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THESIS

THE DETERRENCE OF NUCLEAR TERRORISM THROUGH AN ATTRIBUTION CAPABILITY

by

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June 2008

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The state of the world is such that the pace of nuclear weapons proliferation appears to be increasing. The growing number of nuclear states and amount of nuclear material available poses a great challenge to those that would attempt to keep nuclear weapons out of the hands of terrorists and other non-state actors. This study examines how the development of a nuclear attribution capability using the tools and methods of nuclear forensics can address that challenge.

The prevention of nuclear terrorism is a multi-front battle. One of these fronts is preventing state sponsorship of nuclear terrorism. This can most likely be accomplished through deterrent policies where severe and credible military action is threatened against would be nuclear sponsors. However, such threats only have meaning if the sponsors are convinced that their participation could be detected. Therefore there is a need for a credible means to determine the source of nuclear materials from the debris of a nuclear explosion.

The current state of a national nuclear forensics capability is lacking. There is a need for a more robust database of known nuclear materials, as well as a need for organizational restructuring and equipment development.

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THE DETERRENCE OF NUCLEAR TERRORISM THROUGH AN ATTRIBUTION CAPABILITY

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I. INTRODUCTION

A. BACKGROUND

1. Introduction

Today the state of the world is such that the pace of nuclear weapons proliferation appears to be increasing. The growing number of nuclear states and amount of nuclear material available leads to very important questions regarding the means by which to keep nuclear weapons out of the hands of terrorists and other non-state actors. As indicated by a White House statement issued in September 2006, "Weapons of mass destruction in the hands of terrorists is one of the gravest threats we face." With each new nuclear state, the probability increases that a terrorist organization, that does not have the means to develop nuclear weapons without outside assistance, might obtain one through nefarious means (Carter, May, Perry; 2007).

As former U.S. senator Sam Nunn has pointed out, "Stockpiles of loosely guarded nuclear weapons materials are scattered around the world, offering inviting targets for theft or sale" (as cited in "Rep. Tauscher," 2007). Indeed the Institute of Science and Security (ISIS) reports that there are 1.9 million kilograms of Highly Enriched Uranium (HEU) and 1.83 million kilograms of plutonium worldwide. Much of this material exists in conditions making it very difficult to track (Hecker, 2006, p. 123). The International Atomic Energy Agency's (IAEA) Illicit Nuclear Trafficking Database (INTD) indicated in 2006 that there were 196 known incidents of illegal nuclear trafficking between the years of 1993 and 2004 (Hecker, 2006, p. 128). The following table taken from the INTD 2006 fact sheet provides a summary of these reported events that involved either highly enriched uranium or separated plutonium, both of which are weaponizable without additional processing.

Incidents involving HEU and Pu confirmed to the ITDB, 1993-2006			
Date	Location	Material Involved	Incident Description
1993-05-24	Vilnius, Lithuania	HEU/ 150 g	4.4 t of beryllium including 140 kg contaminated with HEU were discovered in the storage area of a bank.
1994-03	St.Petersburg, Russian Federation	HEU/ 2.972 kg	An individual was arrested in possession of HEU, which he had previously stolen from a nuclear facility. The material was intended for illegal sale.
1994-05-10	Tengen-Wiechs, Germany	Pu/ 6.2 g	Plutonium was detected in a building during a police search.
1994-06-13	Landshut, Germany	HEU/ 0.795 g	A group of individuals was arrested in illegal possession of HEU.
1994-07-25	Munich, Germany	Pu/ 0.24 g	A small sample of PuO_2-UO_2 mixture was confiscated in an incident related to a larger seizure at Munich Airport on 1994-08-10.
1994-08-10	Munich Airport, Germany	Pu/ 363.4 g	PuO_2-UO_2 mixture was seized at Munich airport.
1994-12-14	Prague, Czech Republic	HEU/ 2.73 kg	HEU was seized by police in Prague. The material was intended for illegal sale.
1995-06	Moscow, Russian Federation	HEU/ 1.7 kg	An individual was arrested in possession of HEU, which he had previously stolen from a nuclear facility. The material was intended for illegal sale.
1995-06-06	Prague, Czech Republic	HEU/ 0.415 g	An HEU sample was seized by police in Prague.
1995-06-08	Ceske Budejovice, Czech Republic	HEU/ 16.9 g	An HEU sample was seized by police in Ceske Budejovice.
1999-05-29	Rousse, Bulgaria	HEU/ 10 g	Customs officials arrested a man trying to smuggle HEU at the Rousse customs border check point.
2000-12	Karlsruhe, Germany	Pu/ 0.001 g	Mixed radioactive materials including a minute quantity of plutonium were stolen from the former pilot reprocessing plant.
2001-07-16	Paris, France	HEU/ 0.5 g	Three individuals trafficking in HEU were arrested in Paris. The perpetrators were seeking buyers for the material.
2003-06-26	Sadahlo, Georgia	HEU/ ~170 g	An individual was arrested in possession of HEU upon attempt to illegally transport the material across the border.
2005-03 to 2005-04	New Jersey, USA	HEU/ 3.3 g	A package containing 3.3 g of HEU was inadvertently disposed of.
2005-06-24	Fukui, Japan	HEU/ 0.0017 g	A neutron flux detector was reported lost at an NPP.
2006-02-01	Tbilisi, Georgia	HEU/ 79.5 g	A group of individuals was arrested trying to illegally sell HEU.
2006-03-30	Hennigsdorf, Germany	HEU/ 47.5 g	Authorities discovered trace amounts of HEU on a piece of tube found amidst scrap metal entering a steel mill.

Table 1. Incidents involving HEU and Pu confirmed to the ITDB, 1993-2006 (From: Preliminary 2006 Report from IAEA Illicit Trafficking Database, 2007)

Together these figures indicate that there is a clear security challenge that must be addressed. This thesis will seek to develop a policy recommendation to lessen this threat.

2. Severity of the Consequences

In addressing a proposed plan of action to reduce the probability of a disaster it is useful to understand what the consequences of that disaster would be. It is almost unnecessary to state that the conditions that would result from a nuclear weapons detonation in a U.S. city would be horrific. If a relatively small weapon of approximately 10-kilotons were detonated in the downtown area of a city it would completely destroy the area within about a one mile radius. Just outside of this area projectiles, fire, and intense radiation would leave virtually no chance of survival. Anyone in the area within five to ten square miles of ground zero would receive lethal doses of radiation within hours of the detonation and be dead within days. Longer term damage would depend greatly on wind conditions, but the generated radioactive plume would cause radiation sickness and increased cancer rates for large numbers of people miles away from the blast (Carter, May, and Perry; 2007). Computer modeling using the Consequences Assessment Tool Set developed by the Federal Emergency Management Agency and the Defense Threat Reduction Agency can estimate some of these human costs. The following numbers were generated assuming a 12.5 kiloton yield in the port area of New York City. Such a detonation would likely kill on the order of 50,000 people immediately. It would cause more than 40,000 cases of radiation sickness, with about 25% of these being fatal. The radioactive fallout would then be expected to kill or cause cancer in several hundred thousand more individuals. Medical assistance to those that did survive would be greatly complicated by the 10,000 hospital beds that would become unusable following the detonation, either by being destroyed, or being in an unacceptably high radiation zone. It is expected that surrounding medical facilities would quickly become overwhelmed (Heland, Forrow, and Tiwari; 2002).

The effects of such a detonation would include much more than the death and destruction caused directly from the nuclear yield. In 2005, then UN Secretary-General Kofi Annan estimated that the economic ripple effects of such a detonation would force “tens of millions of people into dire poverty,” and thereby create “a second death toll throughout the developing world” (as cited in Bunn, 2006, p. 106). This has led to the

estimation by some experts that the cost, ignoring the loss of life, of just one nuclear detonation would be on the order of $4 trillion (Bunn, 2006, p. 106).

B. CREDIBILITY OF A NUCLEAR TERRORIST ATTACK

1. Would Terrorists Attempt to Obtain Nuclear Weapons?

Prior to committing significant national resources to preventing a potential problem, it is useful to determine if that potential actually exists. This is certainly true of nuclear terrorism. For a great many terrorist organizations the use of nuclear weapons, even if they could be obtained, would be counterproductive to their goals. The massive numbers of innocent dead alone would almost certainly undermine the political aims of most terrorist groups (Bunn, Wier, and Friedman; 2005).

However, there is evidence that a small number of terrorist organizations in recent history, and at least one presently, have nuclear ambitions. These groups include Al Qaeda, Aum Shinrikyo, and Chechen separatists (Bunn, Wier, and Friedman; 2005). Of these, Al Qaeda appears to have made the most serious attempts to obtain or otherwise develop a nuclear weapon. Demonstrating these intentions, in 2001 Osama Bin Laden, Ayman al Zawahiri, and two other al Qaeda operatives met with two Pakistani scientists to discuss weapons of mass destruction development (Kokoshin, 2006).

Additionally, Al Qaeda has made significant efforts to justify the use of mass violence to its supporters. Sulaiman Abu Ghaith, an al Qaeda spokesman has stated that al Qaeda, "has the right to kill 4 million Americans – 2 million of them children," in retaliation for deaths that al Qaeda links to the U.S. and its support of Israel (as cited in Bunn, Wier, and Friedman; 2005). Indeed Bin Laden received a fatwa in May 2003 from an extreme Saudi cleric authorizing the use of weapons of mass destruction against U.S. civilians (Bunn, Wier, and Friedman; 2005). Further evidence of intent is the following figure taken from al Qaeda documents seized in Afghanistan. It depicts a workable design for a nuclear weapon. Additionally, the text accompanying the design sketch includes some fairly advanced weapons design parameters (Boettcher & Arnesen, 2002).

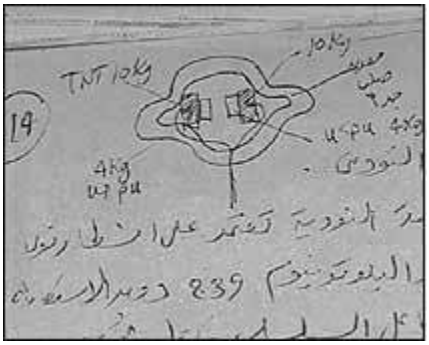

Figure 1. Al Qaeda nuclear weapon design (from: Boettcher & Arnesen, 2002)

Clearly maximizing the loss of life is key among al Qaeda's goals. Thus their use of conventional means of attack presently appears to be a result of their current capabilities and not a function of their pure preference (Western Europe, 2005).

The intentions of the Chechen terrorists are less clear. However, it is clear that this organization has carried out reconnaissance operations at Russian nuclear warhead storage facilities. Additionally, there is evidence that Chechen terrorists considered seizing a Russian research institute in 2002 that contained enough HEU to construct dozens of nuclear weapons (Bunn, Wier, and Friedman; 2005). Some might argue that the decision not to attack the site indicates a lack of nuclear ambitions. However, the fact that the plan was seriously considered lends credence to the possibility that the organization does pose a serious potential nuclear threat.

It is likely that few terrorist organizations seek to obtain a nuclear capability. However, as can be seen from above, such organizations do appear to exist. Sadly, the organizations that have demonstrated these intentions have also demonstrated that they have the capability of conducting complex planning, are well financed, and have an ideology that resonates with significant numbers of people.

2. Pathways for Terrorists to Obtain a Nuclear Weapon

Of course to use a nuclear weapon in a terrorist attack, an organization must first obtain one. There are two very broad ways in which acquisition could occur. A terrorist organization could somehow obtain a fully assembled weapon ready for use, or it could build one from materials obtained through theft, black market purchase, or provision by a

rouge state. Some have argued that the later method of acquisition is not feasible due to the technical difficulties involved in nuclear weapons construction. Such arguments usually point to the years and billions of dollars states put into nuclear weapons programs that often fail (Bunn and Wier, 2006, p. 138). While containing some truth, such an argument is flawed.

The construction of nuclear weapons today with modern machine tools, computer aided design software, and easily molded high explosives, all readily available to a well funded group, is significantly easier than it was in the 1940's (Hynes, Peters, and Kvitky; 2006; p.151). Additionally, such critics fail to distinguish between the fairly complicated process of developing a highly reliable, safe, high yield, light weight bomb capable of being delivered by a missile or a small fighter aircraft, from the much less challenging task of creating a crude, unreliable, unsafe, low-yield, heavy weapon intended to be delivered by boat or truck (Bunn and Wier, 2006, p. 139).

Finally, the most difficult task of weapons production is creating the fuel. According to the U.S. Department of Defense this makes up 90% of the overall technical difficulty in weapons production. Financially this is also true as nuclear materials generation took up more than 90% of the Manhattan Project budget (Bunn and Wier, 2006, p.136). There is good reason to believe that non-state actors could not enrich or otherwise produce their own fuel. To do so would require large facilities with enormous power consumption, fairly advanced technologies, and a great deal of time (Talmadge, 2007, p.24). However, this difficulty should not be confused with the difficulty of weapons design (Bunn and Wier, 2006, p. 139). As was shown above there are massive stockpiles of fissile materials available throughout the world. There is much evidence that some of that material is currently for sale in black markets, and reason to suspect that significant quantities of fissile material is vulnerable to theft. Thus if an organization determined to generate a nuclear weapon is able to obtain fissile material, they will have a difficult, but by no means insurmountable task in constructing one (Hecker, 2006, p. 121).

A terrorist organization could also obtain a fully assembled nuclear weapon from a state. This could occur either by deliberate exchange or by theft. Probably the later is the most credible means. It is uncertain whether a state would risk deliberately transferring a weapon of mass destruction to a terrorist group that it could not directly control. It is certain, however, that security is less than adequate at many nuclear weapons storage facilities (Gallucci, 2005). Indeed the recent incident in the U.S. of the unauthorized and unintended movement of six nuclear warheads aboard an Air Force B-52 even brings into question even American security practices (Spiegel, 2008). Overall, lax security among the holders of weapons grade nuclear material has the potential to provide a reasonable means of acquisition for terrorist groups.

Less likely, but none the less possible, is that a state would sell or otherwise transfer a nuclear weapon to a terrorist organization. This probability is low, because once a terrorist organization had the nuclear device, the state could have no assurance that the weapon would not be used to blackmail that state, or that the weapon's origin could not be traced back to the host nation (Bunn, 2006, p. 115). The best way to reduce this probability further, however, will be to remove all doubt that the origin of such a weapon could and would be determined (Bunn, 2006, p. 116).

3. Mathematical Model for Estimating the Probability of a Nuclear Terrorist Attack

A number of experts have made attempts to quantify the level of risk of a nuclear terrorist attack in terms of the probability of such an attack in the next decade. These estimates of risk generally range from 1 to 50 percent. This large range can be attributed in part to not quantifying all of the variables that determine the actual overall level of risk. To do so still leaves a great deal of room for debate about the individual probabilities, but it allows one to determine where their assumptions are being made, and provides a means of determining how the overall risk can be reduced (Bunn, 2006, p.103)

Such a mathematical model has been developed by Matthew Bunn. In his model, the probability that a nuclear terrorist attack will occur in any arbitrary year, P_c is given by:

$$P_c = 1 - \prod_{k=1}^{\sum_{j=1}^{N_n}(1-P_s(k))} \left(1 - \left(P_{o(j)} \times P_{os(j,k)} + P_{i(j)} \times P_{is(j,k)} + P_{b(j)} \times P_{bs(j,k)} + P_{n(j)} \times P_{ns(j,k)}\right)\left(P_{w(j,k)} \times P_{d(j,k)}\right)\right)$$

where the variables are defined as:

- N_n = The number of terrorist groups that seek a nuclear capability and could plausibly obtain one
- $P_{a(j)}$ = The probability of organization j launching an acquisition attempt in any arbitrary year
- $P_{o(j)}$ = The probability that organization j attempts an outsider theft
- $P_{os(j,k)}$ = The probability an outsider theft attempt is successful
- $P_{i(j)}$ = The probability that organization j attempts an insider theft
- $P_{is(j,k)}$ = The probability an insider theft attempt is successful
- $P_{b(j)}$ = The probability that an attempt to buy material on the black market is made
- $P_{bs(j,k)}$ = The probability of successfully purchasing nuclear material on the black market
- $P_{n(j)}$ = The probability of attempting to obtain a nuclear weapon or nuclear materials from a state
- $P_{ns(j,k)}$ = The probability a state would transfer a weapon or materials to terrorists
- $P_{w(j,k)}$ = The probability a working weapon could be constructed from the obtained materials
- $P_{d(j,k)}$ = The probability a weapon would be detonated if it were acquired

Using this model with the assumption that there are two terrorist groups with nuclear ambitions, Bunn calculates that there is approximately a 3% probability that a nuclear terrorist event will occur each year (2006, p.107).

Of course any calculated probability is extremely subjective as none of the variables listed in the model are known quantities. However, reasonable estimations can be made, and most of these quantities have been shown to be non-zero based on previous acquisition attempts and statements of intent from terrorist organizations such as al Qaeda. Perhaps the most important use of such a model is in determining how changes in

national policy aimed at reducing the value of each constituent probability will affect the overall probability of a successful terrorist attack.

For example $P_{n(j)}$, or the probability that a terrorist organization would seek to obtain nuclear weapons or their materials through a state sponsored transaction might be quite high. It is reasonable to assume that this would be the preferred acquisition method for a terrorist group due to the lower levels of risk involved in the acquisition process. There is probably little the United States could do to lessen the attractiveness of this acquisition mode. However, the total probability of a successful attack is proportional to the product of $P_{n(j)}$ and $P_{ns(j,k)}$, the probability a state would transfer a nuclear weapon or its components to a terrorist organization. This probability could potentially be altered by U.S. policy. One potential way that states could be persuaded not to cooperate with terrorists is by demonstrating to the international community that the U.S. has the capability to reliably determine the source of nuclear materials following a detonation through nuclear forensics and would therefore be able to retaliate (Talmadge, 2007, p.24).

An attribution capability could also reduce the probability of a successful theft attempt. The knowledge that stolen nuclear materials could be traced to the country of origin might persuade some countries to provide better security for their nuclear materials. In the end a nuclear attribution capability cannot prevent a nuclear terrorist attack. However, it could significantly reduce the probability of terrorists obtaining a nuclear weapon which is unarguably a useful endeavor.

C. THESIS SCOPE AND METHODOLOGY

The purpose of this study is to develop a conceptual plan for greatly increasing the difficulty involved in terrorist organizations obtaining nuclear weapons or components. Nuclear terrorism is unique from other forms of terrorism in that it essentially requires some level of state sponsorship due to the nature of the weapons development process (Talmadge, 2007, p. 24). Thus, it should be possible to construct a national policy of deterrence aimed at preventing the transfer of nuclear weapons, components, and technologies to terrorist organizations. Such a deterrent will only be possible if there exists a means of attributing an exploded nuclear device to the source

country. This thesis will examine the current state of such an attribution capability, determine what the policy implications are of threatening or executing a retaliatory strike based on nuclear forensic analysis, and examine means by which the current attribution capability may be improved. A robust and credible attribution capability should lead to the ability to retaliate against a state that willingly provides nuclear materials to a terrorist organization. However, this is merely a means to an end. The ultimate goal in creating such a capability is to never employ it. The manifest desire is that such a capability will effectively deter the actions the forensic capability is designed to detect.

Additionally, physics places some constraints on the capabilities of nuclear forensics and the organizations responsible for the collection, transportation, and analysis of the isotopic remnants from a nuclear detonation. For example, the half-life of the isotopes critical for analysis will place constraints on what the readiness requirements must be for the collection teams and what mode of transport are available for the samples. This thesis will quantitatively analyze these constraints to determine the fundamental organizational requirements to implement a deterrent strategy based on nuclear forensics.

This thesis will use a mixed methods approach. The organizational requirements to implement a meaningful attribution capability will be determined by a quantitative analysis given the physical parameters of a nuclear detonation and the resultant isotopic evidence. The policy implications and recommendations will be determined by a qualitative analysis of deterrence theories.

D. CHAPTER OVERVIEW

This thesis is organized in five chapters. Each of the chapters will build on each other with the ultimate goal of developing an understanding of the policy implications and necessities of a nuclear attribution capability.

Chapter I presents an argument for the severity of the threat of a nuclear terrorist attack both in terms of potential damage and probability. It then presents the methodology of this research project.

Chapter II will discuss deterrence theory. The importance of this chapter will be to present how an attribution capability is important in both the cognitive and classical theories of deterrence.

Chapter III will examine the current state of the science of nuclear forensics. It presents a description of how a nuclear forensics investigation would occur, and points to the challenges that need to be overcome to develop a robust and capable deterrent based on assured attribution.

Chapter IV presents the organizational implications of implementing a deterrent scheme based on nuclear attribution considering the present limitations of nuclear forensics.

Finally, Chapter V presents policy recommendations and conclusions.

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II. DETERRENCE THEORY

A. IMPORTANCE

If a policy is to be developed that intends to deter states from transferring, or tacitly allowing the transfer of, some of their nuclear materials to non-state actors, then it is important to examine the concept of deterrence. Here a general definition of deterrence is offered, and the conditions that enhance or diminish the probability of a successful deterrent scheme are considered. In particular, building a deterrent policy around a nuclear attribution capability presents a unique set of challenges. These challenges include but are not limited to ensuring credibility while at the same time not appearing unnecessarily aggressive to potential adversaries and thus altering their risk calculus to the detriment on the deterrent objective.

B. CLASSICAL DETERRENCE

1. Definition

According to Thomas Schelling deterrence is "persuading a potential enemy that he should in his own interest avoid certain courses of action" (as cited in Talmadge, 2007, p.22). Paul Huth defines deterrence similarly as using a threat of military retaliation in an attempt to convince an adversary that using his military force to pursue an objective will result in unacceptably high costs (Huth, 1988, p.15). By extension the transfer of a military capabilities, such as nuclear weapons or materials, can be viewed as a use of ones military force, and thus deterrent policies designed to prevent such transactions can be analyzed in the frameworks provided by Huth.

According to Huth, the success of a deterrence scheme is largely dependent upon two primary factors. These are the credibility of the deterrent threat and the stability of the deterrent policy (1988, p. 11).

2. Credibility

The credibility of a deterrent threat is also based on two factors. The first of these factors is the potential adversary's perceptions of the other country's ability to carry out the threat implied. The second factor is the potential adversary's perceptions of the other countries intentions and willingness to execute the deterrent threat if the action to be deterred is taken (Huth, 1988, p. 4). Therefore, the success of a deterrent policy requires that a country making a deterrent threat successfully create the perception in a would-be adversary's mind that it possesses the physical means to carry out its threat, and will have the capability to achieve and maintain the political will to do so.

3. Stability

Equally important to the success of a deterrence policy is stability. This means that the deterrent threat itself does not lead the potential adversary to believe that military action is inevitable, regardless of what course of action is pursued (Huth, 1988, p. 11). That is, deterrence requires a strong degree of reassurance that if the action being deterred is not taken, then the deterrent threat will not be invoked (Talmadge, 2007, p.22). Additionally, stability requires that the demands of the deterrent policy not create a situation so unacceptable to the potential adversary that action is taken regardless of the threat (Huth, 1988, p. 11). The later is particularly important in developing a deterrent based on a nuclear attribution capability. Such a capability will require other governments to share specific information about their nuclear materials generation process. It is conceivable that demands for such normally secret information could be deemed as unreasonable, thus weakening the chance of developing a successful deterrent.

C. COGNITIVE PSYCHOLOGY AND DETERRENCE

Deterrence frameworks are almost always based of the assumption that states act rationally. That is, it is assumed that states make foreign policy decisions attempting to maximize their gains while minimizing losses. Such frameworks also assume that mathematically equivalent values for losses and gains are viewed equally by state leadership. For example, a state would attach the same value to the loss of a territory

containing some arbitrary amount of resources, as it would to the gain of the same territory, or alternatively adversary states would assign equivalent values to gains and losses. Merely the sign of the attached value would be reversed. Presumably there is great value in such theories, because they yield predictions of state behavior during political crisis (Berejikian, 2002).

Unfortunately, recent research into human psychology suggests that such models are seriously flawed. It has been demonstrated that decision makers often act in ways not consistent with the rational choice model described above (Berejikian, 2002, p.165). State leaders are often forced to make many and rapid decisions using large amounts of uncertain or imprecise data (Berejikian, 2002, p. 167). When this is coupled with the innate biases of the decision maker, the results are decisions made far more by intuition and personal desire than by a rational cost-benefit analysis (Berejikian, 2002, p.166). Additionally, research seems to indicate that the level of risk states are willing to accept depends on the state's overall level of satisfaction with the status quo. Thus states that perceive their status quo situation as unacceptable are willing to take significant risks to improve their relative position. This is true even if their actions are more likely to result in a worse position than a better one. Rational actor models of deterrence do not predict this behavior; in these models a state's calculus of the utility of actions should be independent of the status quo (Berejikian, 2002, p. 169).

Thus a new model of state behavior and response to deterrent threats is required. A psychological school-of-thought known as prospect theory yields such a model that is both non-rational, but at the same time predictive. The deterrent model based on prospect theory relies on the fact that human decision makers view gains and losses asymmetrically. This results in two important implications for deterrence planners (Berejikian, 2002, p. 170).

The first of these can be called the framing effect. Decision makers are assumed to frame decisions in terms of either gains or losses. Which frame is chosen affects how the decision variables are processed in the mind. This effect is demonstrated by Jeffrey Berejikian in the following gambling scenario:

> Gains frame: Imagine a choice between two options that imply personal gains. Option 1: a sure gain of $80. Option 2: a risky venture with an 85% chance of winning $100 and a 15% chance of winning nothing. When confronted with this choice, most prefer the sure gain to a risky venture although the expected monetary outcome is $5 less.
>
> Losses frame: Now imagine a second set of options that imply personal losses. Option 1: a sure loss of $80. Option 2: an 85% chance of losing $100 and a 15% chance of losing nothing. Here individuals prefer the gamble to the sure thing although the expected monetary loss is $5 greater. (2002, pp. 170-1)

Again rational choice models of decision making behavior do not predict these results. The acceptance of risk should not depend on whether the scenario is presented as a loss or gain, only the probabilistic outcome should be considered. However, multiple attempts at refuting these conclusions have failed. Thus an implied repercussion for deterrence schemes is that decision makers do not necessarily maximize their outcomes when in possession of perfect information. Instead prospect theory predicts that decision makers will be risk averse when in a gains frame, and risk acceptant when in a losses frame (Berejikian, 2002, pp. 171-2).

The second, and related, implication for deterrence is loss aversion. Behavioral studies indicate that a state's leadership "will act more aggressively to avoid a loss than to secure an equal gain, and will pursue loss aversion beyond a rational expectation of benefits." Thus decision makers tend to overvalue what they already posses, relative to what they do not (Berejikian, 2002, p. 172).

D. IMPLICATIONS OF DETERRENCE THEORY AND COGNITIVE PSYCHOLOGY TO AN ATTRIBUTION BASED NUCLEAR DETERRENT

1. Credibility Considerations

There is probably little doubt in the mind of any world leader that the United States posses the physical means through its military might to effect grave consequences upon that leader's country. The realm of possibilities range from small scale clandestine actions aimed at regime change, to a devastating attack using the considerable nuclear

arsenal at the disposal of the American president. However, the possession of such capabilities does not preclude a rouge nation's leadership from concluding that the United States would be unable or unwilling to use its military might. Such a nation might conclude that the level of doubt as to the origin of a terrorist planted nuclear weapon would be sufficiently great to prevent the U.S. from taking action against the maker of the weapon or its nuclear materials. Thus a rouge state's leadership may conclude that the risk of facilitating a nuclear attack on the U.S. and therefore weakening the U.S. economy, and perhaps military, might be worth the risk (Phillips, 2007, p. 439). The challenge is to guarantee that the threat of accountability and retaliation is sufficiently convincing to ensure all nuclear states secure their stockpiles against theft, and to convince all states with potential hostile intentions against the U.S. that any proliferation of nuclear materials to non-state actors will be met with devastating consequences ("Nuclear Counter terror effort evolves," 2007).

Perhaps the most difficult challenge to overcome in a post attack scenario will be convincing both the domestic population and the world community that the evidence of origin is sufficient to warrant military action. A lack of clear and conclusive evidence will almost certainly impair international support for such action (Phillips, 2007, p. 436). Therefore, it is imperative that U.S. attribution capabilities be made public and well known by the leadership of potential proliferators to ensure that the question of sufficient political will for retaliation is not in doubt.

2. Stability Considerations

The U.S. diplomatic stance relative to states that are of proliferation concern will affect the stability of any deterrent strategy. For a state to be deterred its leadership must be convinced that military action is not inevitable regardless of their actions. If U.S. policy toward nuclear states is overly aggressive there may be an incentive to thwart a preemptive attack by any means available. Lacking other delivery means and in apparent extremis, this could entail the transfer of weapons of mass destruction to terrorists organizations that intend to strike the U.S., to obtain whatever benefit that may provide while they still have their nuclear weapons. A state that believes it is on the verge of

invasion might prefer this option to losing their nuclear arsenal in a U.S. first strike (Knopf, 2006, p. 396). Therefore, the U.S. stance toward states of concern must be carefully weighed against this possibility, however remote it may appear. This will be particularly true if the number of nuclear armed states continues to increase in the coming decades as the trend currently indicates.

A nuclear attribution capability will only be possible if there is an extensive database containing the expected signatures from all of the world's nuclear material. This will require obtaining very detailed information about the enrichment and weaponization processes used by the world's nuclear powers. It can be expected that many nuclear states will not desire to share this information. Indeed for a number of military and commercial reasons, the details of nuclear processes are closely guarded. Requests or demands on the part of the United States for such information then may be viewed as unacceptable. This will not be easily overcome. However, it is possible that participation in the database building process will be motivated by the assurance that participants will be included in the attribution process should a nuclear terrorist attack occur (Phillips, 2007, pp. 432). Additionally, non-participant states are likely to be the first suspected following such an event. This too should provide some motivation for participation (Phillips, 2007, p. 443).

Transparency is another factor that is likely to encourage participation. As such an international body should be the primary repository for the database. The UN's International Atomic Energy Agency is the obvious choice. To encourage the participation of all states, the U.S. must also be a full participant. There may be some hesitation with respect to revealing some of the U.S.'s nuclear design criteria. However, in reality there is little threat. If the IAEA lost control of the data, it might help rouge nations develop slightly more efficient weapons, but the resultant blast differential in the limited exchange possible from such nations would be inconsequential compared to the gains from full international participation in the database. Maximizing yield may have been important during the cold war designs intended for all-out nuclear conflict. However, in a world were only a few nuclear detonations are likely, the difference

between a 20 kT and a 10 kT blast do not warrant security measures that would breed resentment toward the U.S. for not taking the same actions that it demands of other nations.

3. Cognitive Considerations

The framing effect discussed above places constraints on U.S. foreign policy if an effective deterrent is to be implemented. A narrow policy based primarily on the transmission of credible threats to a potential advisory can carry the unintended consequence of placing the country's leadership in a losses frame. This would then increase the level of risk that the country's leadership is likely to accept, thus increasing the probability that the action intended to be deterred, is taken (Berejikian, 2002, p. 173).

Various forms of sanctions have the same effect as threatening signals. They are intended to create losses for a state in response to that state's behavior. But those losses have the additional effect of altering the perceptions of decision makers. The resultant mind frame results in an increased acceptance of risky behavior. Here again, this can result in actually causing the behavior that the sanctions were intended to discourage (Berejikian, 2002, p. 179).

The level of acceptance of the status quo is also an important variable. Policies intended to deter states not satisfied with their status quo position are less likely to be effective since defection from the deterrent relationship carries the possibility of improving their position (Berejikian, 2002, p. 173). Thus to improve the effectiveness of deterrent policies, they need to include means by which states can achieve a satisfactory status quo position without defecting from the deterrent relationship. Such measures could include promises for greater economic development assistance and even increased military cooperation aimed at increased national prestige.

Certainly, deterrent schemes are more likely to be effective when the country being deterred is not operating in a losses frame. Thus policies must be carefully selected to avoid creating this frame. In addition to ensuring that a transmitted threat is credible, selected policies must also consider how a country's leadership will interpret its effect on

their status quo (Berejikian, 2002, p. 180). A deterrent framework will be more effective if it contains meaningful rewards in addition to the credible treats. Specifically for nuclear security, this should include additional support and cooperation for programs aimed at securing the existing nuclear material possessed by possible rouge nations (Nuclear Counter terror effort evolves, 2007).

The loss aversion aspect of the framing effect may also point to the failure of policies aimed at preventing nations from continuing the development of domestic nuclear enrichment programs. Policies that attempt to encourage the cessation of domestic uranium enrichment by making low enriched uranium for power production available from outside sources may be viewed as an unacceptable loss. This would be true if the country's leadership placed value in the prestige or security that might be gained from having an independent nuclear program, even if it were for civilian applications. From an outside rational perspective the results of obtaining ready made fuel elements from other nations might have the equivalent effect as manufacturing them domestically. However, a nation might place an irrationally high value on the ability to create such products. Thus the cognitive theory of deterrence would suggest that a country might accept significant risk in continuing the development of such technologies.

If this is so, then sanctions or military threats aimed at forcing a nation to abandon uranium production are unlikely to succeed. Increasing the threat level could instead cause the state's leadership to place more value on the domestic program. Therefore, policies should be selected that target the level of prestige inherent in the independent ability, rather than the behavior itself.

III. NUCLEAR FORENSICS

A. DEFINITION AND EXPLANATION

Nuclear forensics is the term used to describe the technical process by which nuclear or radiological material is analyzed, and the analysis results are interpreted. The samples can be either fully intact, interdicted materials, or the samples can be collected from the debris at and around the site of the employment of a nuclear or radiological weapon. The overall process can be broadly broken down into three primary phases. The first of these is the collection of the material to be analyzed. Next, this material must be subjected to numerous scientific tests to determine the nuclear and chemical properties of the material. Finally, the data obtained from the analysis is compared with either the properties of known materials, or the assumed properties of materials that have not been sampled, but have been modeled using computer simulations. The primary focus of this phase is to determine the history, and ultimately the origin, of the material in question (*Nuclear Forensics*, 2008, p. 3).

In addition to the political goal of assigning accountability to a nuclear attack, there is a more time sensitive requirement. Determining the origin of the nuclear material, coupled with diplomatic and intelligence efforts, may make it possible to determine if sufficient material from the same source is available for terrorist use (*Nuclear Forensics Support*, 2006, p. 9). This would be an obvious information requirement for national decision makers when determining post detonation recovery efforts, and to provide some level of public reassurance.

Nuclear forensics is made possible due to the nature of nuclear and radiological material, and due to the predictable character of nuclear reactions. Weapons grade nuclear materials do not exist in nature. To be weaponized natural uranium must go through an isotopic separation process known as enrichment in order to increase the amount of fissile U-235 relative to the other isotopes found in uranium ore. Likewise,

very little plutonium is found naturally. Weaponizable plutonium must be produced inside an operating nuclear reactor, and then separated from the other elements present in the fuel matrix (Talmadge, 2007, p. 25).

These processes can be performed in any number of ways. The varying methods that are used in the manufacturing processes leave different ratios of isotopes in the final product. These isotopic ratios can be used as fingerprints to identify the likely sources of the material. In addition to the nuclear material, the fabrication and machining processing in the enrichment and weaponization phases leave behind other trace elements and organic compounds. These too can be used to identify the processes used, and hence the likely source of the material, or at the very least certain potential sources can be ruled out (Talmadge, 2007, pp. 25-26).

In addition to examining the material that did not go through the fission process, the particulate debris and gasses given off during a detonation will contain fission products. These fission products contain information about the fuel used for the explosion. Many of these fission products will be gasses that will escape into the atmosphere and thus relatively easily collected by aircraft. This is particularly useful as sampling of particulates at ground level near the explosion site may be delayed due to radioactivity and general destruction. Figure 2 below demonstrates the fission process.

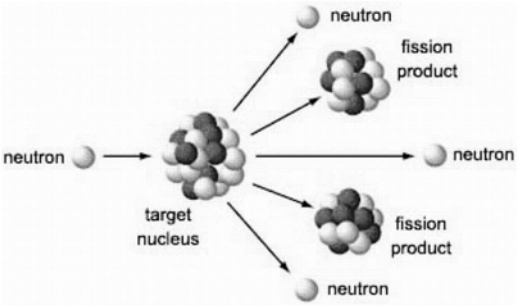

Figure 2. Fission Process (From: Combating Illicit Trafficking in Nuclear and other Radioactive Material, 2007, p. 55)

These processes are inherent to the nature of nuclear weapons. Thus while a skilled criminal may be able to foil traditional forensic investigations by removing fingerprints, or carefully denying investigators DNA evidence, there is no analog in nuclear forensic investigations. The destructive processes cannot occur without leaving behind the isotopic evidence of the history of the material used (*Nuclear Forensics Support*, 2006, p. 10).

B. HOW A NUCLEAR FORENSICS INVESTIGATION WOULD BE CONDUCTED

The completion of a nuclear forensics investigation will be a lengthy process. It would begin within hours of a detonation, but the completion of the attribution process is likely to take weeks to several months. This is due to both organizational and natural constraints. The availability of personnel and equipment will determine the initial pace of the investigation. Later, the iterative nature of conducting nuclear analysis will control the rate of progress (*Nuclear Forensics*, 2008, p. ii). Such an investigation cannot be 'cook-booked', or made into a set of routine procedures. The results of earlier tests will suggest to investigators what subsequent analyses should be performed. This is complicated by the fact that some tests are destructive and consume the evidence. If a limited amount of material was recovered for analysis, then proper sequencing of the tests will be of paramount importance to ensure that all pertinent parameters are determined (*Nuclear Forensics Support*, 2006, p. 24). These factors all contribute to making nuclear attribution a lengthy process.

While nothing can be known for certain about the timeline until such an event happens, there is consensus on the general process and rough pace of events. The forensic investigation can be divided into three phases. Evidence will have to be collected; it will then be subjected to a battery of technical analyses. The data gleaned form this process will then combined with information about world-wide nuclear stockpiles, and conclusions will be formed about the history of the material. Within a few hours of the detonation, it will be possible to determine definitively if the explosion was indeed nuclear, and if so what the yield was. Within about a day it will be possible

to determine what type of weapon was involved (uranium, plutonium, or thermonuclear) and its degree of sophistication. The first few days of analysis will reveal information about the isotopic composition of the weapon. Within a mater of weeks this will yield information about the details of the construction of the bomb, and perhaps its origin. The length of time required for this final effort, however, will depend heavily on whether or not the material matches that contained in databases (*Nuclear Forensics*, 2008, p. 5).

1. Sample Collection

The first step in conducting a nuclear forensics investigation will be to collect the evidence from the ground and atmosphere surrounding the detonation site. The ground collection effort will be particularly complicated due to competing priorities. The on-scene commander will have to balance requirements to protect the remaining population, care for the wounded, provide for the safety of responders, and preserve and collect evidence (*Nuclear Forensics Support*, 2006, p. 13). This complicated set of tasks points to the need for detailed planning and training before such an event, to insure that evidence collection occurs in a timely manner.

Following a nuclear detonation, the required evidence will be located in three areas. There will be some material, both fission products and unspent fuel, chemically fused with glass like melted rocks in the crater at ground zero. A great deal of the same material will be vaporized during the detonation and thrown up into the atmosphere. Much of this material will condense on particulates in the air and fall back to the earth down-wind of ground zero. There will also be particulates and fission product gasses that remain in the atmosphere and travel with the winds away from the explosion site (*Nuclear Forensics*, 2008, p. 17).

Initially the two easiest places to collect samples will be on the ground in the fallout area and from the drifting radioactive cloud. Sampling at ground zero will be more difficult due to the extreme levels of radiation that will be present. However, even in the fallout area radiation will pose concerns for collectors (*Nuclear Forensics*, 2008, p. 17). This concern could be minimized with the design of new or the adaptation of existing robotic vehicles to perform the bulk of collection tasks.

The amount of material that will be required for analysis is actually quite small. Only a few hundred nanograms of fuel material from the nuclear device will be sufficient for radiochemical analysis (*Nuclear Forensics*, 2008, p. 17). Indeed some analysis can be done without disturbing the site. Handheld gamma and neutron radiation detectors, such as those depicted in figure three can be used to determine the general nature of the weapon and the extent of contamination. These devices could also be used to perform a radiological survey of the area, locating the most radioactive areas. These areas of higher radiation would most likely contain the isotopic remnants that must be collected and transported to laboratories for more in-depth study (*Nuclear Forensics Support*, 2006, pp. 14-15).

Figure 3. Hand-held radiation detectors and survey instruments (From: *Combating Illicit Trafficking in Nuclear and other Radioactive Material*, 2007, p. 108)

The solid material identified by these surveys could then be scooped into plastic bags carefully labeled with the sample location. Similarly, fine particulate matter could be collected using absorbent swipes, also individually labeled and stored in plastic bags for transport (*Nuclear Forensics Support*, 2006, pp. 16-17). While very little actual material will be required for analysis, it will be important to gather as much of the radioactive material from as many locations as possible. Due to the explosion dynamics and chemical processes occurring in the few seconds following detonation, materials

from different locations might contain significantly different isotopic remnants. All of these various isotopes may be required in the subsequent analysis (*Nuclear Forensics*, 2008, p. 18).

Airborne collection will also be important for the forensic investigation. Not only will airborne collection pose a lower radiological risk to the collectors, but the skies above ground zero will also be far easier to access than the land due to the destruction that can be expected from the blast. Of particular concern to airborne collection are the non-reactive isotopes of xenon given off during a nuclear reaction. A ratio of the abundance of Xe-133 and Xe-135 can be used for an immediate assessment of the weapon type, because uranium and plutonium fissions produce differing amounts of these isotopes. The half-life of the shortest lived of these too species (Xe-135) is only 0.4 days (Garwin & Hippel, 2006). Therefore, to obtain useful information from these isotopic ratios will require the analysis to be conducted within about two to three half-lives, or within about 28 hours. This poses the greatest time constraint on the sample collection as the remaining isotopes of concern are much longer lived. This information will be of great use to investigators because only thirteen countries have either detonated a plutonium based nuclear weapon, or have enough reactor grade plutonium to form a critical mass. Forty countries are known to posses enough highly enriched uranium to form the requisite critical mass (*Nuclear Forensics*, 2008, p. 18). This information could potentially rule out certain sources of the fissile material, allowing intelligence agencies to focus their traditional collection efforts on the remaining possible sources.

2. Sample Analysis

After the samples are collected and transported to a fully equipped laboratory they must be analyzed. It is not possible to design procedures for this process, as the course of action relies on the professional assessment of scientists based on their iterative tests. However, the overall goal of this phase will be to fully determine the major, minor, and trace constituents of the nuclear fuel and its fission products, including the isotopic ratios

of the constituent elements. To fully complete this process will require between two to four weeks, depending primarily on the number of qualified personnel available to perform the analysis (*Nuclear Forensics Support*, 2006, pp. 24-25).

A wide variety of analytical tools can be utilized to conduct this analysis. They will measure quantities such as decay rates, mass, and radiation spectra to determine useful information such as the manufacturing process employed, the time since chemical separation, and the radiological history of the sample (*Nuclear Forensics Support*, 2006, p. 26). Table 2 contains a summary of the nuclear signatures that can be examined, and what pertinent information can be gleaned from this data.

Signature	Information revealed
In-growth of daughter isotopes	Chemical processing date
Pu isotope ratios	Enrichment of U used in Pu production Neutron spectrum and irradiation time in the reactor
Residual isotopes	Chemical processing techniques
Concentration of short lived fission product progeny	Chemical yield indicators

Table 2. Relevant Radionuclide Signatures (From: *Nuclear Forensics Support*, 2006, p. 30)

3. Attribution Process

The process of determining the source and relevant history of the nuclear material marks the end of the nuclear forensic investigation. This, however, is not a trivial task. There are two ways in which the data obtained from analysis can be used to determine its source. The most desired approach would be to compare the properties of the samples obtained from the debris, with the samples provided from all possible sources of nuclear material or samples seized during illicit trafficking. The alternative method in the absence of samples provided by potential suppliers is to compare the debris samples with the inferred properties of the nuclear materials of potential suppliers based on computer modeling of known nuclear processes (Nuclear Forensics Support, 2006, p. 29). While

the modeling technique should be possible, it is entirely feasible that retaliatory action based on inferred properties would not receive international support or credibility.

What cannot be understated here is the importance of developing as complete a database as possible of the properties of the world's nuclear materials. Without such a database the ability to reliably attribute nuclear material to a single point of origin is in serous doubt. Currently partial databases are maintained by various international institutions containing some of the pertinent data, however, they are all far too limited in scope to provide for the required attribution capability (*Nuclear Forensics Support*, 2006, p. 31).

C. CURRENT NUCLEAR FORENSIC CAPABILITIES AND CHALLENGES

The bulk of the United States' infrastructure that would be used to support the attribution of a terrorist nuclear attack was developed during the cold war. The goal during that period was to asses the yield, design, and location of Soviet nuclear weapons tests (Talmadge, 2007, p.27). This required developing the science of nuclear physics and radiochemistry. Also as a result, nuclear weapons laboratories were created, well equipped, and staffed (*Nuclear Forensics*, 2008, p. 15).

The new emphasis for nuclear forensics, however, is quite different. During the cold war the origin of the weapons was never in question. The new requirement to determine the source of the nuclear material used in an attack complicates the task. While some of this in place infrastructure is useful for the current need, it is not simply a mater of using the old means for new ends (*Nuclear Forensics*, 2008, p. 3). Again, the primary difference is the requirement for a complete database of the world's fissile material to compare analytic results to. Currently, lacking such a complete database, the technical ability to collect data about the details of a nuclear event far exceeds the ability to extract useful and actionable information from the data (*Nuclear Forensics Support*, 2006, p. 25).

Personnel issues are also of concern. There are only a very limited number of scientists with the technical skills required to conduct a nuclear forensic investigation. This is in part due to the relatively high cost of educating and training such experts

(*Nuclear Forensics Support*, 2006, p. 1). Indeed there are only 35 to 50 scientists with the required skills working in U.S. national laboratories, and most of these individuals are set to retire in the coming decade. The replacement of these individuals presents a problem, because the number of graduate students receiving Ph.D.s in the relevant fields has declined significantly over the last few decades, and many universities no longer offer degrees in radiochemistry due to the low demand. Additionally, even the existing number of specialists would make an emergency nuclear forensic investigation difficult because these specially trained individuals will be required both at the laboratory sites performing analysis, and in the field at the site of the detonation facilitating recovery efforts (*Nuclear Forensics*, 2008, p. 20).

Currently, there is no single government entity responsible for the attribution of a nuclear terrorist event. In 2006 the National Technical Nuclear Forensics Center was created under the Department of Homeland Security in an effort to correct this problem; however, much of the responsibility is still spread between the Departments of Energy, Defense, Justice, and State and the various divisions within these bureaucracies (Talmadge, 2007, p.27). While this is almost certainly unavoidable, much can be done to unify the efforts of these organizations. This should entail a standard doctrine for the response to a domestic nuclear attack that clearly delineates authority and responsibility. This doctrine must balance the immediate need to limit further casualties and care for the injured while ensuring that sufficient evidence is collected to determine the source of the material used to perpetrate the attack. Ultimate responsibility for the development and exercise of such procedures should be vested in the Secretary of Homeland Security. A unified doctrine and standardized procedures are also necessary to ensure that legal requirements, such as chain of custody procedures for evidence, are maintained to ensure the legitimacy of any action that might be taken as a result of an attack (*Nuclear Forensics Support*, 2006, p. 2).

A ground evidence collection capability exists in the Defense Threat Reduction Agency. The nature of this capability is not publicly available, but presumably it is rapidly deployable and capable of performing the required collections tasks (Phillips, 2007, p. 433). While details of the team's composition need not be made public, there is

little need to shroud in secrecy the nature of the team and their tasks. To do so is likely to interfere with their ability to effectively interface with other first responders that do not have security clearances, and again to deter would-be providers of nuclear material requires a well known attribution capability, not a secret organization. Unfortunately, current government policy appears to be leaning toward the latter.

The airborne collection capability is also dubious. The United States has only one aircraft equipped to gather airborne radiological specimens. It is the WC-135W Constant Phoenix based out of Offutt Air Force Base, Nebraska. The portion of the crew responsible for operating the onboard sample and analysis equipment is based out of Patrick Air Force Base, Florida. This aircraft has been in constant service since 1965 (*Factsheets: WC-135 constant phoenix*, 2007). With the separation of the flight crew and the technical operators it is doubtful the aircraft could be ready to obtain the desired information from a nuclear detonation before the Xe-135 gas decays to levels indistinguishable from other isotopes.

IV. ORGANIZATIONAL IMPLICATIONS

A. THE KNOWLEDGE REQUIREMENT

In 2005, there was an international controversy as to the origin of the nuclear materials obtained by Libya and subsequently surrendered to the United States. Through a process of elimination scientists at Oak Ridge National Laboratory concluded that the Uranium was manufactured in North Korea, with a 90 percent or better certainty. However, scientist from the IAEA, who also ran similar tests, concluded that the material was just as likely to have been produced in Pakistan. Complicating matters further, the United States would not disclose the details of the forensic testing that confirmed North Korea as the source. A process of elimination was used by both the United States and the IAEA, because samples of nuclear material were and remain unavailable from either country (Phillips, 2007, pp. 434-435).

Had the known terrorist supporting country of Libya used that uranium to construct a nuclear device transferred to and used by terrorists in an attack against the United States, could the U.S. have taken military action against North Korea to prevent further proliferation? With an admitted certainty of only 90 percent, and the IAEA strongly disagreeing with American' conclusions, it is probable that U.S. decision makers would be constrained in their ability to respond. Fortunately, this was not the case, but the event clearly demonstrated how a lack of verifiable samples can result in an inability to conclusively determine the source of nuclear materials.

To effectively attribute the source of nuclear material will require a comprehensive database of nuclear materials and properties, which does not exist today. Additionally, archived physical samples are required. It is likely that new analytical procedures will be developed in the coming years as instrumentation and knowledge of nuclear processes develop, thus being able to examine older material with new techniques will almost certainly be desired (*Nuclear Forensics Support*, 2006, pp. 31-32). The fuel material that these samples would be drawn from are generally very stable, thus radioactive decay slowly diminishing the forensic value of the material is not a concern.

Relying on the assumption that these samples can be obtained after the fact is at best inviting long delays, and likely inviting the above scenario where attribution relies on a dubious process of elimination.

The most difficult challenge to overcome will certainly be convincing other nations that it is in their interest to share some portion of their nuclear secrets. The IAEA is doubtful that some portions of the required data will ever be shared (*Nuclear Forensics Support*, 2006, p. 10). While this pessimistic view is likely to be fairly accurate, it must not stop the formation of a centrally held, rapidly accessible database to support nuclear forensics. The U.S. could then secretly fill in the gaps in the internationally held database using covert collection means. The fact that this has occurred could be revealed through planned media leaks to increase the credibility of the deterrent threat, while not revealing the remaining gaps in the database or the sources and methods used to obtain the sample data. Again, to have any credibility in demanding the participation of other nations, the U.S. must provide samples of its own fissile material.

The concerns that would dissuade some countries from participating in a comprehensive nuclear material database program might be mitigated. One proposed method would allow a small set of vetted analysis to access the data following an event requiring attribution through nuclear forensics. Security protocols enforced by the IAEA would prevent all other access (*Nuclear Forensics*, 2008, p. 26). Such a method, however, carries the risk of unacceptable delays. Certainly more research is required to devise a database access protocol acceptable to the world community, but that also meets U.S. access requirements.

B. PERSONNEL ISSUES

The issue of insufficient numbers of scientists trained in the field of nuclear forensics can be overcome. Due to the low number of institutions offering such programs, funding the best of these programs is a necessary first step. Other steps should include internships for graduate and undergraduate students, and fellowships at the national laboratories (*Nuclear Forensics*, 2008, p. 21). Additionally, providing scholarships to promising undergraduate and graduate students interested in the fields

relevant to nuclear forensics, tied to a period of obligated service at the national labs upon degree completion, could generate the required numbers. This model has worked for the military officer corps for years.

C. DEVELOPMENT OF COLLECTION ASSETS

It is unacceptable to have only one airborne radionuclide collection asset. A routine, but poorly timed, maintenance issue on the forty-five year old aircraft or a snow storm in Omaha could prevent the collection of valuable data that could quickly provide national decision makers useful information. Additionally the 1,400 mile separation of the aircraft from the operators trained to perform the nuclear analysis demonstrates that there is no serious plan to be able to rapidly sample and analyze the airborne debris from a domestic nuclear explosion.

The time available to sample airborne debris is sufficient that the location of basing for collection assets is not critical. There would be sufficient time for an aircraft to make the flight from any continental Air Force base to arrive in time. What is critical is that there is more than one asset available to allow for maintenance down time and inclement weather at the basing site. Crews must be co-located with the aircraft, and have the ability to be recalled within only a few hours.

D. DEVELOPING UNITY OF EFFORT

To effectively respond to a domestic nuclear terrorist attack will require that all responders have a clear understanding of their personal role, how that fits into the overall effort, and how the paths of authority are laid out. This understanding can only be fully imparted by conducting realistic training exercises. Additionally, it is only through realistic exercises that doctrine can be developed, tested, and modified to prepare responders and policy makers for their response role.

Recent exercises have demonstrated some success in developing an attribution capability, on the technical side of the problem. They have also demonstrated a persistent lack of communication between agencies and between layers within agencies. This has led to improper handling of evidence, and conflicting analyses that were never adequately

addressed during the scenarios. Exercises to date have also failed to properly integrate senior level executives into the attribution problem. This could lead to unrealistic expectations, and poor response decisions in the event of an actual nuclear crisis (Nuclear Forensics, 2008, pp. 29-31).

Exercises also need to be developed and executed that involve local and state agencies working in conjunction with the federal agencies that would respond to a nuclear attack. The exercises should be conducted in as many of the major cities as is feasible. This should be an iterative process where the lessons learned from each exercise are used to improve the efficacy of the next. Finally, the results and lessons learned from the exercises need to be analyzed and distilled into useful doctrine for all levels of government. Responding to a nuclear terrorist attack needs to become a skill set for local law enforcement agencies across the country.

V. POLICY RECOMMENDATIONS AND CONCLUSION

A. NUCLEAR ATTRIBUTION AND THE INTELLIGENCE COMMUNITY

The task of creating a credible deterrent threat by ensuring that the United States has a credible means of identifying the source nation of any nuclear material used in a terrorist attack falls upon both the technical experts in the field of nuclear forensics and the various agencies of the intelligence community. The collective means of identifying the provider will have to stand the scrutiny of both skeptics within the U.S. and, perhaps more importantly, the world community (Talmadge, 2007, p. 30). The task will have two fronts. In addition to analyzing isotopic evidence and comparing it with the body of data retained on the worldwide stockpiles of nuclear materials, more traditional means of intelligence collection and analysis should be applied to determine the source of the material. Both of these tasks have unique sets of problems and opportunities.

The development of a technical means to identify the source of nuclear material is critical to minimize the probability of an intelligence failure that might lead to an inappropriate U.S. response. Such failures have been seen in the recent past. A damning such example is the recent reliance on a human intelligence source that led the U.S. to believe that Saddam Hussein's Iraq retained biological and chemical weapons and was developing a nuclear device (Ackerman, 2007). This failure was in part due to preconceived notions of Hussein's regime and a lack of other evidence. As Richards Heuer observes, "When evidence is lacking or ambiguous, the analyst evaluates hypothesis by applying his or her general background knowledge concerning the nature of political systems and behavior" (Heuer, 1999). Following a devastating nuclear attack on the U.S. it is highly conceivable that initially there will be little evidence available without a means to analyze isotopic remnants. This combined with the highly emotional desire for retribution that the intelligence community will not be immune from, could create an opportunity for significant analytical error. Such an error might be minimized in the future if solid physical evidence can be produced.

Developing a technical attribution capability by itself has several challenges for the traditional intelligence community. Even if the means are fully developed to determine the exact physical makeup of the debris from a nuclear event, it is useless by itself. The data obtained from such an analysis must be compared with the expected isotopic signatures from all the world's nuclear stockpiles. This is no small task. It may prove quite difficult to convince many countries that it is in their best interest to share their nuclear secrets with the United States (Phillips, 2007, p. 432). Some progress has been made toward this task. There are over 50 nations that belong to an anti-nuclear terrorism initiative lead by the U.S. and Russia (Doll, 2007). However, examining the list of member countries indicates some very significant missing countries including Syria, North Korea, India, and Iran (*Current partner nations…*, 2008). This indicates that the intelligence community may need to obtain much of this data from non-cooperative countries by covert means. Nuclear forensic means of attribution almost certainly will not guarantee that appropriate blame can be assigned; however, it will be extremely useful in narrowing the search and ruling out certain possibilities (Biden, 2007).

While a nuclear forensics capability is extremely important and must be developed, it cannot replace the requirement for more traditional means to determine the source of nuclear material used in an attack. The clues offered by forensic analysis will be just that: clues. In the absence of other intelligence they will not be sufficient to positively assign blame for an attack for several reasons (Talmadge, 2007, p. 27). First, as noted above the intelligence community must properly correlate the event residue with the appropriate nation's nuclear materials. Secondly, the intelligence community will have to determine how the material was obtained by the terrorists that employed it. Without question the U.S. response will be significantly different if the terrorists stole the material from a stockpile without the consent of the host country, than if the material was intentionally sold or given to the terrorists.

Finally, there is a real and serious threat that a host country and a terrorist organization might attempt to falsely implicate an uninvolved country by including key isotopic indicators from the innocent country's stockpiles. The idea that a nuclear attack

might be blamed on a third party country is not a new one. A 1970 National Intelligence Estimate indicates that the CIA worried that the Chinese would introduce a nuclear weapon into the United States and detonate it with the hope that the U.S. would believe it to be an attack perpetrated by the Soviet Union (Zenko, 2006, p. 93). Such a spoofing of the American forensic system might even be easier than what the CIA worried about in the 1970's since all that is required is the inclusion of a few grams of radioactive material available from many university laboratories throughout the world.

For the above reasons, it is critical that the nation use all available intelligence assets to determine the origin of a nuclear weapon used in a terrorist attack. There will undoubtedly be some motivation and political pressure to rush to judgment based on what evidence the nuclear forensic analysis provides. This is a temptation that must be resisted. The time constraints placed on the formation of a 2002 NIE was one of the many reasons it contained ninety-three pages of inaccurate information with regard to Iraq's WMD capabilities. An additional factor was the fact that the document was intended to motivate action, as opposed to merely presenting policy makers with an accurate picture of the current situation (Zenko, 2006, pp. 89-90). This is exactly the situation the United States will find itself in following a nuclear terrorist attack. The consequences of another inaccurate intelligence estimate, one that might be used to justify a massive retaliatory strike, could be devastating.

The organizational framework within which the intelligence community is to determine the origin of a nuclear device will decide the likelihood of a correct assessment being made. Intelligence analysis is affected by cognitive biases, and analytical methods that simplify the processing of huge amounts of information. While these can be useful there is also a danger that they will lead to inaccurate conclusions (Heuer, 1999). The process must be designed to prevent these biases and methods from creating such a situation.

Perhaps the largest looming danger here is satisficing, or selecting the first hypothesis that appears plausible (Heuer, 1999). This is a likely trap to fall into if the nuclear forensic data quickly indicates a probable perpetrator that was already suspected based on the geopolitical situation at the time. This, however, would open the U.S. to the

scenario that the forensic data was spoofed. Another issue will be preventing a consensus from forming around compelling forensic data before a full intelligence estimate is completed (Heuer, 1999). If this were to occur it might be difficult to present and argue evidence of another country's involvement if this is not supported by the forensic evidence.

To minimize the effects of these and other biases, the analytical process should be divided among four distinct functional groups. The first group's responsibility will be to conduct the forensic analysis and generate a hypothesis based on the isotopic evidence. Nominally, this will serve as the primary body of evidence against the supplier of the material. The hypotheses drawn from nuclear analysis can also be used to focus the collection efforts of the intelligence community in the event that other indicators are not immediately available.

The second proposed group will have access to the conclusions of the forensic group as they become available. Their responsibility will be to disprove the forensic hypothesis. Since it is their sole responsibility to find evidence to refute the most obvious hypothesis they are less likely to inadvertently reject information that contradicts the forensic evidence. This function must necessarily be built into the system as analysts do "not naturally seek disconfirming evidence, and when such evidence is received it tends to be discounted" (Heuer, 1999).

The third group should not have access to the findings of the forensic group as they become available. Their task will be to determine the source of the weapon using purely traditional intelligence processes. They should be denied the forensic evidence until their initial conclusions are drawn to prevent cognitive biases from interfering with the quality of analysis. It is arguable that this will result in a significant waste of effort as forensic data will not be available to steer their collection efforts. However, this waste is a necessary evil to ensure that the final conclusions drawn by the intelligence community are as accurate as is possible.

The final group should have immediate access to the findings of the forensic group as they become available. Again the task of these collectors and analysts will be to determine the source of the nuclear material, but they will be free to use the information from the forensic investigation to guide their efforts. This group should consist of the majority of the intelligence community as it is unlikely that there will be a more pressing issue following a domestic nuclear terror attack.

The determination of the origin of a nuclear device detonated within the United States may be the most important intelligence estimate ever to be made. It will likely determine whether the President of the United States chooses to conduct a large scale retaliatory military campaign, and could potentially be used to justify the use of nuclear weapons in retaliation. An intelligence failure could result in the perpetrators going unpunished and therefore significantly reducing the credibility of the U.S. deterrent threat, thus increasing the possibility of future attacks. Alternatively, the U.S. might strike out against the wrong country, needlessly killing innocent civilians and doing unrecoverable harm to the reputation of the United States. It is therefore critical that the intelligence community have a workable plan to determine the source of such an attack, integrated with the national nuclear attribution function.

B. TRANSMITTING THE DETERRENT THREAT

Deterrent policies and capabilities are meaningless unless they are appropriately communicated to the party they are intended to deter. Not only is the content of the message important, but also the context within which it is delivered will determine how the message is received and interpreted. For a deterrent based on an attribution capability to be successful the U.S. must successfully convince foreign governments and dictators that such a capability exists and that the U.S. would take action based on information gained from this capability (Talmadge, 2007, p. 30).

This is another reason why the U.S. should be very transparent about its attribution capability. To hide the process behind the veil of national secrets will create doubt about the existence of the capability. This may be sufficient to deter a risk adverse adversary. However, all but a certainty of attribution may be required to deter a risk

acceptant adversary operating under a losses frame from allowing the transfer of nuclear materials to an allied terrorist organization in the hope of gaining some advantage over the United States.

Additionally, the deterrent threat should be made clearly, and without ambiguity. This is not in accordance with current administrations policy. With regard to the specific threat of North Korea transferring nuclear materials President Bush said that, "We would hold North Korea fully accountable for the consequences of such action" (as cited in Shanker & Sanger, 2006). The president and other top officials declined to comment, however, on the nature of the accountability. Many leaders instead said that the, "power of deterrence was its very ambiguity." Indeed one White House official stated that, "These declarations are constructed with some elasticity, specifically to raise questions and doubts in the mind of the object" (as cited in Shanker & Sanger, 2006).

There are certainly times when in international relations deterrent ambiguity is an ally. The U.S. position vis-à-vis Taiwan's independence is one such example. Here ambiguity is effective because the PRC is risk averse, and is fairly satisfied with its status quo position. Taking an unambiguous stance could actually alter this position and make the PRC more risk acceptant in order to demonstrate its regional authority. This can not be said of other countries such as North Korea or Iran. The leaders of these countries are likely to be far more risk acceptant and often operate under a losses frame when dealing with the United States. It is entirely possible that relations with these countries could deteriorate even further in the future, increasing risk acceptant behavior.

As Paul Huth (1998, pp. 2-3) explains, ambiguity creates uncertainty. This uncertainty allows the policy makers of deterrent targets to selectively interpret messages according to their biases and desires. This could provide the room necessary then for foreign leaders to decide that the United States would not act decisively if attacked through a proxy. It is not sufficient to assume that the actions of the United States in Afghanistan or Iraq following the September 11 attacks would be sufficient to deter other states from supporting terrorist organizations. It appears that the past actions of a deterring state when in a confrontation with a state uninvolved in the current deterrent

situation have little effect on the credibility of the current deterrent threat (Huth, 1998, p. 81). Thus the deterrent threat must be unambiguously transmitted to each potential threatening state.

Huth's findings have another positive aspect. Since deterrent threats and outcomes vis-à-vis other countries seem to have little effect on how other states view their current deterrent situation, it is possible to have asymmetric deterrent policies with regard to the control of nuclear materials and weapons. For example the U.S. should be very clear that if attacked by a nuclear device of North Korean origin, that prompt, decisive, and regime changing military action will follow. The policy necessarily must be different if the U.S. is attacked by a nuclear weapon found to have been stolen from former Soviet stockpiles. These different policies are unlikely to affect the North Korean or Iranian assessment of the dangers of transferring nuclear weapons.

C. ACTIONS AFTER ATTRIBUTION

If attacked by a terrorist nuclear weapon there is no doubt that the United States must respond, and with devastating consequences for those that facilitated the attack. Not only will there be enormous domestic political pressure to do so, but a failure to punish such an attack could embolden other actors and invite similar future attacks (Talmadge, 2007, p. 30). Instead the only freedom the president will have is in the nature of the retaliatory action.

Undoubtedly there will be those that argue a nuclear strike launched against the country linked to a nuclear detonation on U.S. soil would be appropriate. Current U.S. policy statements seem to reflect this position. The 2002 Nuclear Posture Review indicated that planners view a degree of interchangeability between nuclear and conventional weapons as a deterrence strengthening mechanism. The result is a policy that portrays nuclear weapons as both a strategic deterrent and as a legitimate weapon of war. Indeed this position is not limited to the United States. In 2006 then French President Jacques Chirac stated that France would consider using nuclear weapons in retaliation against states that sponsored terrorist attacks utilizing weapons of mass destruction against France (INTERNATIONAL, 2006).

Such language is potentially dangerous. As Thomas Schelling notes, there is a clear taboo associated with the use of nuclear weapons. This taboo has been sensed by policy makers since at least the early 1950's, yet it is not easy to quantify why the taboo exists. It is possible to make nuclear weapons less destructive than many large conventional bombs, yet these so called 'tactical nukes' have never been used in warfare (Schelling, 2006. p. 6089). It is the fact that this taboo exists, but cannot easily be explained that makes its maintenance tenuous. Indeed, it is a fair assumption that if nuclear weapons are used again in warfare, that it will be difficult to contain their use for some time after the first exchange. It is within the interest of the United States to maintain this universal prohibition against the use of nuclear weapons (Schelling, 2006, p. 6090).

Declared policies of first use, or statements indicating that nuclear weapons would be used in retaliation for supporting nuclear terrorists undermine this prohibition. Indeed publicly suggesting that the use of nuclear weapons is a legitimate policy option may increase the appeal of nuclear weapons and work against counter proliferation efforts. If the U.S. were to respond to a terrorist attack with a nuclear strike, it would only legitimize the terrorist choice of weapons.

There is a need for the U.S. strategic deterrent capability. However, the quiet message sent every time a Trident missile submarine gets underway is sufficient to transmit the deterrent threat these weapons are needed for. Suggesting that the U.S. nuclear arsenal may be employed for any other reason than retaliating against a large-scale first strike from a peer competitor increases the risk that nuclear weapons will be used during conflict, as it erodes the stigma attached to them. Clearly, the U.S. has the conventional force projection capability to retaliate against a rogue state's willful or complicit transfer of nuclear weapons. Signaling the intent to use only these conventional means is both more credible, and less dangerous to the long term counter proliferation effort.

D. CONCLUDING THOUGHTS

Ensuring that a nuclear terrorist attack will not occur is not possible. The best that can be hoped for is to reduce the probability to an acceptably low level. Deterring states from intentionally transferring nuclear material to terrorists, or encouraging adequate security practices by convincing the world community that the United States will determine the source of the material is just one step that must be taken. Equally important are efforts to remove the conditions that cause terrorism, and efforts to increase the difficulty of bringing nuclear weapons into the country through more robust border and port security systems.

That being said, decreasing the likelihood that states might facilitate nuclear terrorism is absolutely necessary. This is technologically feasible now, but key policy points must be implemented, and international cooperation and transparency are absolutely necessary. The sooner such a capability is in place and demonstrated to the world community, the less likely it will be that such methods will ever have to be employed.

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