixture with uranium-238.

Uranium enrichment to levels above 20 percent uranium-235 is an option that appears attractive to nation-state level bomb programs. The relative simplicity and explosive productivity of a uranium-235 weapon can have appeal even though the size of the facilities to make them is formidable and the electrical energy required is likely to be detected. Because the chemical properties of uranium-235, uranium-234, and uranium-238 are so nearly identical, a chemical means cannot be used to isolate one from the others. Thus, a process for isotopic enrichment must be used.

Fifty years ago, two processes were developed based on the mass differences between uranium 235 and uranium-238, as the means of enriching uranium-235. (We can ignore the uranium-234, as it will tend to stay with the uranium-235 from which it varies by only one mass unit.) The first method, "gaseous diffusion," utilized the relative velocities of a mixture of uranium hexafluoride gases. Because uranium-235 hexafluoride gas moves slightly faster than uranium-238 hexafluoride, it provides a means to separate them.

Figure C-2. ***Implosion assembly weapon***



The second method, the "Calutron," uses a magnetic field to separate components of a beam of electrically charged particles (ions) consisting of a mixture or uranium-235 and uranium-238.

In the past 50 years, other methods have been devised to enrich uranium. The centrifuge, which also exploits differences in the mass of isotopes, was used with considerable success; however, many successive passes (a "cascade") were required to obtain a high percentage of isotope separation. There are now a plethora of means for separating isotopes, especially developed around the laser and extensions of electromagnetic phenomena associated with the early Calutron.

The work and time necessary to isolate uranium-235 from uranium-238 mixture can be appreciated by the following generally descriptive analogy. Suppose one has a barrel of mixed uranium hexafluoride gases and a special valve on the barrel. If a uranium-235 hexafluoride molecule comes near the valve, the operator opens it and lets it through. Starting with 0.07 percent uranium-235 in the mixture, one waits a long time between openings, and longer yet as the uranium-235 component of the mixture is depleted. Note that the operator, when he opens the valve, sometimes lets uranium-238 in with the selected uranium-235. Thus, when the collecting vessel contains approximately 50 percent uranium-235 hexafluoride molecules, one might reverse the process, and let the uranium-238 molecules out to further enrich its uranium-235 content.

The diffusion process is not as simple as in the analogy, and 4,000 processing stages may be cascaded in a uranium-235 diffusion enrichment plant to achieve the desired results. The Calutron method approaches the separation differently and, in effect, more efficiently. Only several hundred stages would be required for it. In laser approaches, the unique uranium-235 hexafluoride molecule, or more likely, just the atom of uranium-235, can be "snatched" from the mixture.

There are several approaches for isotope enrichment using lasers. When the nuclear weapons program in the United States began, these methods did not exist. In later years, laser technology was not adequate for producing the large quantity of enriched uranium that the United states required for its arsenal. While these methods were not adequate for the large requirements the United States had, a successful search for terrorist activities must include these as genuine possibilities.

The other method of achieving separate fissionable isotopes utilizes reactor neutron absorption followed by chemical separation. Upon neutron absorption, uranium-238 (not uranium-235) is transformed through intermediates to plutonium-239. Thus, uranium-238 bearing plutonium-239 can be taken through the chemical separation process and the plutonium-239 isolated to obtain usable bomb material. A nuclear fission reaction has been the choice to produce large quantities of neutrons to produce correspondingly large quantities of plutonium-239, but nuclear fission reactions are not the only source of neutrons for transforming uranium-238 to plutonium-239.

Charged particles raised to higher kinetic energy in an accelerator can be slammed against heavy metals like lead to produce as many as 50 neutrons per particle. This is known as "spallation." These neutrons could in principle be used to produce plutonium from uranium-238. The spallation reaction has been proposed in Los Alamos to dispose of radioactive waste. Although this would require a very large machine, smaller machines are possible, and these, as well as small nuclear reactors, should not be ruled out for use by terrorists in producing usable quantities of fission materials.

Plutonium-239 is only the first of several plutonium isotopes produced in a fuel element in a nuclear reactor (or spallation device). In most nuclear reactors most neutrons are so-called slow, or thermal, neutrons. When absorbed in plutonium-239, these bring about fission in about 65 percent of the events, and form plutonium-240 in 35 percent of the events. The presence of more than 5 or 10 percent of plutonium-240 in plutonium-239 lowers the performance of the plutonium mixture as a weapon, because the plutonium-240 spontaneously fissions. This limits the fission rate of the plutonium-239 before the weapon is exploded. Thus, the term "weapons grade plutonium" means that the mixture contains 92-95 percent plutonium-239.

The longer the fuel remains in an operating nuclear reactor, the more the higher isotopes of plutonium are present. Namely, when plutonium-239 doesn't fission, it forms plutonium-240. Plutonium-240, upon absorbing neutrons, seldom fissions. It forms plutonium-241, and plutonium-241, like plutonium-239, fissions part of the time but forms plutonium-242 about 15-20 percent of the time. Plutonium-242, upon neutron absorption, forms curium-242, which can be separated chemically from the plutonium chain. Thus, the term "reactor grade plutonium" is used for compositions like 75 percent plutonium-239, 15 percent plutonium-240, 10 percent plutonium-241, and 5 percent plutonium-242.

Other plutonium isotopes, namely plutonium-238 (approaching 3 percent), are formed by other nuclear reactions. The important thing is that, in principle, fission weapons can be made from reactor grade plutonium, although the spontaneous radioactivity associated with many isotopes would make such weapons difficult to handle. For example, plutonium-238 has a half-life of 86 years and generates about one watt of heat per gram, and one watt per gram of 3 percent plutonium-238 in a 10-kilogram weapon can make cooling necessary. Nonetheless, reactor-grade plutonium may appeal to a terrorist group, even though their lives would be at risk while handling the material and finished weapon. With a laser enrichment scheme, reactor-grade plutonium might be successfully "mined" for essentially pure plutonium-239.

Another potential weapons material can be made through neutron absorption—uranium-233 from thorium-232. If thorium-232 is used instead of uranium-238 in a reactor (India has many pure thorium reactors, for example), or as a spallation target, uranium-233 is formed upon neutron absorption, followed by some intermediate decays. Uranium-233 is, academically, a better bomb material than uranium-235. However, thorium-232, unlike uranium-238, does not have an impurity like uranium-235 that can operate a thermal neutron reactor. Instead, essentially pure uranium-235 is used to start the thorium-232/uranium-233 cycle.

The thorium-232/uranium-233 cycle also produces uranium-232, contaminating the uranium-233. The uranium-232 is produced by neutron interactions with two different isotopes, thorium-230 or uranium-233 itself. Upon neutron absorption, thorium-230 forms protactinium-231, which with another neutron forms uranium-232. Uranium-232 has a 70-year half life, with a rapid decay chain that includes thallium-204. Upon decay, thallium-204 gives off 2.6 million electron volt gamma-rays, which are very difficult to shield against. Therefore, a weapon produced under these clandestine conditions would likely be very heavy and difficult to handle due to radiation shielding requirements. However, it may be possible to remove enough uranium-232, using modern laser techniques, so that the material could be used.

How small a facility or how much spent fuel does a terrorist group need to produce a bomb? As a very rough approximation, the liberation of one megawatt day of thermal heat corresponds to the fissioning of one gram of "heavy isotopes" (uranium, plutonium, etc.). At a conversion rate of 0.8, 0.8 grams of fissile material can be made for every megawatt day of heat generated. Thus, a 1,000 megawatt electrical reactor generates 3,000 megawatts heat, and in a day's time produces 3,000 times 0.8, or 2,400 grams of plutonium. Operating for 300 days a year, it would produce 300 times 2,400 grams per day, or about 720 kg of plutonium.

However, test or experimental reactors may be a more relevant concern here. A 10-megawatt thermal test reactor operating 300 days a year would generate 3,000 megawatt days of heat, or 2,400 grams of fissile material. Hence, on a clandestine basis, there is a large incentive to operate test reactors at 2, 5, or 10 times their nominal ratings.

Accelerators used to produce the spallation reaction are perhaps beyond the scope of the terrorists that are being described here. However, it should be remembered that, as analytical tools, accelerators and electromagnetic separators have a potential for clandestine operation. Mass spectrographs operating today are far more sophisticated that the Calutrons and offer the potential for producing separated fissile isotopes.

Notes

1. This appendix was prepared by Eugene A. Eschbach, Scientist Emeritus, Pacific Northwest National Laboratory.

2. For a good discussion on basic warhead design and development, see *Report of the Executive Seminar on Special Material Smuggling,* U.S. Air Force Academy, Institute for National Security Studies, Center for Strategic Leadership, U.S. Army War College, Carlisle Barracks, PA, September 13, 1996, 39-50.

APPENDIX D:
Example of System Decomposition for a Protracted Nuclear Theft Scenario

(a) Level 1 System Elements ---> Level 2 Subelements

Inputs	Transformation Processes	Outputs
People	**Theft Process**	**Theft**
Individuals	Enter	Outcome
Ad hoc groups	ID material	
Existing groups	Remove material	
	Pack for transport, etc.	
Motives	**Brokering Process**	**Brokering**
Own use	ID broker	Outcome
Instrumental value	Negotiate sale	
	Complete sale, etc.	
Resources	**Sale Process**	**Sale**
Equipment	Locate buyer	Outcome
Information	Negotiate sale	Potential for and data future work
Insider connection	Receive payment	
Money	Transfer material	

Context/Environment

Facilities	Materials	Nat'l/Int'l Events	Social Environments
Weapons production	U235	Middle East	Underdeveloped economy
Weapons disassembly	Pu239	FSU	Terrorist groups
Nuclear fuel	UF6	Korea	Political facility facility suppression
Research	Th232	Africa	Newly facility democratizing
Civil reactor	Spent fuel	SE Asia	Social/economic collapse
Fabrication	Production	China	Political unrest

facilities	scrap		
Separation facilities, etc.	Test reactor fuel		Reduced standard of living

**(b) Level 2 Subelements ----->
Level 3 Subelements**

Inputs	**Processes**	**Outputs**	**Context/ Environment**
Individuals, etc.	**Enter, etc.**	**Undetected theft, etc.**	**Weapons facility, etc.**
Specialized skills	Access required	News reports	Site specifics
Technical	Coordination	Police activity	
Nontechnical	etc.	etc.	
Instrumental value	**ID broker, etc.**		**U235, etc.**
Amass power	Communicate need		Characteristics
Exert influence	Background check		Uses
Credible threat	etc.		etc.
Meet specific needs for nuclear weapons, etc.			
Equipment	**Locate buyer, etc.**	**Middle East, etc.**	**Underdev. economy, etc.**
Shielded vehicle	"Advertise"	Specific events	Characteristics
Laser for cutting	Verify credit		
etc.	etc.		

APPENDIX E:
Workshop Summary and Key Findings

Summary

On February 19, 1997, the Center for Counterproliferation Research (CCP) hosted a Nuclear Smuggling Pathways Model (NSPM) Evaluation Workshop at National Defense University (NDU), Washington, D.C. Participants included over 20 senior and supervisory analytical personnel from the Departments of Defense, Energy and State, the CIA, FBI, and U.S. Customs Service. The objective of the workshop was to test and evaluate the NSPM, a general systems model specifically designed as an analytical tool to assist national security, law enforcement, and customs personnel in understanding, analyzing, and preventing instances of illicit trafficking in nuclear materials.

Participants were divided into three teams, with the principal user agencies represented on each team—CIA, FBI, USCS, DOD, and DOE. Each interagency team was then presented with information from a hypothetical nuclear smuggling scenario and asked to use the NSPM to organize and correlate the given information. A facilitator coached each team in the use of the NSPM. At the end of the analytical phase, all participants reconvened and presented their findings during the wrap-up discussion. Specifically, participants addressed the strengths of the NSPM, as well as areas needing improvement and its utility in their current work. Although each of the three teams approached the workshop task differently, their findings on the NSPM were remarkably consistent.

Overall, participants from all agencies represented believed that the model had a great deal of potential. While they pointed out areas that could use improvement, the general consensus was that the model could be very useful in an interagency setting for organizing data and supporting a holistic analysis process.

Key Findings

Strengths

- The model provides a logical method of capturing data that enables participants to sort through and organize large volumes of information effectively.
- The model allows users to identify information "gaps" and provides direction on identifying where additional resources can be employed to shed light on those gaps. Several participants noted that it is often just as important to identify what is missing as it is to identify what information is available.
- The model is flexible and lends itself to changing situations. It permits users to begin their analysis at any point in the smuggling pathway and allows for continuous data integration. Its flexibility enables users to understand the "big picture" as well as the fine details of any scenario simultaneously.
- The model provides a standardized template useful for the analysis of nuclear smuggling scenarios. The standardized approach allows users from different agencies and with different backgrounds and analytical approaches to communicate and cooperate as an interagency group. It facilitates discussions, group dynamics, and lowers the degree of agency bias.
- The model provides a framework to simplify complex problems by focusing on important components of nuclear smuggling and encourages users to link these seemingly disparate pieces together into a meaningful whole. It allows users to analyze trends across several scenarios that may have similar characteristics. The "motives" category was found to be particularly useful in identifying potential actors.
- The model permits users to evaluate what really happened while avoiding the disruptions, time-sensitive demands, and the need for continual crisis information flow that typically destroys long-term analysis.
- It appears that the model can be adapted easily for computer use.

Areas for Improvement

- Participants recommended timelines to show the relationship of events over time. A mechanism that allows the incorporation of timelines would be useful for the analysis of a large amount of data.
- Participants suggested that the model provide a means to record the relative values of pieces of information. They would like to be able to incorporate diplomatic issues and to separate facts from

assumptions. A feedback process to eliminate useless/irrelevant information and linkages would also be helpful.

- USCS participants believed that the "transportation and movement" of nuclear materials should be given increased emphasis or prominence in the model. They suggested the addition of a high-level category called "transportation and movement."
- For the first-time user and when it is used for a full-scale analysis, the model is resource intensive—i.e., it requires considerable time and effort. It was suggested that an electronic version of the model, such as a relational database, would reduce the time and effort in completing the templates and enhance the model's utility.
- The complexity of the model was somewhat confusing to the new user. Some participants raised the concern that users could easily become mired in the process rather than producing results.
- Most analysts lack of experience with general systems models, and the terminology used in the NSPM necessitates the presence of a coach or facilitator.

Next Steps

- The authors are reviewing the NSPM templates used to organize information in an effort to incorporate user suggestions. Timelines and a means to indicate the relative importance of information may be accomplished simply by use of a system of marks, color codes, or other editing symbols. The authors will also review the templates for a way to ensure that adequate emphasis is placed on the "transportation and movement" area of nuclear smuggling.
- The originators of the model will publish a "Guide to Using the NSPM" to assist new users. It will include examples of how to organize information and how to assign relative value to different data. Instruction on the use of the NSPM is required, as is a good working knowledge of the terms employed in the model.
- The current availability of computer-based tools made everyone realize that the NSPM in an electronic format would provide them easier and expanded use of this analytic tool, to include data management capabilities. The creators of the model view an electronic version as a future objective.

Utility

- The model could serve as a good training tool for senior analysts and investigators involved with analysis of nuclear smuggling scenarios. It would provide a common, systematic approach for senior military, law enforcement, and intelligence officials to analyze nuclear smuggling cases within the framework of a general systems model.

- The model could be used in postincident analysis of real nuclear smuggling cases. Further, the postincident analysis could be leveraged into developing "predictive" scenarios as a means to raise awareness of and prevent potential smuggling situations. In addition, the model could be used to "fill in" past nuclear smuggling cases and to keep a historical record of them for future reference.
- The model could serve as another useful tool available to nuclear smuggling analysts. Specifically, it would serve as a good "fact gathering" tool for nuclear smuggling cases in real time. It was suggested that the model, combined with other decisionmaking tools such as affinity diagrams, cause and effect diagrams, and decision matrices, would complete the nuclear smuggling analyst's tool kit. However, the model would be most useful in electronic format as a database analysis tool.
- The standardized format of the model would facilitate cooperation and communication among foreign and domestic law enforcement, military, and intelligence officials. It would be particularly useful for explaining international nuclear smuggling situations to high-level policy groups and to allow individual analysts or groups to take a long-range, analytic view of the nuclear smuggling problem.
- In emergency situations, the model could be used at a macro level to assess a nuclear smuggling situation and to serve as a checklist to ensure that all important smuggling elements are considered.

Conclusion

Overall, participants were very favorably impressed with the model. Some expressed having had some skepticism at the beginning of the workshop about the utility of such a tool but declared afterward that it really worked "as advertised." There was a consensus that the model could be effectively used in a variety of situations, and that some fine-tuning to address the aforementioned areas for improvement would make it even more effective. Participants recommended that more training on the use of the model be provided to military, law enforcement, and intelligence personnel, and that an effort be undertaken to move it from the research phase into wide use by the national security community.

GLOSSARY

Abrupt theft: A theft that is accomplished during a single occurrence.

Brokering: The process of acting as an intermediary between two individuals or groups, or between an individual and a group.

Complex crime: Not abrupt; a crime which is characterized by a large number of interconnected and complicated actions.

Context/Environment: The circumstances in which a particular event occurs; the total circumstances surrounding an event or thing.

Decomposition: The breakdown or separation of a thing (such as a system) into component parts.

Demand side theft: A theft initiated by a customer, usually to meet a specific need or requirement.

Instrumental value: The value inherent in something that acts as a means to another thing which is desired.

Material Protection, Control and Accounting (MPC&A): An integrated system of physical protection, material control and material accounting measures designed to deter, prevent, detect, and respond to unauthorized possession, use, or sabotage of nuclear materials.

Protracted theft: A theft resulting from a high degree of planning and management, concealed, and usually executed over an extended period of time; may involve repeated occurrences.

Signature: A distinctive, identifying mark or characteristic.

Source material: Depleted uranium, normal uranium, thorium, or any other nuclear material determined to be source material; or ores containing one or more of the foregoing materials in such concentration as may be determined by regulation.

Special nuclear material: Plutonium, uranium-233, uranium enriched in the isotope 235, or any other nuclear material which does not include source material; special nuclear material also includes any material artificially enriched by any of the foregoing, not including the source material.

Supply side theft: A theft initiated by the thief without reference to any particular customer or customer need.

System inputs: The materials or resources put into a system to produce something.

System outputs: That which is produced in a system from the transformation or processing of inputs.

Temporal sequencing: Arranging things (such as events) by their occurrence in time.

Transformation process: The process or activity by which raw materials become a finished product; the process or activity that changes the characteristics or appearance of something.

ABOUT THE AUTHORS

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